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NATURAL WASTEWATER TREATMENT SYSTEMS FOR THE MEDITERRANEAN REGION

In cooperation with

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EXECUTIVE SUMMARY

Wastewater sanitation in the Mediterranean comprises specific environmental issues shared by most countries of the region, which need to be addressed:

- the climate is characterized by heavy rains that occur mainly during autumn and spring, causing frequent floods, and by long dry periods resulting in recurrent droughts. Water scarcity is a matter of concern to many countries in the region, particularly the southern bank, and most of the islands. Therefore, interest in water reuse is increasing and the main purpose of wastewater treatment has become its preparation to meet requirements for reuse;
- wastewater that has been disposed of in dry river beds infiltrates and recharges underlying aquifers; this discharge may threaten the quality of groundwater. The impact of wastewater discharge on surface and underground waters should be taken into account and the treatment and disposal designed accordingly;
- karstic landscape is a typical feature of most Mediterranean countries, which means that that groundwater resources, often the main resource, are at high risk of being polluted by wastewater disposal. Strategies should be adopted to protect karstic aquifers;
- the Mediterranean coastline is becoming more and more populated along both banks, resulting in increasing pressure on the coastal environment, particularly on seawater quality;
- strategies should be adopted to protect groundwater; treatments for the disinfection of wastewater, slow rate infiltration and reuse of treated effluent can provide appropriate solutions;
- tourism has become an essential economic activity in most Mediterranean countries, particularly along the shoreline. Preservation of seawater quality is, therefore, of the highest priority; and
- the economic situation of Mediterranean countries is unequal. Most countries of the north bank can afford expensive wastewater treatments, while southern countries tend to rely on low cost technology. When deciding on a treatment technique, available operating and maintenance (O&M) skills must be considered.

Microbial decontamination appears to be of the highest priority in order to ensure the vital protection of aquifers (particularly in karstic areas), coastal areas, bathing waters and also to satisfy the increasing demand for water reuse in the Mediterranean. Thus wastewater treatment techniques should be capable of producing reliable microbial decontamination and, given the economic situation of the region, be cost effective.

While most big cities are served by sewage treatment plants based on conventional intensive technologies (physical-chemical treatment, activated sludge, etc.), medium and small-size communities are more likely to rely on extensive or “natural” techniques, i.e., waste stabilization ponds, soil filtration or constructed wetlands. Extensive technologies offer several advantages:

- all extensive and natural techniques achieve significant to very important microbial decontamination. This provides a very strong argument in favour of extensive techniques in the Mediterranean;
- investment costs required for extensive sewage treatment techniques are not much lower than those required for intensive techniques. However, extensive techniques have a decisive advantage: very low O&M costs;
- extensive techniques incorporate low technology equipment; O&M do not require highly skilled personnel and are not time consuming;

- sludge production is limited to the settling stage. As settling is performed in Imhoff tanks, septic tanks and ponds, most of the sludge is digested, the excess being removed from twice a year from Imhoff tanks to one year out of 15 for facultative ponds and vertical flow constructed wetlands.

The main shortcoming of the majority of extensive techniques is their large and often excessive footprints. As a result, they cannot be applied in densely populated areas. Neither can they meet any treatment objective. For instance, performances are uneven with regard to nutrient removal, depending on the technique and the season. Very stringent microbial regulations can not be reliably met using only extensive technologies. Typically, they cannot supply effluents of less than 100 faecal coliforms per 100mL. The efficiency of extensive technologies, particularly ponds and reservoirs, are dependent on prevailing meteorological conditions and engineers are not accustomed to dealing with this contingency. Therefore, the potential adverse environmental impact should not be underestimated when planning extensive wastewater treatment facilities. Odour nuisances and proliferation of offensive insects may destroy valuable projects. Fortunately, remedial measures are available.

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1. INTRODUCTION

Wastewater sanitation aims at preventing, or at least reducing, adverse impacts of wastewater disposal on the environment and public health. The aim of wastewater treatment is to remove the pollutants which are harmful to the receiving water bodies and hamper eventual direct or indirect uses of the treated effluent. Sanitation objectives should be ranked and those having priority clearly identified. Sanitation strategies should consistently address the highest priority objectives; technical options should lead to systems that are reliable, affordable, easy to manage and compatible with the environment, including sociological aspects. Sanitation should be carefully planned, and this requires a comprehensive approach to the technical, economic, sociologic and regulatory aspects of the projects.

Wastewater sanitation in the Mediterranean comprises specific environmental issues shared by most countries of the region, which need to be addressed:

- Climatic conditions: The climate is characterized by heavy rains which occur mainly in autumn and spring causing frequent floods, and by long, dry periods resulting in recurrent droughts.

    - Water scarcity, is matter of great concern to many countries of the region, particularly the southern bank and most islands. Therefore, interest in water reuse is increasing and the main purpose of wastewater treatment has become its preparation to meet requirements for reuse. Another consequence of drought is the absence, for long periods, of natural water in river beds; thus, it frequently happens that the river flow is actually pure wastewater. Moreover, wastewater that has been disposed of in river beds infiltrates and recharges underlying aquifers; this discharge may threaten the quality of groundwater. The impact of wastewater discharge on surface and underground waters should be taken into account and the treatment of wastewater designed accordingly.
    - Heavy rainfall means high runoff flow rates which, due to leakage or combined sewer systems, undermine the functioning of wastewater treatment plants. If necessary, a weir should be installed before the inlet of the wastewater treatment plant in order to divert the excess wastewater; an appropriate receiving body should then be found to receive the diverted water. Due to the fact that this last requirement is not fulfilled, many beaches become polluted just after storms.
    - Mild winters, hot summers and long periods of sunshine are favourable conditions for implementation of natural wastewater treatment techniques.

- Karstic landscape is a typical feature of most Mediterranean countries, which means that groundwater resources, often the main resource, are at high risk of being polluted by wastewater disposal. Strategies should be adopted to protect groundwater; treatments for the disinfection of wastewater, slow rate infiltration and reuse of treated effluent can provide appropriate solutions.

- The Mediterranean coastline is becoming more and more populated along both banks, resulting in increasing pressure on the coastal environment, particularly on seawater quality. This situation pleads for the choice of centralized rather than decentralized sanitation options.

- Tourism, which results in high seasonal population variations, has become an essential economic activity in most Mediterranean countries, particularly along the shoreline. Therefore, preservation of seawater quality is of the highest priority. Removing pathogens before wastewater discharge in the vicinity of bathing areas is of the utmost importance.
- The economic situation in Mediterranean countries is unequal. While most countries of the north bank can afford expensive wastewater treatments, southern countries tend to

rely on low cost technology. When deciding of a treatment technique, available operating and maintenance skills must be taken into account.

Microbial decontamination appears to be of the highest priority in order to ensure the vital protection of aquifers (particularly in karstic areas), coastal areas, bathing waters and also to satisfy the increasing demand for water reuse in the Mediterranean. Thus, cost-effective water treatment techniques capable of achieving a reliable level of microbial decontamination would be preferred. There is a considerable difference in comparison to sanitation in regions better endowed with water resources.

The first issue to be addressed when planning sanitation, should be to decide on whether a drainage system and a collective treatment plant is to be constructed or wastewater treated in onsite facilities. Towns and large cities are, of course, equipped with sewers and collective treatment plants. However, in rural areas and city outskirts, decentralized systems would be more appropriate. In both cases, treatment should be carried out before disposing wastewater into the environment, in order to protect streams, lakes, the sea or the underground (including groundwater). In many places, particularly the Mediterranean, onsite wastewater treatment systems have often been conceived as just a septic tank discharging its septic effluent to a soakway. The septic tank achieves only primary treatment, which consists of settling and removal of about 30% of the COD. Soakway or seepage pit (basically, a pit filled with stones) is just a straightforward means to dispose of the effluent to the soil. Therefore, the soakway is a great potential point source of pollutants which threatens the water quality of underlying aquifers. This is the reason why secondary treatment of septic tank effluent should be implemented, using sub-surface absorption fields or buried sand filters.

Most communities and towns are equipped with collective sewerage and wastewater treatment systems. A number of considerations are taken into account when designing wastewater treatment facilities:

- actual and potential environmental value and usages of potential receiving bodies;
- regulations applying to these usages;
- potential scenarios for effluent reuse and related regulations;
- size of the community;
- location and cost of land available for the treatment plant and eventual storage of treated effluent;
- available treatment technologies together with their performance, reliability, construction and O&M costs; and
- skills required for proper O&M of the treatment plant.

When large cities are to be served by sewage treatment plants based on conventional intensive technologies (physical-chemical treatment, activated sludge, etc.), medium and small-size communities are more likely to rely on extensive or “natural” techniques, i.e., waste stabilization ponds, soil filtration or constructed wetlands. This difference stems from well known facts: with the exception of desert zones, large surface areas of land to set up extensive wastewater treatment facilities are seldom available in the vicinity of big cities. Disposal of large amounts of treated wastewater could have a dramatic impact on the environment in the event of treatment failure. Most authorities used to rely on sophisticated technologies and plants operated by highly skilled personnel to prevent the occurrence of such events. Large towns can afford the higher expenses, which is not the case for smaller communities.

Though intensive techniques should not be discarded, medium and small-size municipalities are likely to be served by extensive sewage treatment techniques. Extensive technologies offer several advantages, though their shortcomings should be stressed.

Advantages are as follows:

- all extensive and natural techniques allow significant to very serious microbial decontamination. The more extensive the technique, the higher the decontamination. This presents a very strong argument in favour of extensive techniques in the Mediterranean;
- investment costs required for extensive sewage treatment techniques are not much lower than those of intensive techniques. However, extensive techniques offer a decisive advantage: very low O&M costs. Actually, no (or very limited) energy is required and as electro-mechanical equipment is reduced to a minimum, maintenance is relatively inexpensive;
- extensive techniques incorporate low technology equipment; as a result, O&M is easy, does not require highly skilled personnel and is not very time consuming;
- sludge production is limited to the settling stage. As settling is performed in Imhoff tanks, septic tanks and ponds, most of the sludge is digested, the excess being removed from twice a year from Imhoff tanks to one year out of 15 for facultative ponds; and
- extensive techniques, also called natural techniques, can be classified as “green” techniques which do not undermine the aesthetics of their neighbourhood (Figure 1.1).

Figure 1.1. Facultative pond at Aurignac (France)

Shortcomings are listed below:

- the main shortcoming of the majority of extensive techniques is their large and often excessive footprints. They cannot, therefore, be applied in densely populated areas;
- another serious disadvantage is that they cannot meet all treatment objectives. For instance, their performance is uneven as regards nutrient removal, depending on the technique and the season. Though nitrogen removal has significantly improved,

thanks to the combination of different techniques, it remains highly dependent on the season. Phosphorus may precipitate in ponds and reservoirs but is hardly eliminated in soil filtration systems and constructed wetlands. Very stringent microbial regulations can not be reliably met using only extensive technologies. Typically, they cannot supply effluents of less than 100 faecal coliforms per 100mL;

- the efficiency of extensive technologies, particularly ponds and reservoirs, are dependent on meteorological conditions. Engineers are not accustomed to dealing with this contingency;
- evaporation results in water losses inversely proportional to the water depth and proportional to the water residence time in ponds and reservoirs; and
- potential adverse environmental impact should not be underestimated when planning extensive wastewater treatment facilities. Odour nuisances and proliferation of offensive insects, such as mosquitoes and midges, may ruin valuable projects. Fortunately, remedial measures are available.

The main extensive techniques, i.e., stabilization ponds, intermittent soil filtration (ISF) and constructed wetlands, are described in this chapter. They are most often used to serve small and medium-sized communities, i.e., up to a few thousand p.e. However, they have been (and still are) implemented to treat the wastewater of much larger populations, particularly when land is available. As natural systems have proven to be an efficient means of microbial decontamination, they are also used to treat secondary effluents from conventional wastewater treatment plants. Ponds, reservoirs or infiltration percolation plants may serve very large populations. Many waste stabilization ponds that have become overloaded due to population increase have been replaced by conventional systems, typically activated sludge; ponds have often not been decommissioned but were converted to tertiary lagoons.

2. WASTE STABILIZATION PONDS

Waste stabilization ponds (WSPs) constitute the most widespread natural wastewater treatment techniques over the five continents. WSP systems basically consist of several watertight ponds in series. The treatment relies on the development of bacterial suspended cultures, mainly aerobic, and long water retention times in successive ponds.

2.1 Principles

2.1.1 Suspended solids

Suspended solids borne by inlet wastewater settle after entering the pond and accumulate at the bottom; together with settled, dead micro-organisms, they undergo an anaerobic digestion which results in the production of CO_2, CH_4 and other components (Figure 2.1).

2.1.2 Organic matter

Soluble organic matter is degraded by aerobic heterotrophic bacteria, producing CO_2 and mineral salts. Carbon dioxide and salts resulting from both aerobic and anaerobic degradation of organic matter allow for the synthesis of planktonic algae (microphytes), which develop as a result of exposure to sunlight. The amount of oxygen required for the development and activity of the aerobic bacteria has two sources, the main one being algae photosynthesis and an additional supply being provided by atmospheric air, particularly during windy periods. Heterotrophic aerobic bacteria and algae constitute two populations dependent on each other and on solar radiation. Solar radiation is the main source of energy for the treatment. A significant part of the algae biomass is discharged into the environment with the outlet water. In the European Union, the impact of this discharge has been considered limited; this has led to specific discharge regulations. When the effluents of other wastewater treatment plants have to meet the following criteria: SS = 35 mg/L, total BOD = 25 mg/L, total COD = 125 mg/L, the criteria applying to WSPs are: SS = 150 mg/L, filtered BOD = 25 mg/L, filtered COD = 125 mg/L. It is considered that the impact of algae discharge on the receiving bodies is rather low; it may be beneficial when WSP effluent is used for agricultural irrigation (Mara and Pearson, 1998).

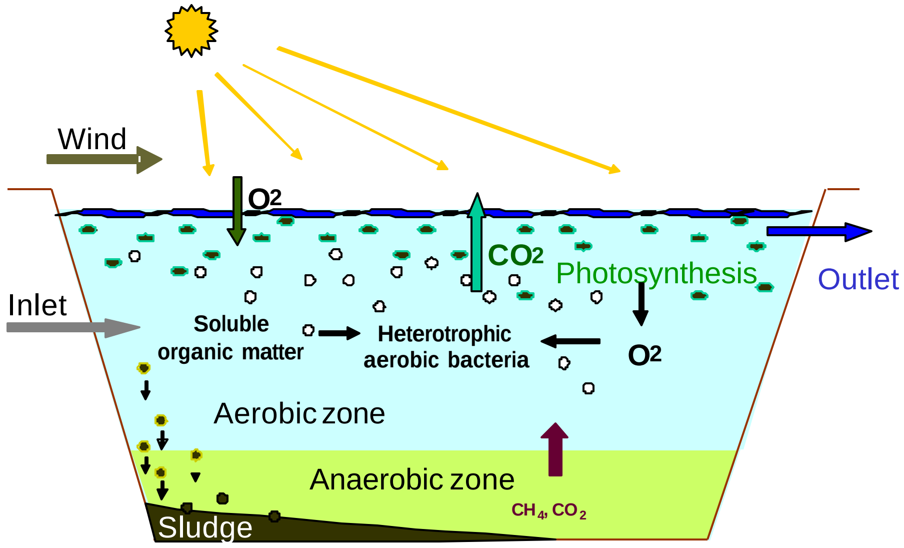


Figure 2.1. Main mechanisms of wastewater treatment in a waste stabilization pond

2.1.3 Nutrients

Nitrogen enters a WSP system essentially as ammonia and organic nitrogen. Most of the organic nitrogen is linked to the suspended solids that settle at the bottom of the ponds; it is further released in the water column as ammonia, due to the anaerobic hydrolysis of the sediments. When a fraction is synthesized as algae, the fate of the main part of ammonia depends on the season. Two processes result in the removal of nitrogen: volatilization of NH_3 when the pH is high enough, and nitrification/denitrification. All these mechanisms are temperature dependent. In winter periods, when the water temperature is low, there is virtually no nitrification and, though it may be very limited, the sole effective removal process is volatilization. When the temperature rises, nitrification can be observed; then denitrification follows, resulting in the elimination of nitrates (Picot *et al.*, 2004a, Zimmo, 2003). During hot periods, enhanced volatilization and effective nitrification/denitrification can result in very high nitrogen removal.

Phosphorus enters a pond as dissolved phosphate and organic P linked to SS. Settled SS accumulate in the sediments together with dead algae. Sediment hydrolysis releases phosphate in the water column. At sufficiently high pH, dissolved phosphate precipitates as compounds of uneven stability and accumulates as inorganic P immobilized in the sediments. During the hot season, pH reaches high values, P precipitation is very effective and under stable compounds. During other periods, re-solubilization of P, due to the decrease of oxido-reduction potential, is observed. Therefore, in many WSP facilities, P is efficiently removed in summer.

Reducing the amount of nitrogen and phosphorus in WSP effluent is of the utmost importance when wastewater is discharged into water bodies that are sensitive to eutrophication, such as freshwater reservoirs, low flow streams and some coastal waters. When treated wastewater is to be reused for irrigation, keeping nitrogen and phosphorus in WSP effluent is beneficial (unless an aquifer tapped for potable water lies below the irrigated area, in which case a nitrate build-up might occur).

2.1.4 Pathogens

Up until now, bacteria of faecal origin have been the most widely used micro-organism indicators in investigating the inactivation mechanisms in wastewater treatment techniques, as well as in setting up regulations. Pathogen removal mechanisms involve a series of complex physical, chemical and biological interactions that occur naturally in aquatic systems. The most significant mechanisms causing micro-organism decay involve DNA damage caused by sunlight ultraviolet irradiation, photo-oxidation caused by the formation of singlet oxygen, hydrogen peroxide and other superoxide and hydroxyle radicals due to humic substances absorbing light and passing to oxygen, predation and starvation due to lack of nutrients or carbon source and algal toxins (Xu *et al*., 2002). Microbial decontamination requires a long detention time and depends highly on meteorological conditions. While high efficiency can be expected in summer, meeting stringent microbial criteria on the North bank of the Mediterranean in winter requires careful design of WSP systems.

Protozoan cysts and helminth eggs are removed from the water column by sedimentation. They accumulate in the sediments where they slowly decrease (Nelson, 2003, Sanguinetti, 2004).

2.2 Different types of WSP

WSP systems comprise either a single series of ponds or several series in parallel. Most common series in Mediterranean countries comprise a facultative and two maturation ponds or an anaerobic pond, a facultative and one or several maturation ponds. Other types of ponds have been installed in the region, at real or pilot scale: aerated ponds, high rate algal ponds, macrophyte ponds and deep stabilization reservoirs.

2.2.1 Anaerobic ponds

Anaerobic ponds are 2 to 5 m deep and receive high organic loads of about 100 g BOB $m^{-3}d^{-1}$, with a few days residence time (Figure 2.2). The recommended design load, which does not entail risk of odour nuisance, depends on the temperature (Mara and Pearson, 1998). Anaerobic ponds function like Imhoff tanks - they allow removal of 30 to 60% BOD and are deep enough to allow for the digestion of the sediments. However, sludge accumulates rather rapidly thus requiring frequent desludging operations.

2.2.2 Facultative ponds

Facultative ponds, 1 to 1.5 m deep, receive either raw wastewater (primary facultative ponds) or effluent from anaerobic ponds (secondary facultative ponds). They are designed to treat an organic load from 80 up to 400 kg BOD $ha^{-1}d^{-1}$, the former value corresponding to coldest Mediterranean regions and the latter to the hottest ones. The load should allow the development of an algae population capable of providing most of the oxygen required by the aerobic bacteria, which are responsible for organic matter degradation. The main role of facultative ponds is BOD removal, which is usually in the range of 70-80% based on unfiltered samples, above 90% based on filtered samples for primary facultative ponds but only about 50% for secondary facultative ponds. Though sludge accumulates more slowly than in anaerobic ponds, desludging should be undertaken every 10-15 years (Picot *et al*., 2004b, Racault & Boutin, 2004).

Figure 2.2. Anaerobic pond lined with a plastic membrane at Arad (Israel), with a facultative pond in the background

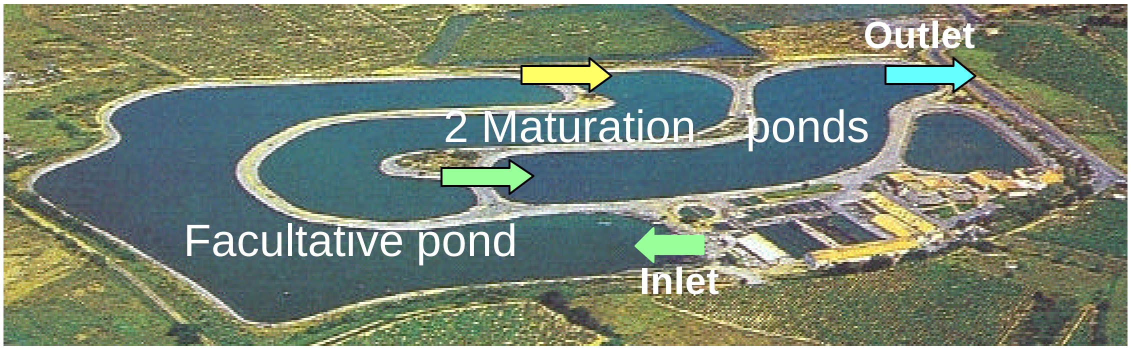


Figure 2.3. Mèze (France) waste stabilization ponds before retrofitting. Typical series of 3 (1 facultative + 2 maturation) ponds

2.2.3 Maturation ponds

A series of maturation ponds, also 1-1.5 m deep, receive facultative effluent. The function of the maturation ponds is, of course, to polish this effluent. However, the primary objective of polishing is either to meet COD, BOD and SS discharge requirements, as stated by the E.U. Directive 91/271/EEC and considered in the CEMAGREF recommendations (CEMAGREF et *al*., 1997), or, the removal of pathogens (Mara & Pearson, 1998). Actually, relatively low BOD removal is achieved in maturation ponds while the elimination of faecal indicators can be very effective. Maturation ponds may play a key role in the removal of nutrients, which is very effective during the hot seasons. The design of maturation ponds depends on their primary function. The primary objectives considered by the CEMAGREF are achieved with a series of two maturation ponds of an equal area of 2.5 m^2/p.e. This ratio applies for the coldest Mediterranean regions and should be adapted (reduced) for milder climates. When microbial decontamination is the primary objective, the dimension of the maturation ponds can be based on the method of Marais, assuming that each pond is perfectly mixed and microbial die-off follows a first-order kinetic, the kinetic constant being highly dependent on the temperature (Mara & Pearson, 1998).

2.2.4 High rate algal ponds

High rate algal ponds usually receive settled effluent from anaerobic ponds. A typical HRAP is a shallow depth (0.3 to 0.6 m) raceway in which an agal/bacterial culture is gently mixed by paddlewheel. Retention time varies between 2 and 20 days, depending on the quality of the wastewater to be treated, the purpose of the treatment and the climatic conditions of the region. Algal photosynthesis provides oxygen for the decomposition of organic matter through the activity of aerobic heterotrophic bacteria. Shallow depth facilitates sunlight penetration and mixing ensures that the whole water body participates in the treatment. The result is an impressive promotion of algal biomass growth (which removes nutrient through biomass assimilation), an important daytime oxygen supply, a high daytime pH and enhanced ammonia stripping and phosphorus precipitation (Oswald, 1988, Gomez *et al.*, 1995). A significant reduction in faecal bacteria is also observed in HRAPs. The high algae content of HRAP effluent should be removed. Therefore HRAP may be combined with an algal settling pond (ASP) with a residence time of 1-2 days, designed for algal sedimentation and removal, followed by a maturation pond where further algal elimination can be achieved through zooplankton grazing (Craggs *et al.*, 2003). Another solution consists of relying only on maturation ponds for algal removal. The energy required for moving a paddlewheel at 0.2 ms^{-1} is considered negligible. Using HRAP allows reduction of the treatment plant footprint.

Figure 2.4. High rate algal pond at the Institut Agronomique et Vétérinaire Hassan II, Rabat-Morocco (El Hafiane and El Hamouri, 2004).

2.2.5 Aerated ponds

Mechanical aeration is another solution to reducing the footprint of WSP systems. The oxygen required for organic matter degradation is supplied by surface aerators or air blowers, instead of relying only on algae photosynthesis and wind action. A typical aerated pond system comprises two stages: aeration and sedimentation. The retention time in the aerated ponds, 2.5 to 4 m deep, is about 2 weeks. The energy is supplied by 1.5 to 5.5 kW aerators; the recommended installed power is 5 to 6 Wm^{-3}, the operating time being adapted to the treatment goals and operating conditions. BOD removal is about 85% thanks to an energy consumption of 1.5 - 2 kWhr per Kg of BOD eliminated. Aeration stage effluent bears high floc content, as happens with activated sludge. Therefore, these suspended solids have to be separated from the water in sedimentation ponds. Sedimentation ponds, 2 to 3 m deep, with a retention time of 4 days, are an effective means to meet EU water quality requirements.

Figure 2.5. Aerated ponds in Noirmoutier (France)

2.2.6 Macrophyte ponds

Systems using floating aquatic plants were favoured several years ago, particularly in tropical countries. Macrophyte pond systems consist of a series of ponds in which water tolerant floating plants are grown (Kadlec *et al*., 2000). The most frequent floating plant species used in wastewater treatment systems are water hyacinth (*Eichhornia crassipes*), water lettuce (*Pistia stratiotes*) and duckweed (*Lemna* spp.). Water hyacinths cannot resist a cold climate while duckweed is more tolerant to low temperatures. Organic matter and SS are eliminated essentially by physical sedimentation and bacteria metabolic activity. Macrophyte roots extending down into the water column play an important part in both processes. The root network acts as a filter, intercepts and thus helps SS to settle. Roots also provide support for the biomass responsible for decomposition of organic matter. When floating macrophyte density hampers the penetration of sunlight in the water column, the development of algae is no longer possible. Therefore, nutrients are essentially removed through plant assimilation. Several experiments have shown that, though sunlight irradiation cannot contribute efficiently to faecal bacteria removal, a highly significant elimination of bacteria is observed. This might be due to the fact that the root network functions as a filter, limiting short circuits and adsorbing the bacteria on the roots where they are further degraded by the attached ecosystem. The comparison between the respective performances of microphyte and macrophyte based WSPs has long been controversial. Contradictory results were obtained in pilot and real scale plants. Macrophyte pond effluents have a very low algal content. Therefore, there is no doubt that the highest removal of SS, COD and BOD is by macrophyte systems. Data related to nitrogen, phosphorus and microbiological removals offer a more contrasting picture. Kengne *et al*. (2004), investigating the performance of the same series of ponds operated with and without floating macrophytes (water lettuce) in a real scale plant set in a tropical country, have found no significant difference in the removal of N and P and a higher removal of faecal bacteria without macrophytes. Macrophytes have to be regularly harvested, which is the main task and can be viewed both as an advantage or a disadvantage, depending on whether an economic benefit can or cannot be made from the harvest. Macrophyte systems cannot be adopted in regions experiencing cold winters. All precautions should be taken in order to avoid dissemination of invasive species, such as water hyacinths, in the environment.

Duckweed ponds have been extensively investigated in Near-East countries (Oron, 1994, Zimmo et al., 2000 and 2003). The plants grow successfully in these countries though the growth rate slightly diminishes in winter and in the hotter summers. Duckweed also grows in countries of the northern bank of the Mediterranean, particularly in summer. Cultivation of duckweed converts nutrients into protein rich biomass. The role played by duckweeds in N and P removal has been controversial. Most recent works show that duckweed-based ponds do not remove more nitrogen than algae-based ponds.

Figure 2.6. Macrophyte-based waste stabilization ponds at Yaoundé (Cameroon)

2.2.7 Reservoirs

Reclaimed water production is fairly constant throughout the year while irrigation demand highly depends on the season. Therefore, during the winter and rainy season, reclaimed water is either stored to be used for irrigation in spring and summer or disposed of in streams, lakes or other receiving bodies. The first function of seasonal storage is to accumulate water in the cold season to satisfy subsequent irrigation requirements. The most common forms of storage are open reservoirs (stabilization reservoirs) and deep stabilization ponds. The depth of deep ponds is around 2 m, 7 -15 m for average ponds and a maximum of 20 m for reservoirs (Juanicó and Dor, 1999). The second function of open reservoirs is to improve the physical chemical and microbial quality of the stored water.

2.3 Design

A scheme of the most widespread type of WSP system in Europe is provided in Figure 2.7. Some useful general recommendations are included for the design and construction of such ponds (Mara and Pearson, 1988, European Commission, 2001).

Figure 2.7 Seasonal reservoir of Arad (Israel)

2.3.1 Location

Significant progress has been made (but not always implemented) to reduce odour nuisances, which can lead to recurrent complaints and the rejection of pond technology. Therefore, ponds should be located at least a few hundred meters downwind of the nearest community. Ponds should be located downwind of the community they serve in order to save energy and where prevailing winds help aerating the ponds. However, if impermeable soils (clay or clayey silt) are available elsewhere, pumping can be considered.

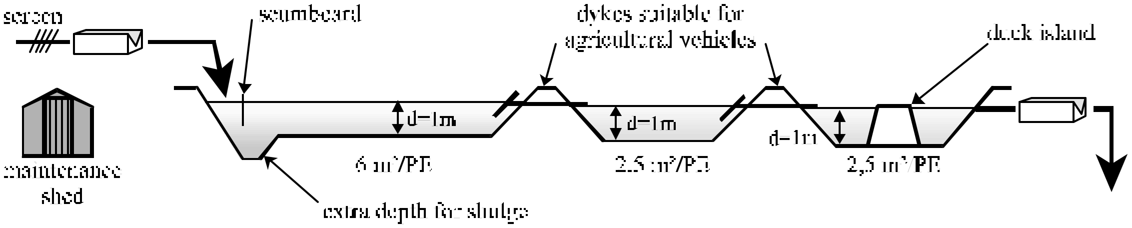


Figure 2.8. Scheme of typical 3 (1 facultative and 2 maturation) ponds system (Racault and Boutin, 2004)

2.3.2 Watertightening and embankments

In order to prevent dissemination of wastewater in the environment, protect groundwater and ensure normal development of the treatment processes, ponds should be made watertight using either impermeable local soil or a plastic liner, which is more costly. Embankments are constructed with the soil excavated from the site and compacted in 15-20 cm layers. After compaction, the soil *in situ* permeability should be less than 10^{-7} m/s (Mara and Pearson, 1998). Embankments are designed to allow for vehicle access. Embankment slopes are at least 1 to 2.5 internally so as to limit erosion by wave action, facilitate maintenance and access to the basins for the cleaning equipments, and 1 to 1.5-2 externally. Slopes may be steeper when a geo-membrane lines the pond. External embankments should be planted with grass to ensure their stability. Internal embankments are protected from wave action by *in situ* concrete, geotextiles and stone rip-rap or self-locking slabs. Protections preventing vegetation form growing down the internal embankments and development of suitable habitat for mosquitoes and snails should be preferred in the Mediterranean.

As can be shown from Figure 2.4, HRAP greatly differs in structure and construction from other ponds. They used to be made of reinforced concrete.

2.3.3 Pond geometry

Anaerobic and facultative ponds are rectangular with length to breadth ratios not exceeding 3 to 1. In facultative ponds this will favour a satisfying balance between algae and heterotrophic bacteria growth. The ratio length to breadth of maturation ponds can be higher, up to 10 to 1; thus the flow pattern is more of the plug flow type, which is regarded as beneficial for the objectives of these ponds, i.e., nutrient and pathogen removal. Ponds should not be strictly rectangular, both for aesthetic reasons and also to prevent water stagnation in the corners. Inlet and outlet structures should be as far apart as possible in order to avoid short-circuits.

Efforts have been made in the past to improve our knowledge of flow patterns. It has been found that the use of baffles, when properly designed, may significantly improve the performance of maturation ponds (Shilton and Mara, 2004). They allow better approximate plug flow (as opposed to a perfectly mixed pattern) and better remove faecal indicators.

2.3.4 Evaporation

Water evaporation increases with temperature, solar radiation and wind velocity, while it decreases with atmospheric air humidity. The most popular expression used to calculate evaporation is the Penman-Monteith equation, though other empirical equations are available (Shuttleworth, 1993). Evaporation rate may reach values as high as 8.5 mmday^{-1} and even more in arid regions. Therefore, it should be taken into account in pond design, particularly in those countries where evaporation is high and when treated water is to be reused in agriculture. Water losses can reach 20-30%, which results in a significant increase of salinity and tends to hamper water reuse in agriculture. Evaporation can be diminished through a reduction of the water detention time and an augmentation of the water depth. Fortunately, as WSP performance is highly dependent on meteorological conditions, it is possible to obtain equal performance on both banks of the Mediterranean with significantly lower pond size on the southern bank where water reuse is more needed.

2.3.5 Inlet and outlet structures

Inlet and outlet structures have specific functions. Inlet structures are equipped with a scum box or board, which prevents the scum from entering the ponds. The inlet of all ponds should discharge well below (anaerobic or primary facultative ponds) or below (maturation ponds) the water level to avoid short-circuiting. The outlet of all ponds should prevent scum and duckweed discharge using a scum guard. Take-off level, which is controlled by the scum guard depth, varies according to the specific function of each pond and particularly with algae content and depth. Outlet structures may be equipped with a variable height weir, which allows storage and discharge of effluent according to the objectives ascribed to the plant, such as mitigating the impact of storm events.

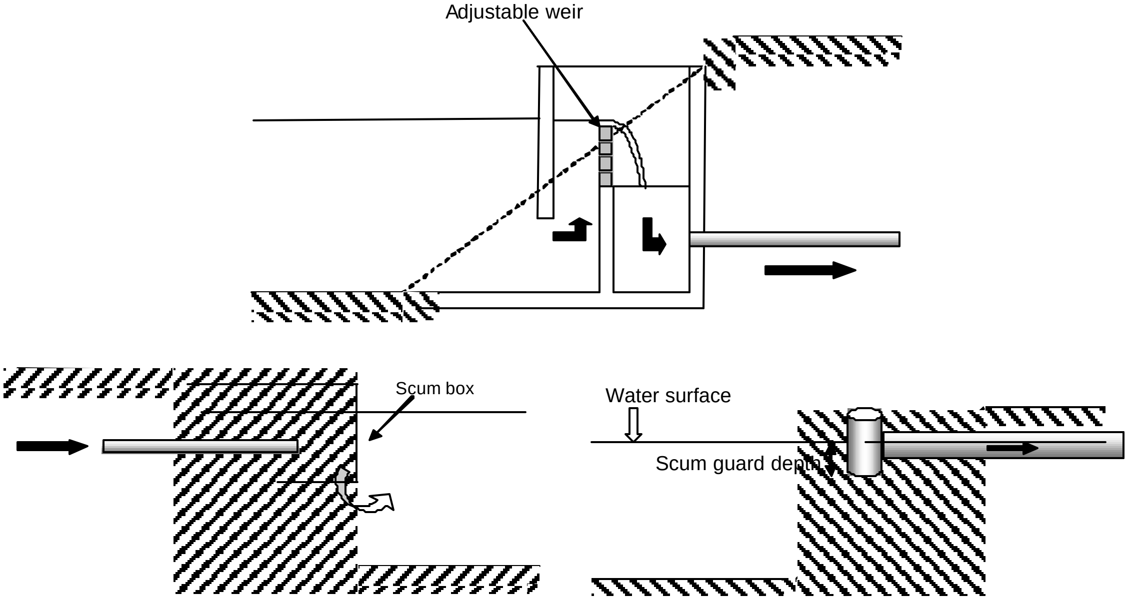


Figure 2.9. Inlet and outlet structures

2.3.6 Bypass pipe work

Pipes should be installed to bypass primary ponds, either anaerobic or facultative, during desludging operations.

2.3.7 Odour nuisances

As mentioned before, the risk of offensive smells is never null. Therefore, WSPs should be located as far from houses and buildings as possible and prevailing winds should be taken into account. Odour nuisances are more likely to occur in spring when sludge that has accumulated in winter is digested due to the increase in temperature. Offensive smells also result from an excess of organic load (discharge of seasonal food processing activities) or from an excessive reduction in the volume of the primary pond due to sludge accumulation. Desludging should, therefore, be undertaken immediately. If this is not enough to handle the entering load, treatment capacity increase and retrofitting works should be seriously considered.

When odour nuisances occur and the applied load has not yet reached the nominal treatment capacity of the WSP system, several solutions can be applied:

- one solution is the recirculation of effluents from the secondary, or tertiary pond, to the inlet of the primary pond. Raw wastewater is diluted, receives an amount of oxygen and is inoculated with micro-algae; thus, risks of anaerobiosis and odour emissions are reduced. To be effective, the recirculation flow rate should be at least equal to the inlet flow rate. Power consumption is minimized when the outlet of the second or third pond is close to the inlet of the primary pond; and

- an alternative solution consists of the mechanical aeration of the primary pond. Low power (< 3 kW) aerators, Venturi type, should be used and located in the central third of the pond; the installed power depending on the applied organic load. This system is considered halfway between the traditional French system and true aerated lagooning; thus, optimizing aeration is not very easy. It is an attractive way to upgrade small WSP facilities, particularly when short duration organic overloads have to be absorbed. However, electric power supply is required.

2.3.8 Algae removal

The main part of COD, BOD and SS content in pond effluent is attributable to algae. This is the reason for the specific regulation applying to pond effluent in the E.U. Directive 91/271/EEC. However, when the sensitivity of the receiving body makes it necessary (low flow river, bathing places), or when required by local regulatory authorities, the pond effluent has to be polished to meet more stringent requirements. Polishing essentially consists of algae removal. Though intermittent sand filtration and wetland systems have been used, the most appropriate technique to upgrade pond effluent seems to be rock filter for it is efficient, cost effective, does not require energy supply and requires little maintenance.

Rock filters are not that common in Europe. They have been used for years in the United States (Middlebrooks, 1995) and are part of current pond design in New Zealand (Archer and Donaldson, 2003). A rock filter is a submerged porous rock bed through which pond effluent travels, causing algae to settle out on the rock surfaces. Accumulated algae are then biologically degraded by bacteria growing on the biofilm wrapping on the rocks. In addition, significant ammonia removal and microbial decontamination can be achieved.

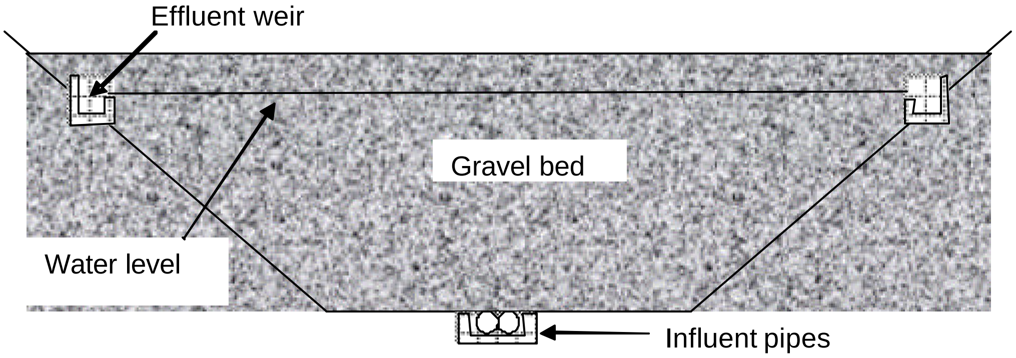


Figure 2.10. Rock filter

The rock size is 40-80 mm; it should be no smaller in order to avoid the risk of clogging. Rock bed depth varies between 0.5 and 1.5 m. The rocks should extend 0.15-0.2 m above water level in the filter to prevent mosquito breeding and development of cyanobacteria on wet surfaces exposed to sunlight.

Performance depends on loading rate, temperature and rock size. Hydraulic loading rates of 0.3 m^3 of maturation pond effluent per m^3 rock bed/day, should allow levels of BOD and SS less than 40 and 60 mg/L, respectively, in the UK (Mara, 2002). Performance would be higher in the Mediterranean.

2.4 Management

Routine management tasks are as follows:

Monitoring inlet and outlet flow rates

- monitoring once a week:
    - water flow, inlet and outlet structures, odours, presence of duckweed;
    - embankments for erosion (particularly internal embankments) and presence of rodents (external banks);
- maintenance of pre-treatment structures once a week; and
- trimming the embankments when they are vegetated and lifting plants rooted in the ponds, two to three times a year. To limit mosquito breeding in the ponds, any plant emerging from the pond should be removed.

Many pond systems are designed with a free board which allows storage of excess water that comes in during storms. This is made possible by varying the level of the weirs of outlet structures. Rising and lowering the weirs should follow clearly defined orders.

Primary ponds should be desludged - every 10-15 years for facultative ponds and more frequently for anaerobic ponds. When a facultative pond is equipped with a settling cone, this cone must be cleaned every 1-2 years.

2.5 Conclusions

Waste stabilization techniques are diverse and offer a large variety of solutions for the treatment of small and medium sized communities.

The main advantages of WSP systems are:

- low management and operating costs, with the exception of aerated ponds which consume a significant amount of energy;
- easy management. WSPs are not labour demanding and do not require highly skilled personnel;
- WSPs are well suited to the Mediterranean climate;
- sludge handling is limited to exceptional desludging operations, the financing of which should be provisioned;
- excess flow due to storms can be stored without jeopardizing treatment performance;
- ponds are easily integrated into the environment, particularly in flat regions;
- ponds are increasingly associated with advanced primary treatments such as Upflow Anaerobic Sludge Blanket process (Von Sperling and Mascarenhas, 2004, El Hafiane and El Hamouri, 2004). This might be a promising association, offering several advantages (land saving, energy recovery), to be successfully implemented on the southern bank of the Mediterranean;
- ponds or better, stabilization reservoirs, offer excellent options when water reuse is envisaged. These techniques allow attainment of the WHO criteria for water reuse and, at the same time, storage of water in winter for use during the hot season; and
- further upgrading the effluent quality is possible, at low cost, using natural systems such as rock filters and wetlands.

The main drawback of WSP systems is the large footprint required by a water residence time of 1-3 months. Another shortcoming is, perhaps, the cost of pond watertightening.

The performance of pond systems highly depends upon meteorological conditions, which hinders prediction and may require some resizing. High evaporation in hot and arid climates leads to significant salinity increase.

Environmental impacts, such as odour nuisances and mosquitoes, may cause severe opposition from the neighbourhood and the general public.

3. INTERMITTENT SOIL FILTRATION

3.1 Intermittent Soil Filtration (ISF) techniques

Intermittent soil filtration (ISF) consists of the intermittent application of primary or secondary effluent on constructed sand filters or permeable native soils. The infiltrated water percolates through unsaturated porous medium. Treated water is collected by a drainage system or percolates down to an underlying aquifer.

ISF is widely applied:

- for onsite treatment and disposal of septic tank effluents (Figure 3.1);
- as infiltration percolation (IP) to treat primary (settled) or secondary effluents (Figure 3.2). It is used to treat settled wastewater of small and rural communities and polish secondary effluents of larger treatment plants, before the reclaimed water is reused or disposed of in sensitive environments (Brissaud and Lesavre, 1993, Salgot *et al.*, 1996). IP is, to a wide extent, associated with underground disposal of treated wastewater, particularly where there is no stream to receive treatment plant effluents. It has also been implemented as soil aquifer treatment (SAT) in the USA (Bouwer, 1996) and Israel (Shelef and Azov, 1996, Idelovitch *et al.*, 2003); and
- as slow rate infiltration of primary or secondary effluents (Figure 3.3).

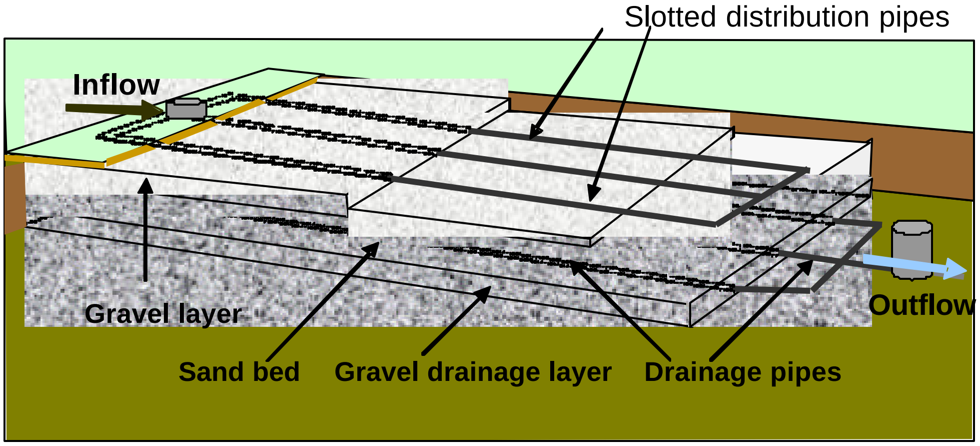


Figure 3.1. Schematic diagram of a drained buried sand filter.

Figure 3.2. Infiltration percolation plant treating secondary effluent in Palamos-Spain

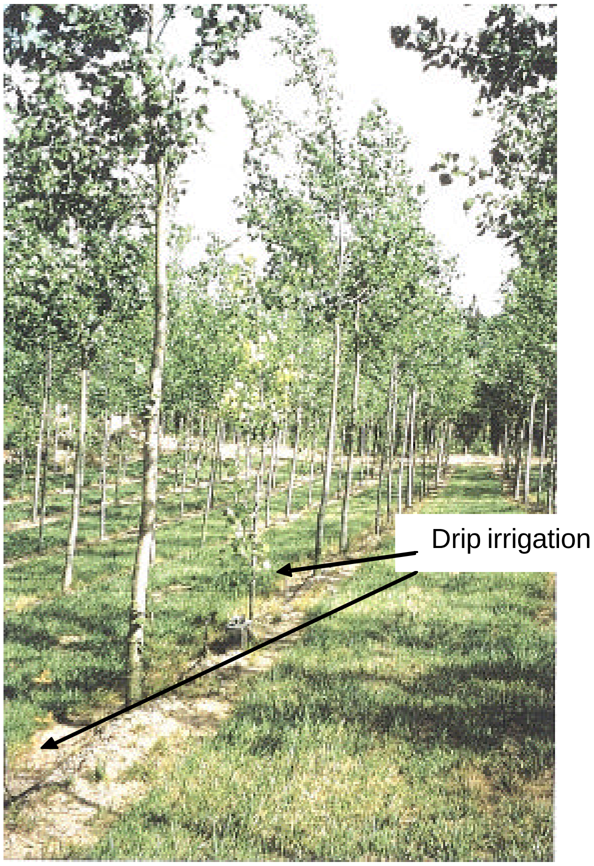


Figure 3.3. Slow rate infiltration of secondary effluents (Begur-Spain)

The main goals of ISF treatment are threefold:

- almost total removal of suspended solids, which do not exceed a few mg/L in the filtered water;
- oxidation of organic matter and nitrogen. COD and Kjeldahl N hardly exceed 60 and 10 mg/L, respectively, in the effluent. The most important part of nitrogen is nitrified and only hardly degradable organic matter remains in the effluent; and
- removal of pathogen micro-organisms, which is the most remarkable characteristic of this process. Nevertheless, perfect management of the technique, or deep non saturated layer in case of SAT, are necessary to reach effluent high microbial quality.

Water doses vary from a few litres per m^2 per day in onsite soil absorption fields (also called drain fields) to a few dekalitres per m^2 per day in buried sand filters. The gravel layer in which the distribution pipes are packed (Figure 3.1) prevents water losses by evapotranspiration.

Hydraulic loads applied on IP filters vary between 0.15 and 0.8 $m^3 m^{-2} day^{-1}$, depending on the water quality. When plants are properly operated, water is completely infiltrated less than half an hour after each application and evaporation uptake is negligible. In the event of heavy rains a few days per year, the hydraulic load and infiltration velocity can be significantly increased, resulting in a brief deterioration in performance of the filter.

Evapotranspiration is an important component of the water budget of slow rate infiltration; this technique is sometimes included in the irrigation or over-irrigation category.

3.2 Treatment mechanisms

3.2.1 Suspended solids removal

Suspended solids, mainly organic, are retained on the surface of the filtrating beds; thus, the particulate organic load and pathogens attached to the SS are removed from the applied wastewater. On the other hand, accumulated SS reduce bed infiltration and oxidation capacities. The most efficient way to avoid surface clogging is to alternate drying and operating periods. The duration of drying periods depends on climatic conditions and SS loads, typically 2 to 3 days for the treatment by IP of secondary effluents, and one to two weeks for primary effluents. Sunshine and dry weather allows for reduction in the duration of drying periods. Dried materials are raked and removed periodically. Operation/drying alternation is scheduled either filter by filter when a plant comprises several filters, or sector by sector when there are only one or two filters in the same plant. In buried filters, a lower applied load may compensate for the difficulty of drying the infiltration surface.

3.2.2 Organic matter and nitrogen oxidation

When percolating through the filter, water is treated by aerobic biological processes resulting in the mineralization of organic matter and the oxidation of nitrogen compounds. Oxidation of dissolved organic matter and oxidizable nitrogen may be achieved as far as the oxygen required is available in the air phase of the filtrating bed, and water velocity is low enough to be compatible with oxidation kinetics. Oxygen is provided by renewal through the infiltration surface of the air phase of the bed by fresh atmospheric air (Figure 3.4). Owing to the size of sand grains, a capillary fringe hampers air renewal through the bottom of the sand beds.

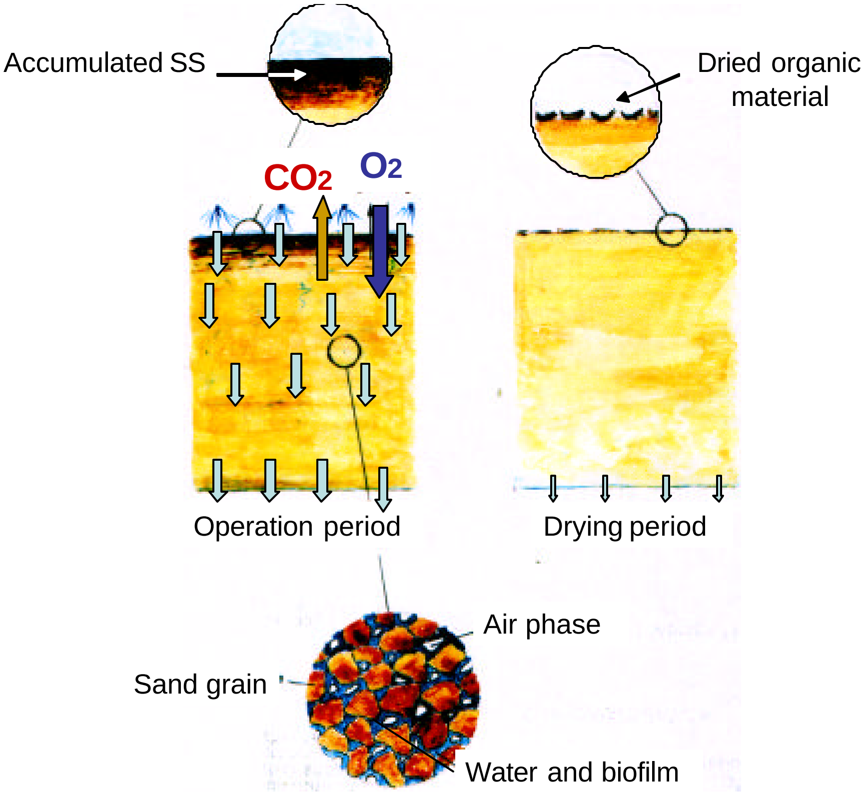


Figure 3.4. Principles of intermittent soil filtration

Two mechanisms are involved in air renewal: air convection and molecular diffusion. When feeding sequences are short and the bed surface not long submerged after feeding, convective volumetric supply of fresh air can be as high as the volume of water infiltrated - and drained - during a feeding/drainage cycle (Figure 3.5). Diffusive supply is a function of air porosity, the vertical distribution of oxidizable pollution and the time available for diffusive transfers. The diffusive contribution is important when hydraulic loads are less than 0.3 $m^3m^{-2}day^{-1}$. Diffusive oxidation capability is dependent upon the soil water content, the hydraulic load and the daily number, f, of application/drainage cycles.

The two stages of organic matter mineralization are: (i) assimilation; and (ii) endogenous respiration. Both stages require an oxygen supply. Organic matter assimilation leads to the growth of the biofilm attached to the sand grains, while endogenous respiration transforms the biomass into CO_2, H_20, and other elements. For the organic loads usually applied, endogenous respiration does not balance assimilation during the operating periods, which results in a biomass accumulation. Uncontrolled biofilm growth results in internal clogging, reduction of infiltration and oxidation capacities and, eventually, failure of the process. Internal clogging, like bed surface clogging, is controlled by alternating operating and drying periods, allowing for the endogenous respiration to mineralize the excess biomass (Figure 3.6).

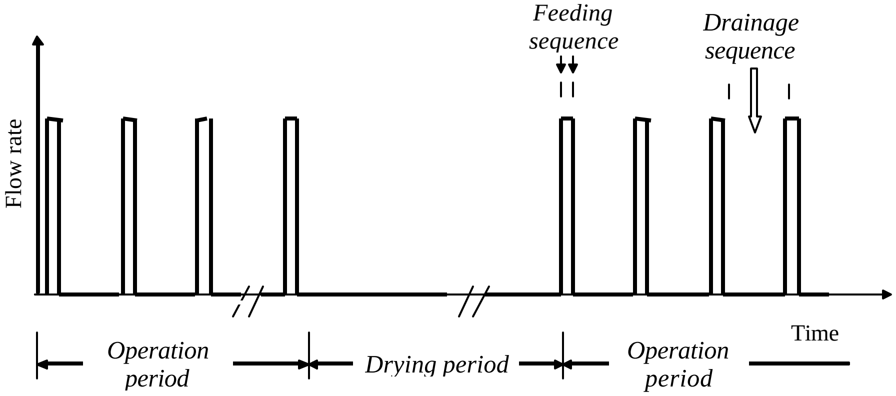


Figure 3.5. Operating schedule of an IP filter

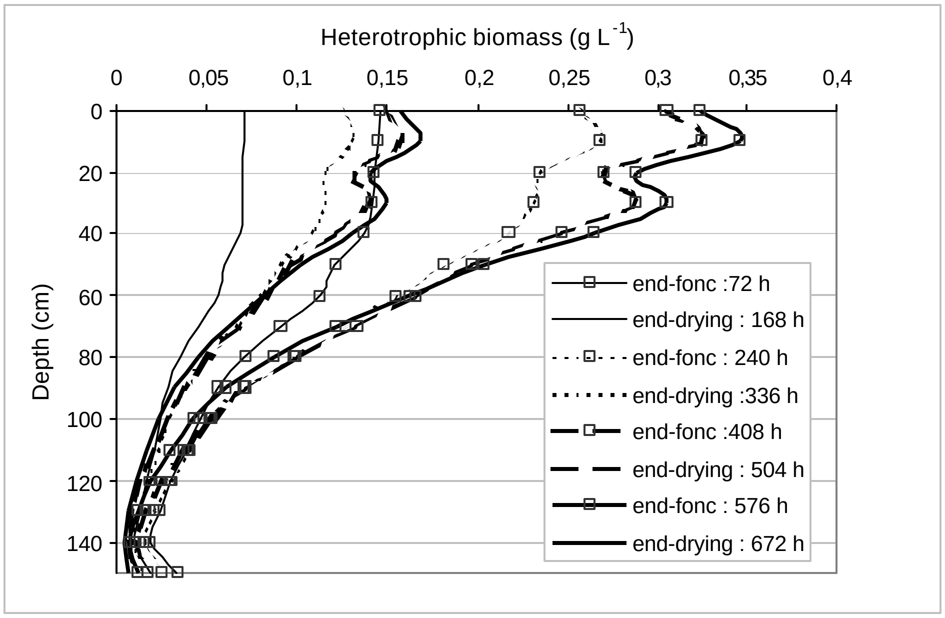


Figure 3.6. Modelling biomass growth (operating periods) and decreasing (drying periods) for a 3 days operation - 4 days drying schedule
(H =0.5 m/d, f =4, influent COD and NTK = 300 and 60 mg/L respectively)

Organic nitrogen entering the filters is rapidly transformed to ammonia-N. Most of the influent ammonia-N is adsorbed in the upper sand bed layers and transformed completely into nitrates when oxygen is available. Nitrates are readily available for down flow. They mix with organic matter brought by a new feeding sequence; then, when oxygen does not meet the total oxygen demand, some denitrification occurs.

3.2.3 Microbial decontamination

Elimination of helminth eggs has always proved to be very effective (Guessab *et al.*, 1993, Peñuelas *et al.*, 1997). They are strained in the very upper layer of the sand filter or onsite soil (Campos, 1999).

Infiltration percolation is appropriate to meet the unrestricted irrigation criteria of WHO (Bouwer, 1996; Salgot *et al.*, 1996a). Three Ulog FC, TC or FS removal is the performance commonly achieved by infiltration percolation plants operated in Spain. However, data collected from several plants exhibited significant variations in FC and FS abatements. Similar removal can be obtained in underground filters provided they are conveniently designed and operated (Fazio, 1987). More than 3.5 Ulog FC means removal was observed in a slow rate infiltration facility treating secondary effluent (Salgot *et al.*, 1996b, Campos, 1999).

Micro-organisms are eliminated through a combination of interrelated processes including mechanical filtration, adsorption and microbial degradation. Efficiency of FC removal has been shown to depend mainly on water detention times in the filtering medium, and on the effectiveness of wastewater oxidation (Brissaud *et al.*, 1999). Detention times are related to operating parameters, such as the hydraulic load, the number of flooding/drainage cycles per day and the feeding rate. The fractionation factor, which is the number of flooding/drainage cycles per day, is of major influence. It should not be less than six for hydraulic loads higher than 0.4 $m^3m^{-2}d^{-1}$ and a bed depth less than 1.5 m in order to avoid short detention times undermining microbial decontamination performance. When sand filters are properly operated and maintained, aerobic conditions are assured within the filter and high faecal indicator removal is observed. In aerobic conditions, the ecosystem accommodated within the biofilm efficiently contributes to the elimination of faecal indicators. Another clue to the impact of the activity of this ecosystem is provided by the influence of the alternation of operating and drying periods on microbial decontamination. Drying periods mean less substrate availability, less biomass development and then a decrease of endogenous respiration, and eventually of enteric bacteria removal. After operation has resumed, bacteria removal efficiency recovers after a few hours or a few days, depending on the duration of the drying period. Therefore, drying periods should be shortened when possible and daily hydraulic loads decreased by way of compensation. (Auset, 2002).

The possibilities of using bacteriophages as model organisms for enteric viruses have been discussed extensively. Bacteriophages are likely to prove very helpful as indicators of process efficiency and their use is increasingly widespread. The resistance of F-specific RNA bacteriophages to water treatments is higher or parallels that of important groups of human viruses. Somatic coliphages are reported to be more questionable as process indicators because of their ability to multiply in unpolluted waters (Campos, 1999).

Seven real-scale IP plants treating primary or secondary effluents in Spain were monitored for F-specific RNA bacteriophages, somatic coliphages and faecal coliforms. F-specific RNA bacteriophages contents were fairly variable in applied effluents and in treated effluent as well. No relationship could be established between faecal coliforms and F-specific RNA bacteriophages contents in applied water or in filtered water. A correlation may be established between somatic coliphages and faecal coliforms content in inlet and outlet waters of several plants. There could be some similarity in the behaviour of somatic bacteriophages and faecal coliforms in the IP process. Average removals and faecal coliforms were 1.9, 2.5 and 3.4 log units, respectively.

In the slow rate facility of Begur (Spain), where 0.008 to 0.025 $m^3m^{-2}d^{-1}$ of secondary effluents are infiltrated through 1.4 to 2.1 m dune sand, mean observed removal of F-specific RNA bacteriophages, CN 13 coliphages and faecal coliforms were 1.5 to 1.9, 2.4 to 2.6 and 3.5 to 3.8 log units, respectively.

3.3 Design

3.3.1 Buried filters for onsite treatment

Septic tank effluent is treated and disposed of into the environment by infiltration through onsite non-saturated soil. Shallow trenches are filled with coarse gravel. Septic effluent is spread along the trenches, through slotted pipes located in the gravel beds (Figure 3.7). The size of the spreading area depends on soil permeability. For instance, the footprint of the infiltration system of a 3-bedroom household is estimated at 70 m^2 for a sandy soil and 90-135 m^2 for a loamy to clayey soil.

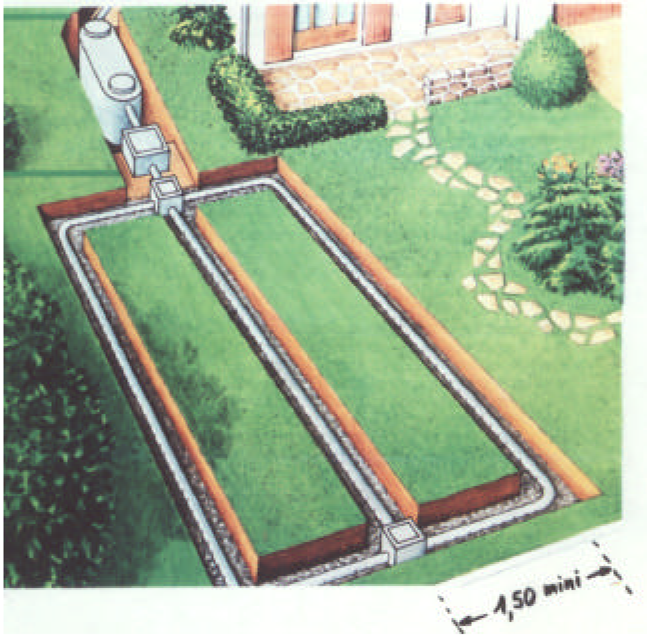


Figure 3.7. Conventional onsite wastewater treatment with soil absorption field

Low soil permeability would result in very large footprints, even for individual facilities. Also, in the case of very permeable soil such as that in karstic zones, it would not be wise to rely on the sole wastewater purification in the vadose zone to protect underlying aquifer, for infiltration velocities are too high compared to decontamination kinetics. Therefore, there are several instances where infiltration in onsite soil is not feasible or would not meet sanitary requirements. The solution most frequently implemented consists of infiltrating septic effluent through buried sand filters, in order to allow controlled treatment prior to percolation to an underlying aquifer or disposal to a ditch or any other receiving body (Figure 3.1).

Onsite treatment can also be chosen as a collective sanitation system for small rural communities or remote quarters on the outskirts of large towns. Treating septic or Imhoff tank effluent through onsite soil would then require large areas, which may not be available or affordable. Buried sand filters require less land.

Filtrating beds are constituted of sand, the mean grain size of which ranges between 200 and 800 µ and the uniformity coefficient, d_{60}/d_{10}, less than 10. The recommended depth of sand beds is 0.7 m. As in conventional trenches, septic effluent is distributed through slotted or perforated pipes, packed in a gravel bed. The distribution system should be designed to provide fairly uniform spreading all over the bed. It is, therefore, highly recommended that the filter be intermittently fed by pumping or using an automatic dosing batch (Figure 3.8) - for gravity fed systems - the flow rate being high enough to fill the distribution pipe network rapidly.

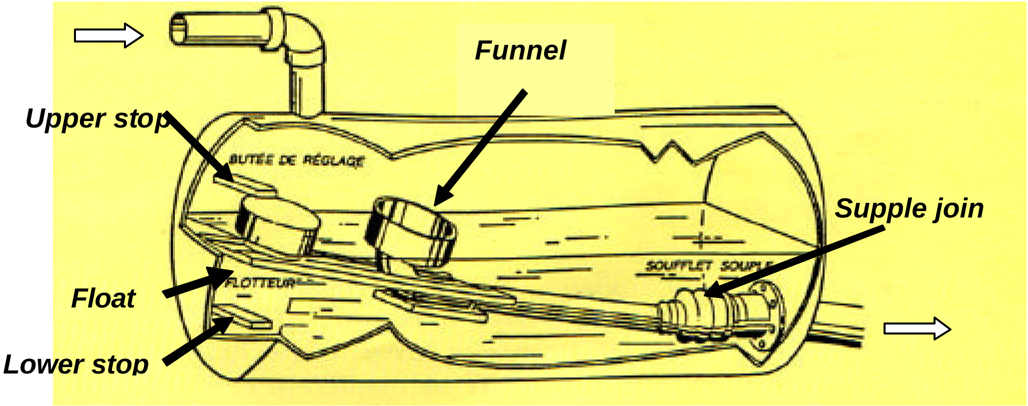


Figure 3.8 Automatic dosing system

When filtered water is to be reused and also when permeability of onsite soil is low, the filter is drained through a gravel layer (Figure 3.1).

The recommended hydraulic load applied on sand filters should not exceed 0.03 m^3m^{-2} per day for individual facilities and 0.05 $m^3m^{-2}d^{-1}$ for collective filters. This rather low load is the result of three difficult situations, the first one being the ability to achieve a uniform distribution of wastewater at the surface of a buried filter, the second being the supply of oxygen, and the third the management of clogging in a confined atmosphere. Leaching chambers (EPA 2002) and new devices designed to overcome these difficulties (recently proposed by manufacturers) allow an increase in the acceptable load up to 0.13 $m^3m^{-2}d^{-1}$.

To avoid or limit the risk of odour nuisance, buried filters and seepage fields are ventilated. Distribution pipes are connected to an air extractor set above the roof of the nearest house or building.

3.3.2 Infiltration percolation

Infiltration percolation plants (Figure 3.9) aimed at treating primary effluent comprise:

- an overflow spillway to limit inflow during storm events, even when the sewer system is of the separate type;
- pre-treatment (bar screen, and more seldom degritting and degreasing);
- primary treatment, typically an Imhoff tank;
- a storage tank or dosing chamber;
- a feeding splitter;
- one or more infiltration units. In case of a single infiltration unit, sectors that can be operated independently should be identified in order to alternate operating and drying periods (Figures 3.2 and 3.10); and
- return of filtered water to the aquifer, or a drainage and withdrawal system

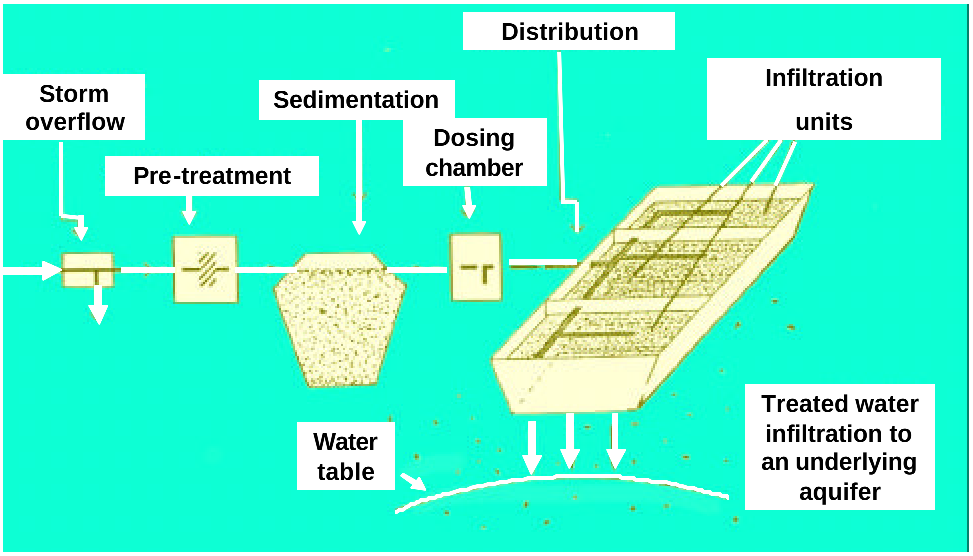


Figure 3.9. Infiltration percolation layout

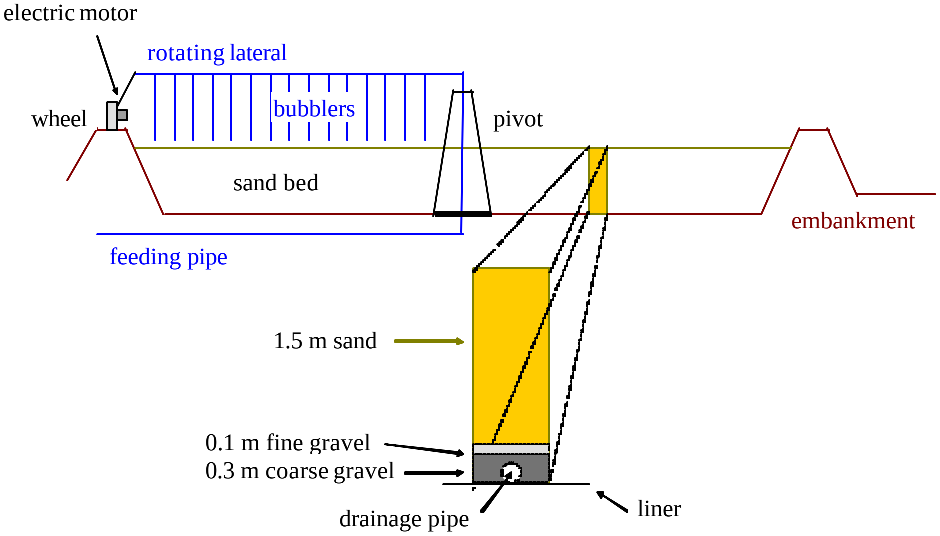


Figure 3.10. Cross-section of an infiltration percolation unit

Large systems are divided into more than one infiltration field. Fields in operation are intermittently fed, flooding sequences alternated with drainage sequences, and the daily number of feeding/drainage cycles, f, ranges between 1 and 20 (Figure 3.5). The duration of the flooding sequence should not exceed half an hour.

Constructed filtrating beds are constituted of the same sand used for buried filter - the mean grain size ranging from 200 to 800 µ and uniformity coefficient being less than 10. The hydraulic load that can be treated depends on the balance between the oxygen that can be supplied to the filter - the oxidation capacity - and the amount of oxygen needed to oxidize organic matter and nitrogen - the total oxygen demand. Total oxygen demand, TOD, is as follows:

$$\text{TOD} = \text{COD measured on filtered samples} + 4.57\ \text{TKN}$$

TOD of primary and secondary effluent is about 500-600 and 250-350 mg O2L^{-1}, respectively. Corresponding bed surfaces can be derived from Table 1, i.e., 0.7-0.75m^{2}p.e.$^{-1}$ to treat a primary effluent and 0.2 m^2 p.e.$^{-1}$ for a secondary effluent. However, clogging management requires alternating operating and drying periods. On the northern bank of the Mediterranean, equal operating and drying periods are recommended as method leads to double bed surfaces. On the southern bank, because of the higher temperatures and solar irradiation, the duration of drying periods can be reduced, thus saving sand volumes and costs.

Table 1

Bed surface as a function of wastewater total oxygen demand

Hydraulic load (m^{3}m^{-2}d^{-1})	**0.2**	**0.3**	**0.5**	**0.8**
Oxidation capacity (mg O_2 L^{-1})	**550 - 600**	**410 - 460**	**310 - 370**	**250 - 320**
Bed surface (m^2 p.e.$^{-1}$)	**0.75**	**0.5**	**0.3**	**0.19**
Bed surface for equal operation and drying times (m^2 p.e.$^{-1}$)	**1.5**	**1**	**0.6**	**0.4**

Bed depth depends on the objectives of treatment. When pathogen removal is not at stake, a depth of 0.7-0.8 m is regarded as sufficient. On the contrary, when IP is aimed at providing water for reuse or protecting bathing water, the depth of the sand bed depends upon the expected level of microbial decontamination. Rough and highly conservative estimates can be derived from Figure 3.10 (Etude Inter Agences n°9, 1993). These estimates apply to facilities that are poorly operated, particularly with regard to hydraulic load fractionation, inlet water spreading homogeneity and clogging and horizontality of the sand bed surface.

Homogeneous infiltration flow rate of wastewater is a key factor in successful treatment, particularly when microbial decontamination is among the objectives. Therefore, two conditions have to be met: (i) uniform wastewater spreading over the infiltration surface; and (ii) an even sand bed surface. The first condition can be achieved either through flush feeding, the inlet flow rate being high enough to rapidly inundate the whole bed surface (Figure 3.11), or using irrigation technologies.

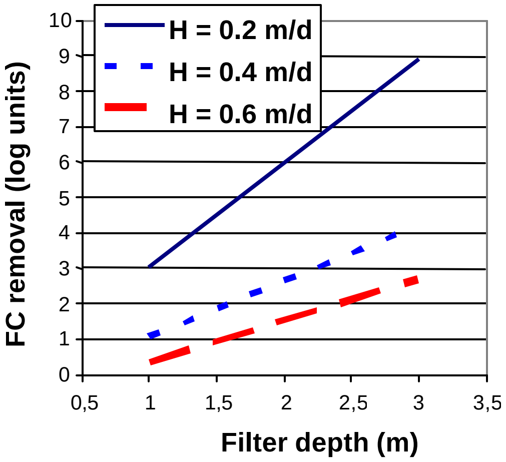


Figure 3.11. A conservative appraisal of sand bed depth

The most practical way to achieve uniform spreading consists of feeding the filters with pumping and frontal move or centre pivot irrigation systems equipped with bubblers; bubbler flow rate of pivot systems is proportional to the distance to the centre of the pivot. Bubblers are located at 0.3-0.5 m above the sand surface. Their design and location minimize the emission of aerosols (Figure 3.12).

Figure 3.12. Flush feeding of an infiltration percolation basin

Each passage of the frontal move system, or pivot's lateral, delivers a water height depending on the pumping flow rate and the velocity of the lateral; a few centimetres hydraulic load can be delivered at each passage. The movement of the lateral and the pumping are scheduled by a programmed clock. The bed surface is divided into identical sectors, identified by a mark in the perimeter or the side of the filter. Stopping the feeding when passing over a single sector can be scheduled, thus allowing for operating/ drying alternation.

Bubblers are appropriate spraying systems for low SS content secondary effluent. Special emitters unlikely to be plugged have been designed for high SS content primary effluents (Figure 3.13).

Figure 3.13. Feeding an infiltration percolation unit in Torrevieja (Spain)

Figure 3.14. Emitters adapted to high SS content effluent.

3.3.3 Slow rate infiltration

Slow rate infiltration is a very extensive technique for the treatment and disposal of settled wastewater of small communities, and secondary effluent of villages and small-size towns. It consists of applying low hydraulic loads on large areas dedicated to wastewater treatment. Low hydraulic load means high oxidation capacity, low infiltration velocity and high pollution removal. The soil should be permeable but not too permeable. Karstic areas deserve particular consideration. In Mediterranean karstic regions, the absence of water bodies able to receive and evacuate the effluent discharged by wastewater treatment plants is commonplace; in this situation, the final destination of the effluent is often an aquifer, which is the only available water resource. Therefore, spreading the effluent over large areas would considerably reduce the risks of aquifer pollution. However, the spreading areas should be carefully chosen. Effluent should not be directly applied to cracked calcareous rocks and a soil layer of a minimum depth of 20-30 cm should be available, in order to prevent direct flow paths to the aquifer.

Spreading areas are planted with trees or other non-edible crops. Applying low hydraulic loads allows evapotranspiration to play a very significant part in the fate of wastewater and pollutants: plant transpiration reduces infiltration, while nutrients are taken up for plant growth.

Though furrow irrigation has been used in the past, the actual preferred spreading devices are based on drip irrigation technology, or underground networks of water distribution pipes. Both systems prevent the dissemination of pollutants in the environment.

Hydraulic loads depend on soil permeability and should not exceed a few $Lm^{-2}d^{-1}$. When planning slow rate infiltration, the eventual influence of runoff on pollution dissemination should be taken into account and provision made for storing wastewater during rainy periods.

3.3.4 Remarks

All ISF facilities should be efficiently protected from damage that might be brought about by run-off and floods. For this reason, their location should be carefully chosen.

3.4 Management

The main management tasks are related to the monitoring of wastewater distribution systems, clogging risks, sludge accumulation in settling facilities and sludge handling.

3.4.1 Wastewater distribution and clogging

Clogging and wastewater distribution in underground systems cannot be monitored directly. However, periodic monitoring of the water level in inflow distribution boxes and dosing chambers allows checking to some extent whether the distribution is properly operated. The pre-filter, often inserted between the septic tank and the leach field to prevent clogging of the latter, has to be cleaned regularly. Whatever precautions have been taken, buried filters may clog. To overcome this possibility, two filters can be constructed and operated alternatively on a yearly basis. This allows the one not in use to recover its infiltration capability.

Bubblers should be cleaned every month. The flooding of the surface of an infiltration percolation unit beyond the time usually necessary for total infiltration and the related shortening of the drainage sequence, provide easily observed evidence of clogging. The clogged unit should then be put to dry. Drying period is long enough for the clogging layer to dry, crack, curl up and be raked off. Clogging remnants are removed after several operating/drying alternations, either mechanically or manually. Raking should be tied with the control of infiltration surface horizontality, which is crucial for a homogeneous infiltration.

Drip irrigation devices used for slow rate infiltration should be cleaned at least yearly.

3.4.2 Sludge management

Settling or pre-treatment before treatment in leach fields, buried sand filters, infiltration percolation sand beds and slow rate infiltration facilities entails sludge accumulation. The time interval between two successive desludging operations of septic tanks depends on the ratio of the tank volume to the received load. A period of 3 to 10 years is acceptable. Sludge should be extracted of Imhoff tanks every six months.

3.5 Conclusion

ISF techniques share the advantages and disadvantages of *natural* wastewater treatment systems.

The advantages are:

- ISF provides very effective oxidation of organic matter and nitrogen and allows, when properly designed and operated, high faecal indicator removal. In the Mediterranean, microbial decontamination is considered a very important asset owing to the absence of permanent streams, the vulnerability of karstic aquifers and the proximity of beaches;
- the energy consumed for running ISF facilities is limited to the energy required by the low pressure pumping to feed the filtrating beds and movement of the pivot of infiltration percolation plants;
- the Mediterranean climate does not negatively affect ISF functioning; high temperature and wind help significantly;
- operation and management are not labour demanding, with the exception of infiltration percolation which requires two visits a week for normal maintenance and follow up of infiltration capability, and a monthly raking and evening out of infiltration surfaces. O&M does not require high professional skills. However, the operator should be trained and aware of the treatment process;
- though belonging to the category of extensive techniques, infiltration percolation and buried sand filters require much less land than waste stabilization ponds;
- sludge handling tasks are limited to desludging at intervals of 6 months (Imhoff tank) to a few years (septic tank) time interval; and
- ISF do not jeopardize the aesthetics of the place where they are set.

The disadvantages are:

- most parts of the inflow nitrogen are released from ISF facilities as nitrate, which may be a concern for aquifers and streams that are sensitive to eutrophication;
- phosphorus is removed during the first months of operation but not on a long term basis, which is not a drawback when effluent is reused for irrigation;
- infiltration percolation requires a great amount of sand; this may lead to high construction costs if sand is not available nearby; and
- ISF facilities can hardly mitigate the impact of hydraulic overloading unless they have been purposely oversized.

4. CONSTRUCTED WETLANDS

A wetland is an accumulation of water, substrate, plants, litter (fallen plant material), invertebrates and micro-organisms. Numerous and often interrelated mechanisms contribute to water quality improvement: settling of suspended solids, filtration, precipitation, chemical transformation, adsorption, breakdown and transformation and uptake of pollutants and nutrients by micro-organisms and plants, predation and natural die-off of pathogens (IWA, 2000). Constructed wetlands (CW) mimic and try to optimize the conditions found in natural wetlands in order to treat a variety of wastewaters. The two basic types of CW are: (i) free water surface, or surface flow wetlands; and (ii) subsurface flow (SSF) wetlands.

Surface flow wetlands typically have a water depth of less than 0.4 m and are densely vegetated by a variety of plant species, floating or rooted in the sediments at the bottom of the ponds. Emergent plants growing in SSF wetlands are rooted in a bed of soil or gravel. Wastewater, pre-treated or not, flows by gravity, horizontally or vertically, through the bed substrate, where it contacts a variety of microbes fixed on the substrate and plant roots. The bed depth is typically between 0.6 and 1.0 m. The most frequently used plant species are common reed (*Phragmites australis*), cattail (*Typha* spp.), bulrush (*Scirpus* spp.), reed canary grass (*Phalaris arundinacea*) and sweet manna grass (*Glyceria maxima*)

SSF wetlands are increasingly used to treat domestic, agro-industrial and runoff wastewater.

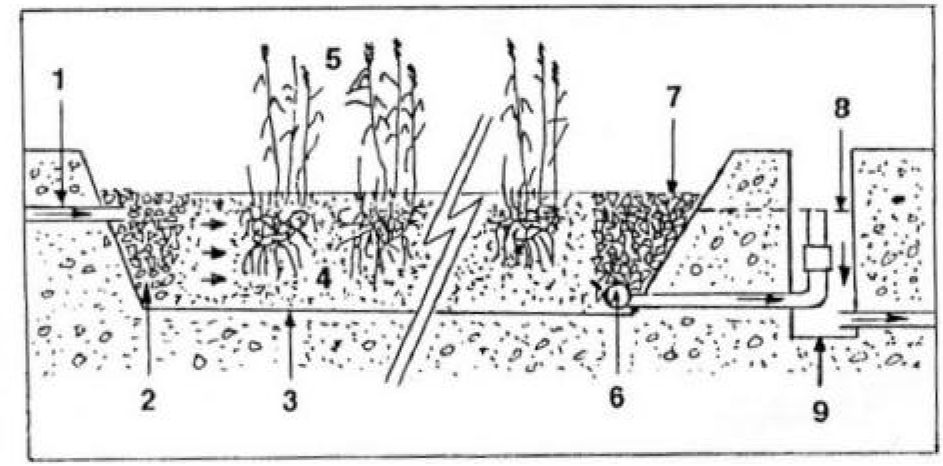
4.1 Types of SSF wetlands

The flow in SSF wetlands is vertical (VF) or horizontal (HF).

4.1.1 Horizontal flow systems

Horizontal flow (HF) systems treat mechanically pre-treated (screened), settled municipal wastewater or secondary treated effluent as well. The wastewater that is fed in flows slowly through the porous medium under the surface of the bed before it reaches the outlet (Figure 4.1). SS that have not been removed by pre-treatment are retained by filtration and settlement in quiescent areas. During its passage through the bed, wastewater comes in contact with aerobic, anaerobic and anoxic zones where it is cleaned by microbiological degradation and physical-chemical processes. Aerobic zones occur around roots and rhizomes which leak limited amounts of oxygen to the bed. However, it has been shown that the oxygen transport capacity of reeds far from satisfies the needs for aerobic degradation of the wastewater, and that anoxic and anaerobic degradation play a very important part in horizontal flow systems. For the same reason, if the BOD of the inlet water is significant, Kjeldahl (oxidizable) nitrogen is unlikely to be removed. As the oxygen supply is limited, only a small fraction of ammonia is oxidized then denitrified. On the contrary, if the water that is fed in contains nitrate, denitrification occurs, removing the corresponding amount of nitrogen. The removal of phosphorus is very limited, except when the porous medium contains great quantities of Fe and Al hydrous oxides, which is very uncommon.

Flow through HF systems may be an efficient means of microbial decontamination. It was shown by Masi *et al*. (2004) that 2.9-3.2 log units faecal indicators removal was obtained in a 5-10 mm gravel-size horizontal filter treating Imhoff tank effluent. The establishment of reeds significantly improved the decontamination. Similar results were obtained by Baeder-Bederski *et al.* (2004) with 1.5 and 3.5 Ulog *E. coli* removal through horizontal submerged systems, encompassing a 0.6 m thick filter layer constituted of 2-4 mm Exclay (expanded clay) mixed with 0-2 mm sand (d_{10} = 0.6 mm; d_{60} = 2.8 mm) and 0.2 mm sand (d_{10} = 0.3 and d_{60} = 0.9), respectively, and treating effluent from a secondary VF constructed wetland.



Longitudinal section of a constructed wetland with horizontal SSF.
Key: 1. inflow of mechanically pre-treated wastewater; 2. distribution zone filled with large stones; 3. impermeable liner; 4. medium (e.g., gravel, sand, crushed stones); 5. vegetation; 6. outlet collector; 7. collection zone filled w iht large stones; 8. water level in the bed maintained with outlet structures; 9. outflow (Vymazal, 1997).

Figure 4.1. Horizontal flow subsurface constructed wetland (from Vymazal, 1997)

4.1.2 Vertical flow systems

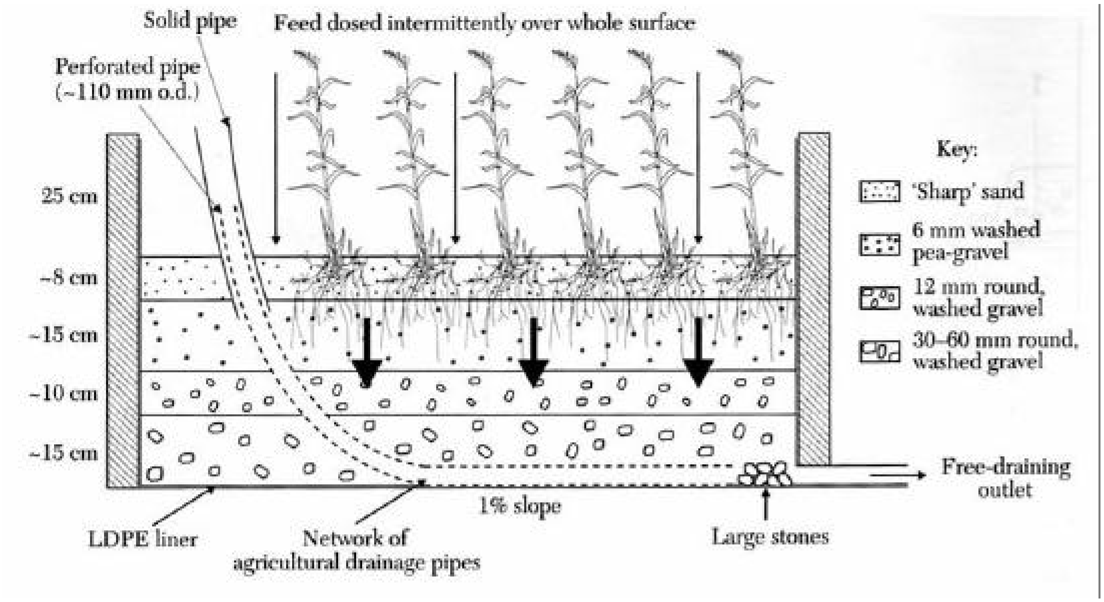


Figure 4.2. Vertical flow subsurface constructed wetland (Cooper *et al.*, 1996).

Vertical flow (VF) systems are composed of a flat gravel bed topped with sand or fine gravel. They are planted with reeds at the same density as horizontal flow systems. VF systems are fed intermittently with settled or raw wastewater. Wastewater is dosed on the bed in a large batch, the whole surface being flooded in order to reach homogeneous infiltration. SS are retained on the bed surface or in the very upper layers. The liquid percolates down through the bed and is collected by a drainage system.

Perforated ventilation pipes aerate the drainage layer. The size of the gravel does not allow the existence of a capillary fringe in the bed, thus air convective and diffusive movements throughout the bed are only hampered by plant roots. Between two feedings, the bed drains completely, drained water being replaced by fresh air, thus providing oxygen to the bed. Oxidation of dissolved organic matter and nitrogen occurs in a similar way to that in intermittent soil filtration processes. Oxidation is made possible by close contact between heterotrophic bacteria attached to the substrate (gravel) and the roots and water percolating down. The amount of oxygen yield by plant roots and rhizomes is negligible.

Phosphorus may be removed over a few months but, as shown by monitoring of several plants, it seems that P removal becomes less significant in the long term.

Masi *et al.* (2004) have observed removal 0.7-1.2 log units of faecal indicator in VF units performing a tertiary treatment of HF effluents. After reeds developed in the system, the water quality consistently met the Italian regulations for water reuse (when using a natural treatment system, *E. Coli* must be <50 CFU/100 mL in 80% samples with a maximum value of 200 CFU/100 mL). Vertical filters removed 1.9 and 3.3 *E. coli* log units from settled municipal sewage. Filtering media characteristics are mentioned in sub-paragraph 4.1.1.

4.1.3 Role of plants

The role of macrophytes growing on SSF constructed wetlands has been questioned. They are an essential part of the design for the following reasons:

- roots provide support for attached micro-organisms;
- root growth helps maintain the hydraulic properties of the substrate, i.e., infiltration and aeration capacities; and
- movement of stems by the wind maintains the infiltration capacity of the sludge layer on the surface of the beds.

Additionally, vegetation protects the surface from erosion and shading prevents algae growth. Litters provide some insulation. The oxygen released from the roots into the rhizosphere represents a small contribution to the oxidation requirements. Nutrient uptake is also rather low (Langergraber, 2004).

Because the hydraulic load is a few hundred litres per square meter and the infiltration velocity rather high, water losses due to evapotranspiration are low in VF constructed wetlands. However, they are not insignificant in hot periods. Water losses are more significant in HF systems, particularly during the growth period. Dramatic evapotranspiration rates, from 20 to 60 mm.day^{-1}, have been reported for 2 m^2 plots planted with *Tamaris* and *Arundo donax* in Northern Morocco (Cadelli et al., 2004). More representative data are that El Hafiane and El Hamouri (2004a), who found water losses of 40 and 20% for hydraulic loads of 65 and 190 mm.day^{-1}.in HF SSF wetlands of 18 m x 3.5 m unit surface planted with *Arundo donax* in Rabat (Morocco). If the evapotranspiration potential of constructed wetlands is being used in some countries to meet a zero discharge objective, it may preclude treated water reuse in agriculture.

4.2 Options for sewage treatment

4.2.1 Vertical Flow + Vertical Flow (VF + VF)

Different combinations of HF and VF subsurface constructed wetlands have been proposed. A two-stage VF system, developed by CEMAGREF 20 years ago, is rapidly becoming widespread in France, where more than 200 such facilities have already been installed (Molle *et al*., 2004). A distinctive feature of this option is that raw wastewater is applied on the first stage VF, which means that a settling stage is not necessary. Thus, the burden of sludge handling is considerably alleviated.

The characteristics of the filters, as shown in Table 2, differ slightly from the design of Cooper *et al.* (1996). The gravel size of upper layer, 2-8 mm, aims at reducing the risks of clogging. A primary VF receives incoming raw sewage for 3 to 4 consecutive days and is then rested for twice the amount of time. As for ISF systems, alternating feeding and resting (drying) periods are crucial, for they facilitate surface control and internal clogging through mineralization of filter biomass and SS accumulated on the bed surface. This alternation requires that the system comprises 3 VF units. The treatment is completed in the secondary VFs, which are intermittently fed and where nitrification is achieved; operating and drying periods are of equal duration. Both stages are batch fed.

Table 2

Layers	1st stage VF	2nd stage VF
0.3 m top layer	Fine gravel (2-8 mm)	Coarse sand ($0.25<d_{10}<0.4$ mm)
0.1-0.2 m transition layer	Gravel (5-20 mm)	Fine gravel (3-10 mm)
0.1-0.2 m drainage layer	Coarse gravel (20-40mm)	Coarse gravel (20-40 mm)

Sizing depends on the climate, discharge permit requirements and the hydraulic load. Bed surface recommendations for France are: 1.2 m^2 per p.e. divided into 3 units for the first stage, and 0.8 m^2 per p.e. divided into two units for the second stage.

Sludge deposit on the bed surface contributes to a better distribution of the incoming water and slows down its infiltration, thus allowing enough time for the biological process to degrade the pollution load. Sludge accumulates on the filters rather slowly, even on the primary VF system. Molle *et al.* (2004) report sludge heights of 13 and 25 cm in primary vertical filter of a plant designed for 1600 p.e., after 9 and 15 years operation, respectively. SS mineralization rate was estimated to be more than 60% (Boutin *et al*., 1997); this mineralization was proven to be aerobic (Chazarenc and Merlin, 2004). Because the dry matter content was greater than 20%, sludge deposits were easily removed. As rhizomes were not withdrawn, the desludging operation did not affect the re-growth of the reeds. It appears that high a deposit layer does not significantly hamper the infiltration capacity, thanks to the mechanical role of the reeds.

4.2.2 Horizontal Flow + Horizontal Flow (HF + HF)

The planted surface of HF systems treating settled wastewater should be about 5 m^2/p.e., though some experts recommend 10 m^2/p.e., particularly in northern Europe. The depth of the bed is equal to the maximum depth of the roots, i.e., 60 cm for *Phragmites*. The incoming water is distributed along the entire horizontal cross-section of the bed in a distribution zone filled with gabion, or large stones (Figures 4.1 and 4.3). The filtering medium should be of fine gravel, the size of which depends on the water to be treated: 3 -6, 5-10 or 6-12 mm, the permeability being between 1 10^{-3} and 3 10^{-3} ms^{-1}. Effluent is collected close to the bottom of the filter. The water depth may be adjusted owing to a variable level outlet structure. The water surface should be maintained at 5-10 cm under the bed surface - it should never circulate above the surface of the bed.

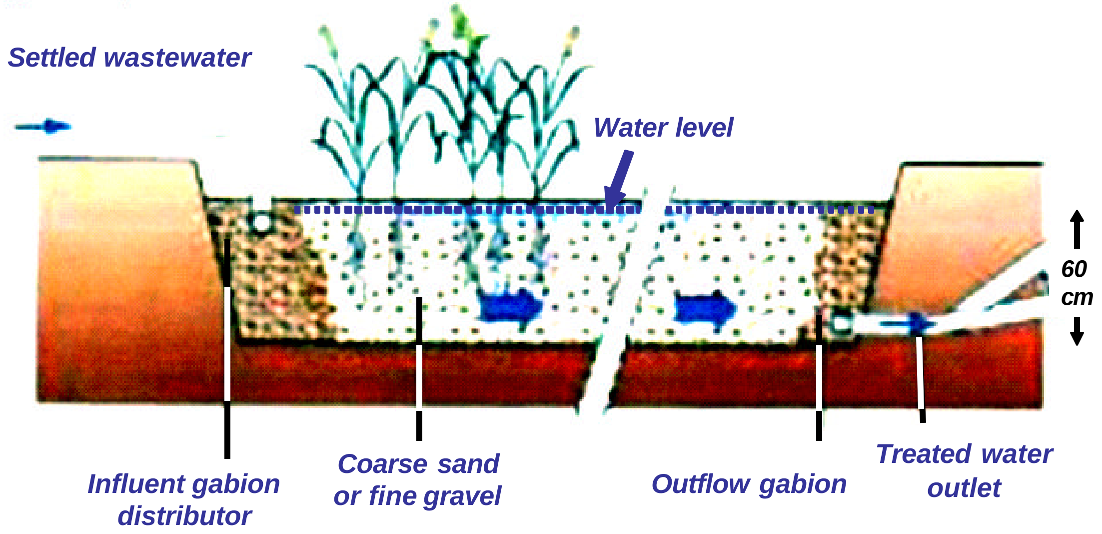


Figure 4.3. Horizontal flow reed bed filter (after European Commission, 2001)

Horizontal flow wetland systems are more common, particularly in northern European countries (Germany, Denmark, UK, etc.). Such systems used to treat primary effluents, typically after pre-treatment and settling in an Imhoff tank. Only one HF unit is used to treat the sewage produced by a single household or when the community to be served is < 50 p.e. For larger systems, multiple cell configurations set in parallel, are highly recommended, for clogging and hydraulic management. However, systems with HF in series have also been constructed, so as to enhance treatment efficiency. Vymazal (2004) reported 88, 88, 99 and 50% removal for respectively BOD, COD, SS and TN in a facility comprising an Imhoff tank, and two series of two parallel HF cells in a series. The surface of the vegetated beds was 3520 m^2 for a load of 700 p.e. Mean removal of faecal coliforms and faecal streptococci was respectively 3.51 and 3.34 log units.

4.2.3. Horizontal Flow + Vertical Flow (HF + VF)

The treatment capacity of HF systems with regard to BOD, COD and SS is high but nutrient removal is rather low. Therefore, when nutrient removal or higher protection of the receiving medium is required by local authorities, it is possible to combine HF and VF in series. The main result is that nitrification is enhanced; ammonia is replaced by nitrate in the effluent. Phosphorus removal may also be improved. However, a substantial level of improvement requires materials to be selected on the basis of their phosphorus binding capacity.

4.2.4. Vertical Flow + Horizontal Flow (VF + HF)

A concern related to VF + VF combined systems is that most sewage-borne nitrogen is released into the environment as nitrate. Reducing nitrate release can be obtained through the replacement of secondary VF systems by horizontal flow systems. Another driving factor for choosing HF systems as a secondary treatment stage, is insufficient slope for gravity feeding of two successive VF stages (Paing and Voisin, 2004). Combining vertical and horizontal flow systems provides efficient means of microbial decontamination. It allowed mean *E. Coli* contents to be reached equal or less than 100/100 mL in the effluent of the experiments of Baeder-Bederski *et al.* (2004).

4.3 Management

The main management tasks are as follows:

- Twice a week, alternating operating and resting cells (VF)
- Once a week:
    - maintenance of pre-treatment structures in order to limit clogging risks;
    - cleaning feeding siphons (VF) and distribution devices (HF);
    - checking water distribution; and
    - checking the embankments when the systems are above ground level.

- Once a year
    - removal of invading weeds; and
    - cutting and disposal of reeds (VF). This operation is optional for HF systems. Cuttings can be used as green waste for compost production, or be burned.

- Every 10-15 years, removal of the deposit at the surface of VF systems.

4.4 Conclusion

Submerged flow-constructed wetland systems provide very effective removal of SS and organic matter. Impressive microbial decontamination is reached in one-stage systems. Therefore, implementing two-stage systems should meet the WHO criteria for unrestricted water reuse. Pumping, when gravity feeding is not possible is the only source of energy consumption by the operation of SSF constructed wetlands. O&M tasks do not require highly skilled personnel as the most sophisticated devices are pumps and siphons for batch feeding of VF systems. The footprint of VF systems is not that important, but the same is not true for HF systems. As they are planted, constructed wetland facilities will not jeopardize a rural landscape. No significant offensive odour has been reported in the vicinity of regularly maintained SSF wetlands. Sludge handling is very limited, particularly when raw wastewater is applied on VF systems as proposed by Boutin *et al.* (1997).

Nutrient removal is not performed very efficiently in constructed wetlands. Nitrification and denitrification can be enhanced when combining VF and HF, thus eliminating a significant part of nitrogen, but the removal of phosphorus is limited. Horizontal flow systems require considerable areas of land. Constructed wetlands, as ISF systems, are not the best solution for absorbing high hydraulic variations resulting from storm events, unless some cells are particularly dedicated to receive combined sewer overflows.

5. CONCLUSION

Wastewater sanitation in the Mediterranean should meet several objectives that are connected to the specific context of the region:

- protection of groundwater resources, particularly those stored in karstic aquifers and in aquifers that might be contaminated by the leakage of sewage treatment plant effluent discharged in dry river beds;
- protection of coastal waters and bathing places; and
- increasing demand for treated wastewater that can be reused for beneficial purposes.

Special attention should be given to water reuse. In the Mediterranean, the main application of water reuse is, and will long remain, irrigation. Secondary effluents are used to irrigate fodder, cereals and industrial crops in Tunisia (Bahri and Brissaud, 1996), Spain (Salgot and Huertas, 2001) and Israel (Chikurel *et al*., 2001), orchards in Italy and even golf courses in Tunisia (Bahri *et al*., 2001). Secondary effluents that have undergone conventional or extensive disinfection treatment are used for unrestricted agricultural irrigation in Israel and the irrigation of public parks, lawns and golf courses in Spain and France (Faby *et al*., 1999). As reported by Bahri (1998), the selection of reuse options has not always been made on a rational basis. Sufficient consideration has not always been given to the cost-effectiveness of reuse projects. As a consequence of the attitude of state or regional authorities towards the agricultural sector, expensive reuse projects have been funded to irrigate a few hundred hectares (located in remote areas) of low income crops with secondary effluents. Such projects are unlikely to be economically efficient or to help develop water reuse and water savings in the region. Reclaimed water is a valuable but limited water resource. For example, the daily flow rate of a town of 20,000 inhabitants is just sufficient to meet the irrigation needs of a 40 ha golf course. With respect to the limited volumes of reclaimed water, transportation costs must be reduced as much as possible and reuse sites located close to the places where wastewater is produced, treated and stored. More projects should be devoted to towns or nearby applications. Reclaimed water applications that should be envisaged are: (a) urban uses such as irrigation of public parks and lawns, landscape and golf courses (Bahri *et al*., 2001), or toilet flushing (Shalabi, 2004), which often means offsetting potable water for non-potable purposes and maximizing the efficiency of reuse projects; and (b) vegetable crops and orchards, often located in the vicinity of towns, the income from which may allow recovery of the costs of the supply of treated water. These applications require removal of pathogenic micro-organisms from reclaimed wastewater.

Protection of aquifers, bathing places and efficient water reuse require that the effluents of wastewater treatment plants are pathogen free and have undergone treatment allowing for microbial decontamination.

Taking into account the economic situation of many countries in the region, development of economically sound water reuse and sanitation strategies ensuring the protection of water resources and coastal water, relies on (a) the availability of wastewater treatment techniques that meet health related standards at low investment and O&M costs; (b) require low O&M skills; and (c) are reliable. Thus, extensive technologies are likely to be preferred to intensive processes, particularly those that are to serve small and medium-sized communities. Investment costs of extensive wastewater reclamation techniques are not much lower than those related to intensive technologies. Moreover, several extensive techniques require large areas of available land and cannot be applied in areas that are too densely populated. However, extensive techniques do offer decisive advantages: very low O&M costs, easy O&M and high microbial decontamination potential. The main characteristics of natural wastewater treatment techniques reviewed in this paper are summarized in Table 2.

Some concerns remain regarding extensive techniques planned to meet health related criteria. Namely, what microbial quality can be achieved and to which extent is this achievement reliable? Extensive techniques have not originally been designed for microbial decontamination, particularly in Europe. Their decontamination potential has only been considered relatively recently. Efforts have been made during the past few years to assess and better understand microbial removal in extensive treatments. Recent studies have shed light on (i) the microbial decontamination that can be reached through extensive techniques; (ii) the reasons why microbial performances may vary; and (iii) the measures that can be taken to improve the predictability and reliability of extensive techniques (Brissaud *et al*., 2003). These studies also show that the current design of extensive treatment plants -

consultants often use nothing more than a rule of the thumb- should be improved to provide more predictable performances and reliable disinfection.

Table 2

Main characteristics of natural wastewater treatment techniques. (The advantages common to all these techniques, i.e., low O&M costs, low required O&M skills, reliability, are not specified. Evaporation can be regarded as a drawback when water is to be reused but as an advantage when zero discharge is expected)

Technique	Treatment stage	Performance (removal)	Advantages	Disadvantages
Waste stabilization ponds				
Anaerobic pond	Primary	SS, BOD, COD	Small footprint	Odours, Frequent desludging
Facultative pond	Primary Secondary	BOD	Desludging at 12-15 year intervals	Large footprint, Risk of odours, Evaporation
Maturation pond	Secondary Tertiary	COD, Nutrients, Pathogens		Large footprint, Evaporation
HRAP	Secondary	BOD, Nutrients, Pathogens	Small footprint	Production of large amounts of algae
Aerated pond	Primary Secondary	BOD	Small footprint	Power consumption
Macrophyte pond	Primary Secondary Tertiary	BOD, COD, Nutrients, Pathogens		Large footprint, Frequent harvesting,
Reservoir	Tertiary Quaternary	COD, Nutrients, Pathogens	High performance when batch-operated	Evaporation
Intermittent soil filtration				
Soil absorption field	Secondary	SS Organic matter and N oxidation Pathogens removal		Large footprint Clogging risks
Buried sand filter	Secondary		Small footprint	Clogging risks
Infiltration percolation	Secondary Tertiary		Small footprint	Clogging risks Nitrate build up
Slow rate infiltration	Secondary Tertiary			Large footprint
Subsurface Flow Constructed wetlands				
Vertical flow	Primary Secondary Tertiary	SS, COD, N oxidation, Pathogens	Small footprint	Limited sludge handling tasks
Horizontal flow	Secondary Tertiary	SS, COD, N, Pathogens		Large footprint, Evapotranspiration

If extensive techniques are affordable and can reliably meet WHO guidelines for unrestricted reuse, they are unlikely to offer suitable options to comply with much more stringent standards for both economic and technical reasons, unless they are combined with conventional intensive techniques.

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