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ENVIRONMENTAL AND HEALTH IMPACTS OF WASTEWATER TREATMENT PLANTS

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1. INTRODUCTION

Sewerage systems comprise several facilities, starting from the final, non-consumptive users of water which generate the wastewater, to the disposal of treated effluent and the by-products generated during the treatment.

This document will focus only on what happens inside the facilities devoted to wastewater treatment, with the two main lines (water and sludge) and the secondary by-products (waste generated in the pre-treatment). From the facility, other outputs will be dealt with, namely aerosols, gases, water vapour and the like (see Figure 1).

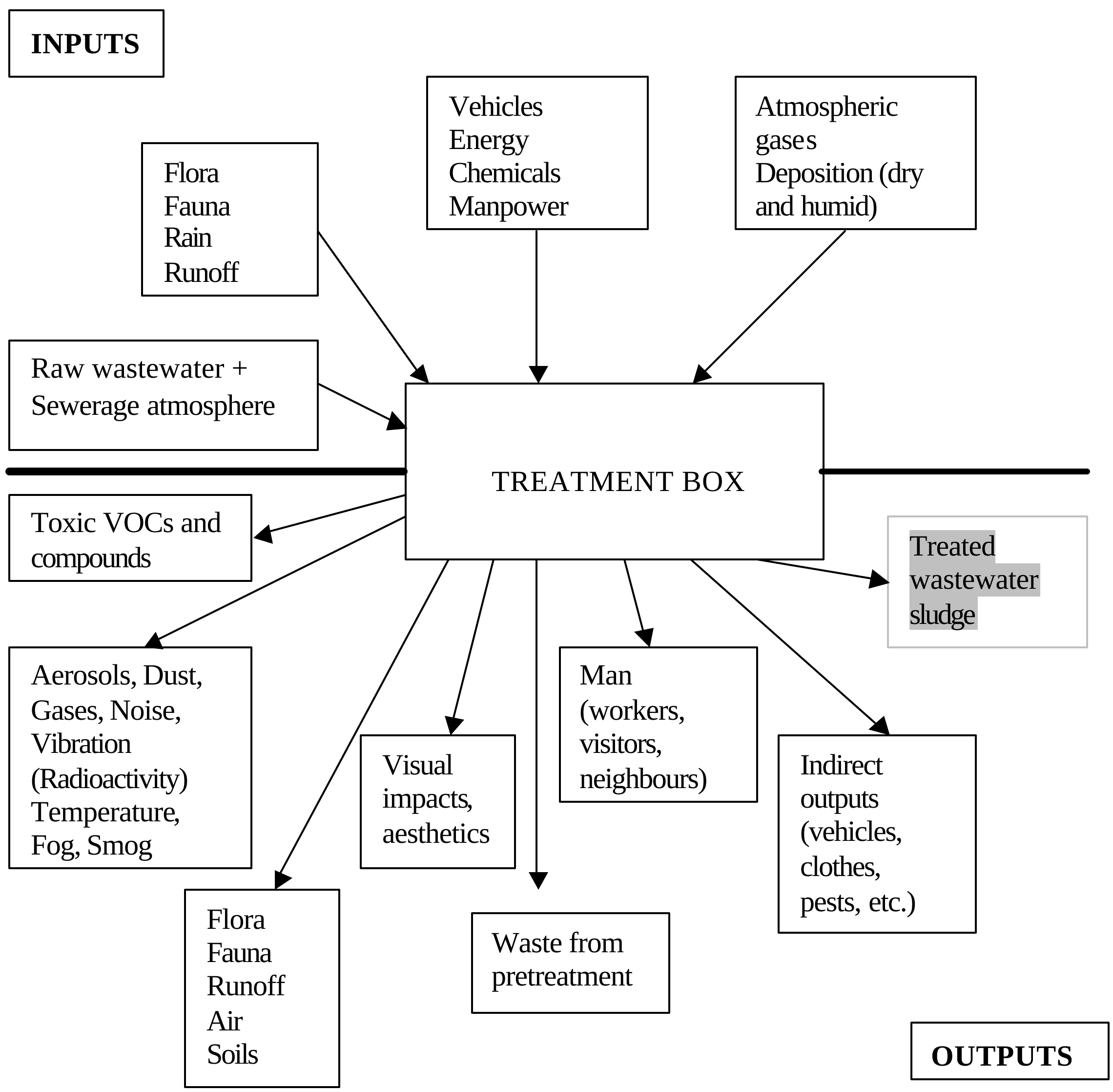

Figure 1. Inputs and outputs in a classical wastewater treatment plant affecting the environmental impact of the facility (the box in grey will not be dealt with)

From this viewpoint, it is important to state the origin of wastewater which will define its characteristics, and the concepts which lead to the planning, design, operation and maintenance of the WWTP (wastewater treatment plant).

Almost any wastewater treatment plant can be considered as having positive aspects and impacts on the environment. Nevertheless, because the positive impacts of such facilities must be established at county level and not local level, we will not deal with the positive impacts, except for minor aspects in the extensive wastewater treatment plants.

A programme for the implementation of a wastewater treatment project has several major steps, usually consisting of:

a) facilities planning;
b) design;
c) value engineering;
d) construction; and
e) start-up and operation.

In all cases, impacts can be found and will be described in this document.

1.1 Origin and collection of municipal wastewater

Wastewater generated in municipalities is theoretically of domestic origin. Nevertheless, in almost all towns there are a certain amount of industries and non-domestic facilities which can export wastewater to the sewerage system and reach the WWTP. In addition, runoff from rainwater, street cleaning, underground facilities water pumping, and others can reach the sewerage, thus diluting and modifying the “domestic” wastewater.

Domestic-related components are to be classified in relation to their origin; human/animal and non-human. Human components are the excreta, either liquid or solid and the water used to carry them through the sewerage systems. Excreta from domestic animals can also be included here. In certain towns, other types of animal excreta can be found, like those generated by horses, animals in zoos, etc. Because man and animals can consume drugs and other molecules not strictly related to food, such substances can also be found in wastewater.

Non-human components are the substances derived from household life, like food waste, pesticides, chemicals including detergents, paints, lead from plumbing, furniture, and similar. In sewerage systems which only collect domestic wastewater, there is usually a minor dilution of waste in comparison with systems collecting wastewater, rainwater and urban runoff.

If two separate collection systems appear, the second one is usually devoted to rainwater and runoff. Apart from the rain, which has to be eliminated from towns, several flows can enter both types of sewerage systems: water losses from tapwater distribution; water coming from street cleaning and sewerage maintenance; groundwater, lakes or streams and seawater entering the system from natural water bodies; and water pumped out from other urban infrastructures (underground or railway, subterranean parking lots, etc.); which is disposed into the sewerage system, etc. The amount of water reaching the conduits can occasionally be quite considerable and cause management problems.

Lately, a combination of the two systems is gaining acceptance. Rainwater in excess of the capacity of the WWTP can be collected in reservoirs (usually underground) in towns, and released slowly into the sewerage, in order to be treated after the rain event.

1.2 Municipal wastewater characteristics

Municipal wastewater characteristics reflect the activities, social aspects and welfare of the population they serve. For this reason, wastewater from one municipality is different to that from another, and the characteristics can only be described as an average for every place. In addition, in each town there are circadian, weekly and seasonal variations on flow and quality, depending on the activities of every wastewater generator and on the group of people being served by a sanitation system. In several countries, there is a tendency for people to have several residences (i.e., a town house, summer resort (beaches) and winter resort (ski season). Apart from this, the impact of tourism is not negligible in terms of water use and the differences in population throughout the year.

There are also variations taking into consideration the location of the sanitation facilities, i.e., coastal towns have greater amounts of sand (bathers, wind-driven sand, etc.), and salts (seawater entrance into sewers) than mainland ones. The quality of the water delivered to the urban user has also a strong influence on the final composition of wastewater.

Nevertheless, several characteristics are to be considered as common, namely the by-products of human metabolism, the amount of water used for dilution and the like. There are several authors who summarize the composition of wastewater, even by country. Good examples are to be found in Henze *et al.* (1995), Rowe and Abdel-Magid (1995), and Metcalf and Eddy (2003). Several UNEP funded works also refer to wastewater composition (UNEP 2000 and UNEP 2004). The following table from Metcalf and Eddy (1991) gives a good insight, while classifying untreated (raw) domestic wastewater as weak, medium and strong (Table 1).

Table 1

Typical composition of untreated domestic wastewater (from Metcalf and Eddy, 2003)

Contaminants	Unit	Concentration (Strength)		
		Low	Medium	High
Solids, Total (TS)	mg/L	390	720	1230
Dissolved, total (TDS)	mg/L	270	500	860
Fixed	mg/L	160	300	520
Volatile	mg/L	110	200	340
Suspended Solids, total (TSS)	mg/L	120	210	400
Fixed	mg/L	25	50	85
Volatile	mg/L	95	160	315
Settleable solids	mL/L	5	10	20
Biochemical Oxygen Demand, 5-day, 20ºC	mg/L	110	190	350
Total Organic Carbon (TOC)	mg/L	80	140	260
Chemical Oxygen Demand (COD)	mg/L	250	430	800
Nitrogen (total as N)	mg/L	20	40	70
Organic	mg/L	8	15	25
Free ammonia	mg/L	12	25	45
Nitrites	mg/L	0	0	0
Nitrates	mg/L	0	0	0
Phosphorus (total as P)	mg/L	4	7	12
Organic	mg/L	1	2	4
Inorganic	mg/L	3	5	8

Chlorides [a]	mg/L	30	50	90
Sulfate [a]	mg/L	20	30	50
Alkalinity (as $CaCO_3$)	mg/L	50	100	200
Oil and grease	mg/L	50	90	100
Cryptosporidium oocysts	Nr/100 mL	10^{-1}-10^{0}	10^{-1}-10^{1}	10^{-1}-10^{2}
Giardia lamblia cysts	Nr/100 mL	10^{-1}-10^{1}	10^{-1}-10^{2}	10^{-1}-10^{2}
Total coliforms	Nr/100 mL	10^{6}-10^{8}	10^{7}-10^{9}	10^{7}-10^{10}
Faecal coliforms	Nr/100 mL	10^{3}-10^{5}	10^{4}-10^{6}	10^{5}-10^{8}
Volatile Organic Compounds (VOCs)	µg/L	<100	100-400	>400

a: Values should be increased by amount present in domestic water supply.

1.3 Planning of facilities

WEF/ASCE (1992) indicates that the wastewater quality and quantity characteristics of a plant's influent typically reflect the nature of the contributing area, water uses, and conditions of the conveyance system. Except for infiltration/inflow and industrial discharge conditions, these characteristics are not usually subject to alteration by the engineering planning required for the wastewater treatment plant project. In general, the plant designer determines the wastewater characteristics and develops an end-of-the-pipe solution responsive to compliance standards and other wastewater management objectives.

A facilities plan is a document established to systematically analyze the technical, economic, environmental and financial factors necessary to select a cost-effective wastewater management plan (Metcalf and Eddy, 2003). Later on, this procedure was been designed as "Best Available Technology" or simply BAT (Table 2).

Table 2

Best available technology conditions

Wastewater characteristics
Size/type of the facility
Existing rules and regulations
Available technology
Landscape integration
Economy (town, county, country…) Social acceptance
Centralization vs decentralization
Desired final quality of water (following rules and regulations)
Reclaimed water reuse possibilities
Political decisions
…

BAT procedures describe, at the planning levels, the technology most suitable for a given location or town. Sometimes, this approach is described as BATEA (best available technology economically achievable), BPWTT (best practicable technology currently available) or BPCTCA (best practicable control technology currently available) for industries (Rowe and Abdel-Magid, 1995).

1.4 Design of facilities

Two types of wastewater treatment facilities are to be described, intensive and extensive. With respect to the environmental impacts caused by both, it should be said they differ from one another in several ways, which will be explained immediately.

The natural or soft technologies are defined as including the presence of natural components, or complete ecosystems, for wastewater treatment. Those are systems are built purposely for wastewater treatment with the intention to fully preserve natural ecosystems, and because the use of existing natural systems is usually forbidden. The extensive systems constructed are usually compared to the intensive ones in terms of efficiency, energy consumption, occupied surface, technological degree, and other characteristics.

The main characteristics of both types of technology are described in Table 3. The basic differences between them are the types of energy used and the space needed. Hard technologies use electrical energy and not much space is necessary, while soft technologies mainly use energy from the sun or wind and occupy a comparatively large amount of space.

Table 3

Soft and hard technologies for wastewater treatment: a comparison

Hard/Intensive	**Soft/Extensive/Natural**
Electrical energy for mixing and gas addition to the reactors (high costs).	Natural energy (sun and occasionally wind).
Concrete, hard technology equipment in important amounts.	Reduced amounts of concrete and high-technology equipment. The movement of material (sand, terrain) is important.
Proportionally reduced surface.	High surface needs (comparatively).
Highly specialized tasks (qualified workers).	The manager must know the processes and be capable of preventing deviations.
The processes can be quickly modified.	Treatment mechanisms have great inertia.
Artificial “hi-tech” aspect.	High integration in the landscape.
Artificial processes (highly accelerated eco-systems).	Natural processes at “natural” speed, slightly improved.

Metcalf and Eddy (1991) indicate that the processes involved in natural systems include many of those used in mechanical or in-plant treatment systems - sedimentation, filtration, gas transfer, adsorption, ion exchange, chemical precipitation, chemical oxidation and reduction and biological conversion and degradation - plus other unique to natural systems such as photosynthesis, photo-oxidation, and plant uptake. Following the BAT, it seems that nowadays facilities having important wastewater flows must rely on intensive systems, while small towns or municipalities must rely on extensive systems if cheap surface is available.

1.5 Operation and management / reactive

Some of the principal concerns in wastewater management relate to start-up, operation and maintenance of treatment plants. The challenges for operation and management include (Metcalf and Eddy, 1991):

a) providing, operating, and maintaining a treatment plant that consistently meets its performance requirements;
b) managing operating and maintenance costs within the required performance levels;
c) maintaining equipment to ensure proper operation and service; and
d) training operating personnel.

The plant management's functions include planning, organizing, directing, and controlling in order to accomplish the plant's mission by providing vision, direction, style, inspiration and training (WEF, 1996).

For several processes, chemicals are to be added to wastewater or sludge lines in the facilities. For example, lime, iron salts, polyelectrolyte, aluminium salts, chlorine, oxygen peroxide, ozone, and the like can be added at different points. Those reactive are to be transported to the plant and when inside the facility must be stored, handled and used (WEF, 1996). As a result, dust, aerosols, odours and other nuisances can be generated, which can cause problems. Physical processes, although they do not add chemicals, can also generate problems, like UV or gamma radiation.

Machinery is part of the normal operation of a wastewater treatment facility, especially the heavy ones. Noise and other nuisances (lubricants, grease, odour, and other) related to machinery can appear in specific areas of the facility. Hazards derived from moving machines and electricity (power) must also be considered.

When anaerobic digestion is present, excess gas is usually burnt in a stack. Then, combustion byproducts can be generated and are added to the atmospheric contaminants, if there is a malfunction. Other sludge-related processes imply the presence of stacks or release into the atmosphere of important quantities of water vapour, which can sometimes affect the microclimate of a small area near the facility. This happens especially on calm days or nights and could slightly increase the number of foggy days.

1.6 The basics of wastewater treatment

When dealing with the mechanisms and processes involved in all wastewater treatment technologies, studies can be undertaken at two levels: microscopic and processes. It is important to know such processes, because the environmental impacts of wastewater treatment will depend in some way on such mechanisms

Microscopically, the cellular biochemistry and physical-chemical mechanisms at reaction level must be included. At the macroscopic level, processes are to be defined at matrix or ecosystem level. E.g., the respiration of algae is a biochemical process at cellular level, while gas exchanges (O_2, CO_2) with the atmosphere, derived from photosynthesis and the respiration of all algae in a lagoon, can be considered as included in the macroscopic level.

Among the microscopic, molecular or micro-level mechanisms, we can mention the following biochemical processes:

- organic matter enzymatic decomposition reactions: hydrolysis, methane;
- generation of micro-organism colonies;
- complex clay-organic matter formation; and
- nutrient generation from decomposition of organic matter.

The most important physical-chemical processes are:

- adsorption- desorption;
- ionic exchange;
- complexation;
- redox reactions; and
- gas exchanges.

If we work on the macroscale, several biochemical processes can also be stated:

- organic matter decomposition;
- photosynthesis; and
- respiration.

As physical-chemical processes, we can define:

- physical filtration;
- dispersion;
- dilution;
- floc generation;
- aggregate formation;
- settling;
- evaporation;
- transpiration;
- deposition; and
- biofilm support.

In all cases, the components can be classified as inert (non-living) or living. In the inert part of the treatment the physical-chemical processes are dominant; in the living part the biochemical reactions are dominant. Nevertheless, the physical-chemical or biochemical reactions can change in the whole system or parts of the existing conditions, which can interact with the other type of reactions, thus adding more complications to the systems.

Usually, the processes inside a wastewater treatment plant are indicated for the water line as (WEF, 1996):

a) preliminary treatment;
b) primary treatment;
c) biological processes;
d) physical-chemical treatment; and
e) effluent disinfection.

In relation to the sludge line, we can describe (WEF, 1996):

a) thickening;
b) anaerobic digestion;
c) aerobic digestion;
d) additional stabilization methods; and
e) dewatering.

1.7 Waste generated

The scope of this subject is purposely limited to waste obtained in the pre-treatment of the wastewater treatment plant. The other inputs from the wastewater treatment plant are treated wastewater and sludge; wastes are the ones generated in the normal activity of the plant, like personnel and machinery wastes. Also, as previously explained, minor outputs could be combustion or anaerobic digestion gases (coming from digesters, burning or drying processes and the like).

The removal of debris in the screening area and the removal of sand, rocks, gravel and other inorganics in the grit removal system, protect downstream treatment processes (WEF, 1996). The debris removed usually consists of wood, tree limbs, sand, rocks, rags, cinders, coffee grounds, cigarette filters, and other large, usually non-putrescible organic and inorganic substances. Grease and oil could also be included here.

The final destination of all this material is usually a sanitary landfill, although it is sometimes incinerated in the same or neighbouring facility. Nevertheless, the waste remains in the plant for some time while the container is being filled. During this time, because the material is putrescible there is a concentration of flies, other insects and rodents, which can cause undesirable odours.

2. ENVIRONMENTAL IMPACT AND HEALTH ANALYSIS BASICS

The impact of wastewater treatment facilities, in the terms described above, is mainly on the facility itself and in the surrounding areas, on a local scale. Although it seems clear that in this case the impacts are usually negative, there are also several and important positive ones when the facility is considered on a regional scale. At first sight, there are only negative impacts caused by noise, odour, micro-organisms and pests, and secondarily on the landscape. However, there is a need to further develop this subject.

As UNEP (1990) indicates, environmental impact assessment[1] is a process analyzing the positive and negative impacts of a proposed project, plan or activity on the environment. The specific purpose of the assessment is to provide the decision-makers with information allowing them to introduce environmental protection considerations in the decision-making process, leading to the approval, rejection or modification of the project, plan or activity under examination.

Wastewater treatment has usually been defined and implemented to obtain a quality to comply with the laws; i.e., the 91/271 EU Directive. The quality is assessed using mainly two parameters, organic matter (BOD or COD) and suspended solids (SS). It can be said that there is not a direct relationship between the quality demanded and the health point of view. It could also be stated that, indirectly, the elimination of SS from the water leads to the elimination of pathogens associated with the particulate organic matter.

As stated previously, wastewater treatment facilities can be classified into extensive and intensive. Intensive treatments use a certain amount of energy, but a reduced amount of space. Extensive treatments on the contrary, rely on natural energy, but occupy a lot of space. This means that in terms of space, the "footprint" of an extensive system is greater than the one of intensive facilities, although the appearance of the former can easily overwhelm the inconveniences caused.

[1] From here on, environmental impact assessment or EIA will be used as a synonym for environmental impact.

In the United States and in the European Union countries before the last enlargement, and in most developed countries, activated sludge has been the selected technology for almost all medium and large-size facilities. In terms of environmental impact it usually means the generation of aerosols, noise and occasionally odours, which is not usually the case for extensive systems. Apart from the aforementioned, workers are living an entire work journey inside the wastewater treatment facility, meaning there are hazards associated with their job.

2.1 Environmental impact analysis

In general, EIA can be defined as the process of identifying, predicting, interpreting and communicating the potential impacts that a proposed project or plan may have on the environment. EIA can also be described as a process for assessment of how a project or plan may affect, negatively or positively, various impact indicators; i.e., elements or parameters that provide some sort of measure of the magnitude of an environmental impact (UNEP 1990).

The indicators may be either qualitative or quantitative, depending on the parameter and the means by which it is evaluated. Some indicators can be evaluated against standards. Others may have numerical values and in some cases it may be necessary to use a purely subjective value-based scale of assessment, such as acceptable and unacceptable change (UNEP 1990). Sometimes, there is a series of Statements inside an EIA.

The Council on Environmental Quality (CEQ, USA) issued guidelines on the preparation and content of the statements. A brief outline of the content of an EIS (environmental impact assessment) is as follows (Rowe and Abdel-Magid, 1995):

1. a description of the proposed action, a statement of its purposes, and a description of the environment affected, including information, summary, technical data, and maps and diagrams where relevant, adequate to permit an assessment of potential environmental impact by commenting agencies and the public;
2. the relationship of the proposed action to land use plans, policies, and controls for the affected area. This requires a discussion of how the proposed action may conform or conflict with the objectives and specific terms of approved or proposed federal, state, and local land use plans, policies, and controls, if any, for the area affected;
3. the probable impact of the proposed action on the environment, including environmental costs in the decision-making process;
4. alternatives to the proposed action, including, where relevant, those not within the existing authority of the responsible agency;
5. any probable adverse environmental effects, which cannot be avoided (such as water or air pollution, undesirable land use patterns, and damage to life systems, urban congestion, threats to health, or other consequences adverse to the environment);
6. the relationship between local short-term uses of man's environment and the maintenance and enhancement of long-term productivity;
7. any irreversible and irretrievable commitments of resources that would be involved in the proposed actions; and
8. any indication of what other interests and considerations of federal policy are thought to offset the adverse environmental effects of the proposed action.

When applying EIA to wastewater treatment plants, we can indicate the goals and principles as follows (adapted from UNEP, 1990).

Goals:

1. to establish that before decisions are taken by the competent authorities to undertake or authorize a wastewater treatment facility, the environmental effects of the facility should be taken fully into account; and
2. to promote the implementation of appropriate procedures through which the foregoing goal may be realized.

Principles:

1) states should not undertake or authorize a wastewater treatment plant (certain minimum size is to be defined according to rules and regulations) without prior consideration, at an early stage, of their environmental effects. Where the extent, nature or location of the wastewater treatment plant is such that it is likely to significantly affect the environment, a comprehensive environmental impact assessment (EIA) should be undertaken with the following principles;

2) the criteria and procedures for determining whether a wastewater treatment facility is likely to significantly affect the environment and is, therefore, subject to an EIA, should be defined clearly by legislation, regulation or other means, so that the facility activities can be quickly and surely identified, and EIA can be applied as the facility is being planned.

   For instance, this principle may be implemented through a variety of mechanisms, including:

   - list of categories of activities that by their nature are, or are not, likely to have significant effects (wastewater treatment facilities are included under this item);
   - list of areas that are of special importance or sensitivity (such as national parks or wetland areas), so that any activity affecting such areas is likely to have significant effects. (A number of wastewater treatment facilities are located in or near such areas, because of the need to receive wastewater by gravity wherever possible);
   - lists of categories of resources (such as water, tropical rain forests, etc.), or environmental problems (such as increased soil erosion, desertification, deforestation) which are of special concern, so that any diminution of such resources or exacerbation of such problems is likely to be significant (in this case, the main by-products could affect the environment, which is out of the scope of this work);
   - an "initial environmental evaluation", a quick and informal assessment of the proposed activity to determine whether its effects are likely to be significant (of course, it depends on the size of the facility); and
   - criteria to guide determinations whether the effects of a proposed activity are likely to be significant (a large amount of effects can be described).

3) in the EIA process, the relevant significant environmental issues should be identified and studied. Where appropriate, all efforts should be made to identify these issues at an early stage in the process;

4) an EIA of a wastewater treatment facility should include, at a minimum:

   - a description of the proposed activity (wastewater treatment and disposal);
   - a description of the potentially affected environment, including specific information necessary for identifying and assessing the environmental effects of the proposed activity (on the air, soil, groundwater, flora and fauna…);
   - a description of practical alternatives, as appropriate (extensive instead of intensive systems, fully covered facilities…);

- an assessment of the likely or potential environmental impacts of the proposed activity and alternatives, including the direct, indirect, cumulative, short-term and long-term effects (e.g., aerosols on workers, or on workers clothes);
- an identification and description of measures available to mitigate the adverse environmental impacts of the proposed alternatives, and an assessment of those measures (cover parts of the station, change old machinery…);
- an indication of gaps in knowledge and uncertainties which may be encountered in compiling the required information (lack of knowledge on the actual groundwater depth);
- an indication of whether the environment or any other state or areas beyond national or other jurisdiction is likely to be affected by the proposed activity or alternatives (e.g., interbasin water exchanges); and
- a brief, non-technical summary of the information provided under the above headings.

5) the environmental effects in an EIA should be assessed with a degree of detail commensurate with their likely environmental significance (depends on the size of the plant, its sludge disposal…);

6) the information provided as part of EIA should be examined impartially prior to the decision;

7) before a decision is made on an activity (in this case wastewater treatment plant), government agencies, members of the public, experts in relevant disciplines, and interested groups should be allowed appropriate opportunity to comment on the EIA;

8) a decision as to whether a proposed activity should be authorized or undertaken should not be taken until an appropriate period has elapsed to consider comments pursuant to principles 7 and 12;

9) the decision on any proposed activity subject to an EIA should be in writing, state the reasons therefore, and include the provisions, if any, to prevent, reduce or mitigate damage to the environment. This decision should be made available to interested persons or groups;

10) where it is justified, following a decision on an activity which has been subject to EIA, the activity and its effects on the environment or the provisions (pursuant to principle 9 of the decision on this activity should be subject to appropriate supervision;

11) states should endeavour to conclude bilateral, regional or multilateral arrangements, as appropriate, so as to provide, on the basis of reciprocity, notification, exchange of information, and agreed-upon consultation on the potential environmental effects of activities under their control or jurisdiction which are likely to significantly affect other states or areas beyond national jurisdiction;

12) when information provided as part of an EIA indicates that environment within another state is likely to be significantly affected by a proposed activity, the state in which the activity is being planned should, to the extent possible:

(a) notify the potentially affected state of the proposed activity;
(b) transmit to the potentially affected state any relevant information from the EIA, the transmission of which is not prohibited by national laws or regulations; and
(c) when it is agreed between the states concerned, enter into timely consultations.

13) appropriate measures should be established to ensure implementation of EIA procedures.

Further on, the document (UNEP, 1990) includes a suggested procedure for EIA and a chapter on general guidelines for preparation of EIA documents for selected types of development projects. It is especially important for the purpose of the present document the description of the procedure for a sewage treatment plant for a city between 100,000 and 1,000,000 inhabitants.

The main interesting considerations are the following:

- from the environmental standpoint, the most important aspect of a sewage treatment plant is the proposed disposal or use of the sludge and the treated sewage water. As those two aspects will not be dealt with in this part (there are others dealing with those items), other aspects indicated are as follows;
- some treatment processes (e.g., oxidation ponds, aerated lagoons) may lead, under the influence of wind, to the spread of pathogens through air transport over considerable distances;
- most sewage treatment and disposal processes are a serious source of offensive odour;
- improperly constructed or operated sewage treatment plants may become a most serious public health problem. Therefore, whatever level of treatment and method of disposal and use is approved, it should strictly comply with national standards and internationally accepted environmental quality criteria, taking into account the recipient environment and the biological targets which may be affected, specifically man; and
- elements specifically recommended for inclusion in the follow-up monitoring and re-evaluation programme are: regular compliance with methods approved for sewage treatment and disposal, including for use of treated sewage water; seepage of contaminants from the treatment plants into freshwater aquifers or coastal waters; wind transport of pathogen originating from the treatment plants.

Apart from it, several points are to be included in the EIA:

- description of the proposed project;
- reasons for selecting the proposed site and the technologies;
- description of the environment of the site;
- indication of possible impacts;
- proposed measures to prevent, reduce or mitigate the negative effects of the proposed plant; and
- proposed programme for monitoring of the environmental impact of the project.

Under the indication of the possible impacts, the following are described:

- odours and air pollution from the plant;
- infiltration of sewage into topsoil, aquifer or water supply and impact on drinking water quality;
- mosquito breeding and diseases transmitted by mosquitoes;
- pollution of water bodies such as rivers, lakes or sea by effluents and impact on bathing water quality;
- flora and fauna;
- noise levels around plant and its sources;
- solid waste disposal;
- devaluation of property values;
- tourist and recreation areas such as nature reserves, forests, parks, monuments, sport centres, beaches, and other open areas which would be impacts;

- possible emergencies and plant failure, the frequency at which they may occur, and possible consequences of such emergencies; and
- anticipated or foreseeable impacts on the areas outside the national jurisdiction.

2.2 Ecotoxicology

Ecological risk assessments are more complex than human health risk assessments and are fundamentally different in their inferential approaches. The greater complexity is mainly due to the large number of species and the diversity of routes of exposure that must be considered in ecological risk assessment. However, the differences in inferential approach and part of the greater complexity are due to the fact that ecological risk assessments for waste sites (compared with a wastewater treatment plant) may be based on epidemiological approaches while human health risk assessments for the waste sites are nearly always based on modelling (Suter et al, 2000).

The goal of ecological risk assessment (Newman and Unger, 2003) is the estimation of the likelihood of a specific adverse effect or ecological event due to a defined exposure to a stressor[2]. Relevant effects can range from the suborganismal to the landscape scale. Unlike human risk assessment, ecological risk assessment must consider many species with diverse niches and phylogenies. It might even consider ecological entities; e.g., communities composed of many species occupying a heterogeneous landscape. There are also steps, the first one being the problem formulation, the second the analysis, and the third risk characterization.

- Problem formulation includes the initial planning and scoping that establishes the framework around which the assessment is done. It includes the selection of assessment endpoints, a conceptual model, and a plan of analysis.

- The analysis step has two components, exposure characterization and ecological effects characterization. Exposure characterization describes the characteristics of any contact between the contaminant and the ecological entity of concern. It summarizes this information in an exposure profile. Temporal and spatial patterns in contaminants distribution are defined in addition to the amount of contaminant present. The source of contaminant, any potential costressors, transport pathways and type of contaminant are described.

- Ecological effects characterization describes the effects that are elicited by a stressor, links these effects with the assessment endpoint, and evaluates how effects change with varying stressor levels. It also specifies the strength of evidence associated with the effects characterization and the level of confidence in the causal linkage between the contaminant and the effect.

- Risk characterization draws together the information from previous steps to produce a statement of the likelihood of an adverse effect to the assessment endpoint. Risk can be expressed in several ways, including a simple quantitative judgement or hazard quotient. It could involve a richer interpretation, including description of the influences of concentration and temporal variations on estimates of effect, or it could employ complex models that also generate some estimate of confidence in the risk predictions.

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[2] **Stressor** is defined in ecological risk assessments as "any chemical, physical or biological entity that can induce adverse effects on *ecological components*, that is, individuals, populations, communities, or ecosystems. Obviously, there is extreme latitude in this definition and many effects at higher levels will more often be ambiguous than clearly adverse.

The final statement of risk must include details about the adequacy of the data, the uncertainty involved in the conceptual mode or calculations, and about the weight of evidence for each causal relationship.

2.3 Risk analysis

Wastewater treatment facilities can be considered as an industrial facility. Therefore, as in any facility, there is a possible hazard risk to workers and other persons related directly or indirectly to the facility, and also to the environment, either inside the facility or directly or indirectly related to it.

Once the scope is defined, the problem arises of how to define and calculate such risks in the broader context of health and environmental impacts.

From previous statements, it seems that the hazards to humans are:

a) physical hazards (e.g., accidental falls into water, conjunctivitis from UV radiation, etc.);
b) pathogenic hazards (diseases derived from exposure to pathogens carried out by aerosols or ingested accidentally with water); and
c) toxic hazards (e.g., accidentally released gases like chlorine for disinfection).

It is possible to calculate the probability of a worker, neighbour, visitor or other person becoming ill from exposure. However, this is a complex matter which is out of the scope of this paper. Nonetheless, occupational safety and health of workers must be considered. A good description can be found in WEF (1991).

3. WASTEWATER TREATMENT FACILITIES

As already indicated, there are two main types of wastewater treatment plants: extensive and intensive. The classification is mainly for the secondary part of the treatment, while pre-treatment is usually common to all facilities.

There is also a distinction between large and small facilities. The extensive ones are mainly employed for small communities, and the intensive ones are used for almost all purposes. Metcalf and Eddy (1991) indicate that the threshold is located in 1000 p.e., but other authors establish it in 2000 p.e.

3.1 Common features

This part describes the basic equipment that every system must have. In Table 4 the usual operations in pre-treatment common to all facilities, are indicated. It does not mean, however, that all of the operations are carried out at every wastewater treatment plant.

Nevertheless, there is a minimum number of operations required for almost all facilities, like a minimum screening.

Then there is the possibility to choose among intensive or extensive wastewater treatment plants (see above).

Table 4

Physical units operations in wastewater treatment plants
(modified from Metcalf and Eddy, 2003)

Operation	Application
Screening Comminution	Removal of coarse and settleable solids by interception (surface straining): bar racks, screens, rotary disks and centrifugals. Grinding of coarse solids to a more or less uniform size.
Flow equalization	Equalization of flow and mass loadings of BOD and suspended solids.
Mixing	Mixing chemicals and gases with wastewater and maintaining solids in suspension.
Flocculation	Promotes the aggregation of small particles into larger particles to enhance their removal by gravity sedimentation.
Sedimentation	Removal of settleable solids and thickening of sludge.
Flotation	Removal of fine divided suspended solids and particles with densities close to those of water. Also thickens biological sludge.
Filtration	Removal of fine residual suspended solids remaining after biological or chemical treatment.
Micro-screening	Same as filtration. Also removal of algae from stabilization pond effluent.
Gas transfer	Addition and removal of gases.
Volatilization and gas stripping	Emission of volatile and semi-volatile organic compounds from wastewaters.

3.2 Intensive systems

In intensive systems, two different lines can be described: water and sludge lines.

a. Water line

There is the need to establish initial classification amongst:

- primary treatment;
- physicochemical treatment;
- secondary treatment;
- nutrient elimination;
- advanced treatments (other than nutrient-related or disinfection); and
- disinfection.

- Primary treatment

When a liquid containing solids in suspension heavier than water is placed in a relatively quiescent state, the solids tend to settle, and those solids with lower specific gravity tend to rise (WEF, 1991; Haller, 1995; Metcalf and Eddy, 2003). These principles are used in the design of sedimentation tanks for treatment of wastewaters. Sometimes, when problems appear (e.g., an unexpected increase in population), primary sedimentation can be enhanced by pre-aeration or chemical coagulation, thus permitting the facility to treat higher loads. Primary sedimentation tanks can precede biological treatment processes, and have also been used as storm water retention tanks or provide sufficient detention periods for effective chlorination of such overflows.

- Physicochemical treatment

In some localities, industrial wastes have rendered municipal wastewater difficult to treat by biological means. In such situations, physical-chemical treatment may be an alternative approach (Metcalf and Eddy, 2003). In other cases, chemical processes can be used for additional treatments (see advanced treatments below). Edeline (1992) provides a comprehensive treatise of the physical-chemical treatment of wastewaters. There are several chemical processes that can be described (see Table 5).

Table 5

Chemical processes in wastewater treatment (modified from Metcalf and Eddy, 2003)

Advanced oxidation processes	Advanced treatment, removal of refractory organic compounds.
Chemical coagulation*	Chemical destabilization of particles in wastewater to bring about their aggregation during flocculation.
Chemical disinfection	Disinfection process. Used also for control of biofilm in sewers and odours.
Chemical neutralization	pH control.
Chemical oxidation	Removal of BOD, grease, ammonia, destruction of micro-organisms, control of odours, removal of resistant organic compounds.
Chemical precipitation*	Enhanced removal of total suspended solids and BOD in primary sedimentation facilities.
Chemical precipitation	Removal of phosphorus and heavy metals. Corrosion control in sewers.
Chemical stabilization	Stabilization of treated effluents.
Ion exchange	Removal of ammonia, heavy metals, total dissolved solids and organic compounds.

* “Classical” physical-chemical treatment.

For a better picture, all chemical processes are described, although several of them are located in other parts of the document (e.g., under Disinfection). It should be considered that physical-chemical processes add reactive to the system, which later on can be eliminated, generating more sludge.

- Secondary treatments

Secondary treatment is synonymous with biological. The most essential biological processes used are aerobic, anaerobic and biological phosphorus removal (Henze et al, 1995). Nitrogen treatment must be added here. Except for wastewater with high organic matter content, anaerobic systems are not widely used. Biological treatments are based on the participation of a number of different species of micro-organisms living in reactors. Henze *et al.* (1995) define two main types of biological treatment plants: the biofilters and the activated sludge plants. Bacteria, algae, fungi, protozoa and metazoan thrive in those systems. There is also a division in processes with suspended-growth and attached-growth. The main processes used for secondary treatment are indicated in Table 6.

Table 6

Main processes used in biological secondary treatments of wastewater (modified from Grady et al, 1999; and Metcalf and Eddy, 2003)

Activated sludge	Several variations (completely mixed, contact stabilization, conventional, extended aeration, high purity oxygen, sequencing batch reactors, step feed). Suspended growth.
Trickling filters Rotating biological contactors	Packed tower with large media. Fixed film. Rotating disk. Fixed film.
Lagoons	Several types and variations (anaerobic, facultative, maturation), including the aerated ones. Suspended growth.
Intermittent sand filtration	Infiltration-percolation, I-P modified. Fixed film.
Wetlands	Planted reactor. Vertical or subsurface horizontal flow. Fixed film.
Packed towers	Submerged packed tower with small media.
Fluidized bed biological reactors	Fluidized bed. Suspended growth.

- Nutrient elimination

The nutrients to be eliminated (the ones which exert the main impacts on the environment when the effluent is disposed) are nitrogen and phosphorus. The treatment can be biological or chemical (see Table 7).

Table 7

Main processes used for nitrogen elimination in wastewater treatment (modified from Edeline, 1993; Metcalf and Eddy, 2003)

Suspended growth nitrification and denitrification	Several variations, combining aerobic, anoxic, anaerobic… High number of processes.
Fixed film nitrification and denitrification variations Ammonia stripping	Biological denitrification process. Usually an exogenous carbon source is added. Mass transfer of ammonia from the liquid phase to the gas phase.
Ion exchange	Natural or artificial ion-exchange materials, like zeolites, are used for ammonium ion removal.
Breakpoint chlorination	Free chlorine reacts with ammonia. In a point of the reaction N_2O and N_2 are formed.
Natural systems	Several systems, like wetlands, infiltration-percolation can modify or eliminate nitrogen forms. Plants can contribute to the elimination of nitrogen.

For phosphorus there is also a similar variation which can be seen in Table 8.

Table 8

Main processes used for phosphorus elimination in wastewater treatment (modified from Edeline, 1993; Metcalf and Eddy, 2003)

Precipitation with aluminium and iron	The addition of aluminium or iron salts will cause the precipitation of metallic phosphates.
Lime coagulation/sedimentation	Dosage of lime. Decreasing because of the mass of sludge to be handled.
Biological phosphorus removal	Basically, include an anaerobic zone followed by an aerobic zone. High number of processes.
Biological-chemical phosphorus removal	Combine chemical and biological processes.
Natural systems	Several systems, like wetlands, infiltration-percolation can eliminate phosphorus forms by plant absorption or by precipitation of insoluble forms.

- Advanced treatments

Grouped here is a miscellaneous amount of processes, like elimination of refractory organics, heavy metals, dissolved organic solids and other (See Table 9).

Table 9

Miscellaneous advanced treatments (modified from Metcalf and Eddy, 2003)

Refractory organics	Adsorption (activated carbon).
	Tertiary ozonization.
	Natural systems (wetlands, IP, soil-based systems)
	Membrane (surface) filtration, depth filtration.
Heavy metals	Chemical precipitation.
	Ion exchange.
	Natural systems, usually including organic matter or exchange processes.
	Membrane filtration.
Dissolved organic solids	Ion exchange.
	Membrane procedures (reverse osmosis and electrodialysis reversible).
	Natural systems (soil-based, wetlands, etc.).
	Depth filtration.
Toxic substances (not yet indicated)	Physical-chemical treatments (coagulation-flocculation plus sedimentation and filtration).
	Air stripping.
	Carbon adsorption.
Volatile Organic Carbon and ammonia	Stripping towers.
Salts	Distillation.
	Membranes (EDR, RO).

- Disinfection

There are several disinfection procedures, from the natural ones (e.g., lagooning), to the more sophisticated and technological (e.g., ozone). A division can be made: chemical; physical; and biological.

Among the physical, radiation (UV, gamma) and natural radiation (sun UV) are to be mentioned. The use of membranes is to be included in this classification. Depending on the side of the pores, different organisms are retained. The problems related are the impact that radiation can cause on man (e.g., UV and conjunctivitis).

The chemical include the use of reactive. The main ones are chlorine and its compounds, ozone, and peracetic acid. The main problem in this case is the amount of byproducts generated, which must sometimes be eliminated. This makes the use of chlorine gas or hypochlorite not fully advisable.

The natural systems are not usually specific for disinfection, but are seldom capable of reducing pathogens in an appreciable way. Wetlands, infiltration-percolation and lagooning are among the best known. The main problem is the amount of surface occupied.

b. Sludge line

The sludge resulting from wastewater treatment operations and processes is usually in the form of a liquid or semisolid liquid that typically contains from 0.25 to 12 percent solids by weight, depending on the operations and processes used. Of the constituents removed by treatment, sludge is by far the largest in volume, and its processing and disposal generates a complex problem (Metcalf and Eddy, 2003). Usually, sludge is treated inside the facility, but occasionally there are exports from untreated sludge to other facilities. This is the case for small units, where sludge is sometimes treated in a centralized facility, or when big plants are located nearby, and the scale benefits are used for implementing huge facilities. Because sludge is mainly organic, not stable or putrescible, contains a lot of water and needs to be disposed of, it must undergo several operations. The most widely used are stabilization (includes digestion, aerobic and anaerobic), dewatering and conditioning (see Table 10).

3.3 Extensive systems

The natural, extensive or soft technologies are defined, including natural components or complete ecosystems, for wastewater treatment and constitute an alternative to the energy-consuming intensive secondary processes. The systems are built purposely for wastewater treatment with the intention to fully preserve natural ecosystems, because the use of existing systems is usually forbidden. The constructed extensive systems are to be compared in terms of efficiency, energy consumption, occupied surface, technological state-of-the-art, and other characteristics with the intensive, hard, classical ones. The extensive systems can, in some cases, avoid the sludge line because sedimentation can occur inside the reactors (e.g., lagooning) or because the sludge generated is transported to other facilities.

Table 10

Sludge treatment

Thickening	Elimination of part of the water prior to stabilization.	Gravity Flotation Centrifugation
Stabilization	Controlled degradation of organic substances in sludge.	Digestion (aerobic) Digestion (anaerobic) Chemical stabilization Composting Co-composting Thermal Pressure and thermal Phragmite beds
Drying/Dewatering	Elimination of part of the water contained in the sludge.	Drying beds Covered drying beds Lagoons Phragmite beds Pressure (belt, plate, filter) Vacuum filtration Centrifugation Heat drying
Volume reduction	Reduce the volume and weight of sludge for easier disposal.	Incineration Wet oxidation
Conditioning	Preparation for other treatments.	Polyelectrolytes addition Lime or aluminium salts addition
Other transformations	Additional processes for further reclamation or for disposal.	Composting Screening E.g., transformation on bricks, activated carbon or fuels

As indicated, natural systems use environmental components or part of the ecosystems, like:

- soil and subsoil (solid matrix);
- plants (including microflora);
- surface waters;
- groundwater; and
- sediments.

Additionally, the roles of the following must be considered:

- fauna (micro and macro); and
- atmosphere.

Natural systems use mainly, or only, one of the natural components of the mentioned complex systems with natural components, or even full ecosystems. In reality, it is not usual to use only a single natural component as the basis for the treatment, although sometimes technologies are described in this way for simplification. When trying to study extensive systems in detail, it seems necessary to classify them which will allow us to work in a systematic way. Consequently, at least two methods of classification could be used, as indicated in Figures 2 and 3.

In all natural ecosystems used for wastewater treatment, it must be taken into account that:

- grease, toxic compounds, salts in excess, and the like, carried by wastewater, can be toxic or harmful to the natural systems;
- the effective capacity of the system should not be overcome (e.g., hydraulic and organic matter);
- there is a need for indepth knowledge of the processes inherent to the system (biochemical, physical, chemical and technological); and
- adequate management adapted to the special features of natural systems, is of paramount importance.

4. ENVIRONMENTAL IMPACT AND HEALTH-AFFECTING FACTORS

As established above, two major impacts of wastewater treatment plants are to be considered; the ones relating to the environment and those relating to health.

It should be mentioned that the first stimulus for wastewater management was aesthetics. Aesthetics is now, and is likely remain, the foremost concern of the general public. Regardless of the success of the plant in meeting its numerical performance standards, the public will judge the treatment facility to be unsuccessful if it is aesthetically offensive to the neighbours. If facility designs focus on possible aesthetic impacts and their control, by process selection and source and site mitigation, plants will likely best serve the public and avoid the controversy and expense of remedial actions (WEF, 1992).

In this sense, it is also important to establish a good location for the facility; e.g., locating the plant in protected areas, such as wetlands, coastal bird habitats and similar is totally unacceptable.

With respect to health, ill effects can be experienced by workers, residents and visitors, as well as passers-by. The main problem relates to pathogens that can reach the people and animals, because toxicity problems derived from the facilities can affect a limited number of people.

4.1 Environmental matrices

a. Waters

Water is the common feature to all wastewater treatment plants. It means that this matrix is present all over the plant, except at the end of some types of sludge lines. As indicated elsewhere, the existence of free water bodies generates a risk for people to fall into. Safety measures could be implemented to manage this hazard. Apart from this, water from the facility can reach other types of water inside the wastewater treatment plant. Wastewater can escape from the reactors, pipes and in any place where it exists in liquid form, can be evaporated or aerosolized, or used for irrigation.

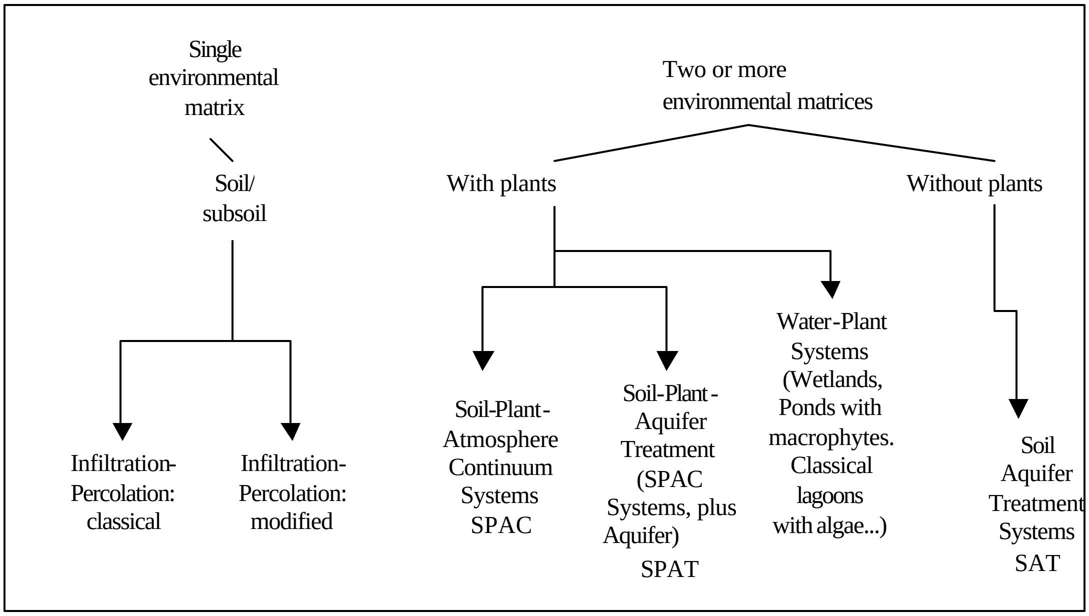

Figure 2. Classification of natural systems for wastewater treatment considering the number of environmental matrices used.

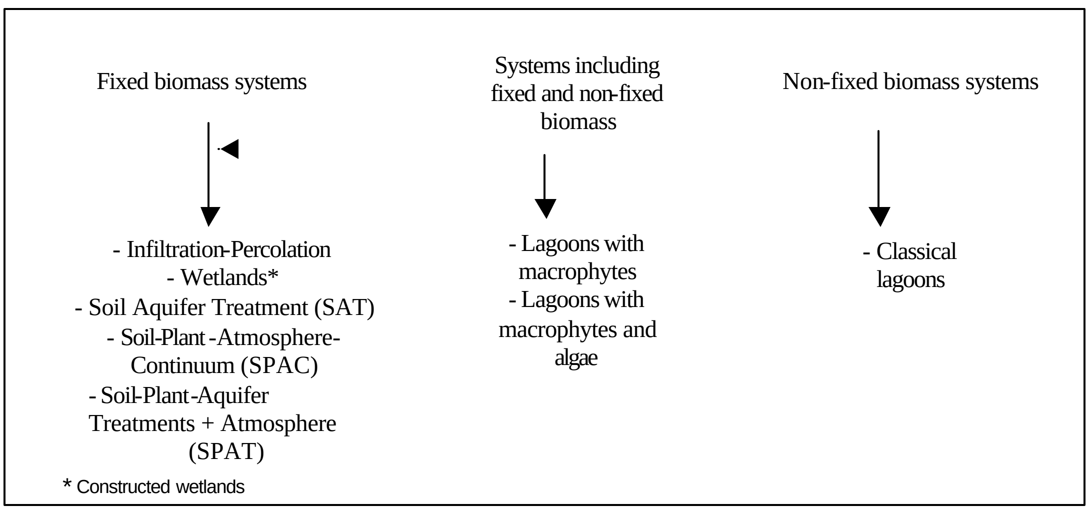

Figure 3. Classification of natural systems for wastewater treatment considering the type of biomass in the system.

This water reaches the facility and subsequently the atmosphere, groundwater under the facility, surface water besides the plant, exits it by runoff, contaminates workers' clothes, etc. In all cases, and depending from the point where water escapes, can be raw, partially or completely treated. Obviously, the impacts generated will differ depending on the degree of treatment reached. There are then, different contaminants that can exit the facility, thus creating a risk for the other matrices of the environment.

b. Air

Dust, smoke and mists are aerosols and particulates common to treatment plants. Aeration tanks, cooling towers, spray irrigators, incinerators and boilers are potential sources of such air emissions (WEF, 1992). VOCs (volatile organic chemicals) and inorganic gases are common.

Dust is not usually a major problem after construction activities are completed. Once paving is completed and lawns are established, dust problems are controllable by plant personnel.

Gases are generated in a controlled way (e.g., digestion) or uncontrolled (e.g., unwanted fermentation processes of the accumulated sludge), or reach the wastewater treatment plant with the raw wastewater. In other cases, gases are used as reactive in the facility, like ozone (O_3), liquid oxygen or chlorine (Cl_2). Gases commonly found in untreated wastewater reaching the treatment plant include nitrogen (N_2), oxygen (O_2), carbon dioxide (CO_2), hydrogen sulphide (H_2S), ammonia (NH_3), and methane (CH_4). The first three are common gases of the atmosphere and will be found in all waters exposed to air. The last three are derived from the decomposition of the organic matter present in wastewater (Metcalf and Eddy, 2003).

VOCs are present in great numbers in wastewater. For example, we can mention trichloroethylene, 1,2-dibromo-3-chloropropane, indol, skatol, mercaptans, etc., and several of them can be toxic and are mentioned as VTOCs (volatile toxic organic compounds). Metcalf and Eddy (1991) indicate that VOCs are of great concern because:

- once such compounds are in the vapour state, they are much more mobile, and, therefore, more likely to be released into the environment;
- the presence of some of these compounds in the atmosphere may pose a significant public health risk; and
- they contribute to a general increase in reactive hydrocarbons in the atmosphere, which can lead to the formation of photochemical oxidants.

The release of these compounds in sewers and at treatment plants, especially at the head works, is of particular concern with respect to the health of collection system and treatment plant workers. There are places where it is usual to encounter VOCs which are released by volatilization or stripping. These processes (in the facilities) usually take place in pump stations, bar racks, comminutors, grit chambers, equalization basins, primary and secondary settlers, biological reactors, open-air channels and digesters.

Apart from the problem of odours, which are just annoying, several gases are hazardous in certain concentrations, could be explosive, and can even cause death, like carbon monoxide, methane or hydrogen sulphide. Special care must be devoted to manage closed rooms, where equipment capable to release VOCs and inorganic gases is located. Signs, clear instructions and the like must appear and ventilation devices (active or passive) must be installed. Even more concerns appear when the facility is fully located underground.

c. Soils

Wastewater treatment facilities are physically located over soils, and although an important part of the surface is made impervious, there is the possibility of leaks and wastewater runoff due to accidents. Additionally, if there is a garden in the plant, it is usually irrigated with reclaimed wastewater. So, it seems that wastewater components can remain in the soil and subsoil, and appear when there are works inside the plant. Nevertheless, it is not usual to experience problems derived from soils in wastewater treatment facilities, except when they are decommissioned.

In any case, the amount of soil used for wastewater treatment purposes is usually not relevant, except in a few cases for huge facilities. Perhaps the classical example is the old wastewater treatment system by lagooning- 170 ha - that was in operation for many years in the Dan Region (Israel). The old extension will be used for property developments.

d. Landscape/aesthetics

There are two ways to consider the impact on the landscape or aesthetics of a wastewater treatment plant. The landscape impact refers to the vision that neighbours or passers by receive from a wastewater treatment facility. The aesthetics refers to the “inner” view; i.e., the management of the plant in a way that creates an environment not unpleasant to the workers or visitors. Depending on the manager or owner, gardens can be created in the facility for improving the aesthetics. In other cases, large equipment (e.g., digesters) is painted or decorated.

The usual far view of an intensive wastewater treatment facility is a concrete mass, headed by a sort of cap, covering the anaerobic digester or the gas storage dome. Extensive facilities usually show a different look; a small building surrounded by lagoons or constructed wetlands. Occasionally, pre-treatment or primary settler can appear, although it can be installed underground to reduce visual impacts.

From the inner point of view (aesthetics), there is a need to protect the facility from unacceptable visual, odour and pest problems, as well as other visual evidence of wastewater solids being managed through the facility.

e. Flora and fauna

As soon as a water body appears, interactions between such mass and the surrounding wildlife appear. Several of these relationships are fairly evident, like the presence of birds inhabiting secondary settlers or lagoons, while others are not so evident. Moles are a classical example of undesired hosts, which can affect the permeability of extensive facilities.

Birds can be a desired consequence of the appearance of a wastewater treatment facility in the area, or can generate problems. Flocks of hundreds of seagulls cleaning themselves and defecating in the final stage of a lagoon are not precisely a benefit, and sometimes concerns are created by the protective attitudes of conservationist groups when trying to discourage such undesired guests. On the contrary, birds inhabiting fully-developed constructed wetlands are usually welcome.

Occasionally, aquatic pets are disposed of in wastewater treatment plants, especially lagooning systems, where exotic fish, crabs and turtles can from time to time be found.

These few examples show the need to prevent or facilitate relationships between the facility operator and environment.

4.2 Environmental and health concerns

From previous indications, several additional concerns affecting the neighbours, workers and other persons related to the wastewater treatment plants, can be deduced.

a) Noise

During the normal operation of the wastewater treatment facilities, noise is generated in the operation of several devices, mainly mechanical or electrical, like pumps, blowers, turbines, sludge-related machinery, generators, waterfalls, and other. Sound concerns are mostly limited to noise generated by large, powered equipment. Variation, pulse, and tone of the noise can affect the listener as much as or more than the decibel energy of the sound wave (WEF, 1992).

There is a need to consider two aspects in noise management:

- the transmission of noise beyond plant boundaries; and
- the impact of noise on the health and welfare of plant personnel.

The effectiveness of noise control is determined by measuring the noise level and comparing it to a specified design standard. The noise or sound level is expressed as either sound pressure or sound power. Sound power level is related to the total acoustic power emitted by a source, expressed relative to a reference power quantity. The sound pressure level is a measure of the acoustic disturbance at some point and depends on the distance from the source, losses in the air, room effects, and other factors.

b) Vibration

Although little considered when dealing with environmental impacts of wastewater treatment plants, vibration can be traced to some equipment. WEF (1992) indicates draft fans for fluid bed furnaces and induced draft fans for multiple-hearth furnaces. It seems that in any case, vibration will not be an external problem of the facilities, but will always remain internal. Reduction of vibration calls for special attention in the design of a fan mount and on the ductwork to minimize unbalanced airflow to the fan. Good housekeeping practises will reduce the build-up of materials on the fan blades that could result in fan imbalances. Vibration can also be minimized by base isolations (WEF, 1992).

c) Organic matter/odours

Wastewater-related facilities discharge atmosphere gaseous compounds into the, thus producing a sort of odoriferous negative impact. The emission of compounds, sometimes with a really low detection limit for humans, from sewer systems and wastewater treatment plants, can cause serious annoyances in the neighbourhood of the facilities. Although the scope of this work is not related to the sewerage systems, it has to be noted that the odorous compounds formed during the passage of wastewater through the sewers appear when wastewater reaches the treatment facilities.

The increase of complaints from people affected by wastewater-related environmental odours has caused increased interest in developing new detection methods, as well as new technologies to eliminate these unpleasant odours. The odour-responsible substances can be classified into two main groups: reduced and oxidized compounds, being hydrogen sulphur the most significant reduced substance. Offensive smells can also expand from oxidized compounds emanating from organic molecules usually present in domestic wastewater, like carbohydrates, greases and proteins, and also by substances present in industrial discharges.

Sulphur in wastewater is often the main cause for the generation of bad odours, but methane and other compounds could also be common in sanitation facilities if anaerobic conditions occur throughout the sanitation system. H_2S can be found at hazardous concentration levels that can be considered harmful to health and can even cause death. Another important group of compounds also producing unpleasant odours are the volatile organic compounds (VOCs) discharged to municipal wastewater from different sources including industries, commercial facilities, public institutions and residences (Corsi *et al*., 1995).

Emission sources

The two main places of the sanitation systems where odour problems arise are the sewerage network and the wastewater treatment plant.

Sewerage systems: Most of the odorous substances are formed inside the wastewater collecting systems, especially hydrogen sulphur, generated by a specific kind of bacteria, the strictly anaerobic ones. The amount of sulphur generated depends on the physical and chemical conditions of the wastewater flowing into the conduits, as well as its aeration, velocity and residence time. Besides the processes discussed above, other sulphur-containing substances can be generated which also contribute to the generation of odours. There are both inorganic, particularly ammonia, and organic substances, like mercaptanes, amines, organic acids and alcohols. Apart from wastewater holding odoriferous substances, a series of circumstances favour the diffusion from the liquid phase to the gaseous phase and then to the atmosphere. The liberation of the odoriferous compounds of wastewater usually takes place where there is turbulence or hydraulic movement (Frechen and Köster, 1998), especially in the point where wastewater reaches the facility.

Wastewater treatment plants: The principal sources of odours in intensive wastewater treatment plants are: septic wastewater, industrial wastes, screenings and unwashed grit, septage-handling facilities, scum on primary settling tanks, organically overloaded biological treatment processes, sludge thickening tanks, waste gas-burning operations, sludge incinerators, digested sludge in drying beds and sludge composting operations (Metcalf & Eddy, 1991). In extensive systems, amongst others, anaerobic lagoons (Grady *et al*., 1999) or wastewater applying devices in land could be mentioned.

Nevertheless, the most significant problems are often found in two areas of the plant: pre-treatment and primary sedimentation processes. Also, when high amounts of organic matter are transported odours can also appear, as in sludge trains.

Sampling and detection methods

First of all, a full study of the main points of generation must be undertaken, because every facility has its own characteristics. Then, a sampling plan must be conceived, but the selection of the sampling method will depend on the composition expected in the sample to be analysed (APHA, 1992). Failing this, a method able to detect a wide range of substances will be chosen. Two sampling systems are available: collecting a volume of the air where the odoriferous compounds are found, or concentrating the odoriferous compounds existing in the air. The choice of the sampling strategy will depend on the volume needed for the analysis and the system used.

Odour can be measured by sensory methods, and specific odorant concentrations can be measured by instrumental methods (Metcalf & Eddy, 2003). The choice depends on the compounds present in the sample and their concentration. Analytical (instrumental) techniques available are: gas chromatography, hydrogen sulphur meters, electronic noses, and other less common devices. Sensorial detection has a main inconvenience in that it requires trained people capable of classifying the odour on a scale, and quantifying their intensity. The most common devices are olfactometers and odour panels.

A new, fast, simple and reliable method for detecting volatile and/or odoriferous compounds is the electronic nose. This device imitates the natural olfaction system which consists of three essential elements: an array of olfactory receptor cells placed in the roof of the nasal cavity; the olfactory bulb which is located just above the nasal cavity; and the brain. The electronic nose has three equivalent elements: an odour sensor array; a data pre-processor; and a pattern recognition engine. The electronic nose recognizes more odour sources and monitoring of the efficiency of the operative units, measuring the attenuation of odours between the input and output stages of the system. Nevertheless, it does have some limitations and must be calibrated by means of olfactometric tests. The development of the electronic nose method for automatic detection of odours offers a fast and relatively easy way of testing wastewater (Dewetting *et al*., 2001).

Some experience of these devices show that there is a linear relationship between odour strength and electronic nose response. According to Stuetz *et al*. (1999) the electronic nose distinguishes between samples of different origin and from different points in the treatment process. In summary, the main advantages of the electronic nose are speed and reliability.

Odour management

An appraisal of the problem and a programme for odour control must be established in order to evaluate the most suitable methods for management. Preliminary control involving the compilation of all the available information about the design, construction and handling of the sewer and treatment plant systems must be performed. At this stage the critical points can be identified. Then, a programme for characterizing wastewater and gases in the problematic zones can be developed. This will permit the establishment of a preliminary strategy of the required system for odour control.

Once the requirements for effective odour control have been established, an analysis of cost-effectiveness must be elaborated to find the best solution. This requires a preliminary design, an appraisal of required costs, an evaluation of the essential chemical reagents and equipment, and their maintenance. Once the control degree required to reduce the odoriferous emissions is known, the system should be evaluated in order to guarantee that the objectives initially planned will be reached.

Odour treatment systems**.** The main treatment systems available are (Metcalf & Eddy, 1991; Amirhor *et al.,* 2002; Kiang *et al.*, 2002):

- containment. Installation of covers, collection hoods and air-handling equipment;
- atmospheric dispersion or dilution with odour-free air: To mix the gases liberated to the air in order to dilute the odour flux;
- addition of chemical reactants: Most of them are useful for treating sulphur, but also can be effective for odoriferous organic compounds. Can be added to the sewers or in the plant and can be classified as follows:
    - Substances or methods adding oxygen to wastewater. Among others, we can mention air or oxygen injection, chemicals like chlorine, chlorate compounds, hydrogen peroxide, potassium permanganate, nitrate, and ozone; among others;
    - metallic salts: mostly, iron salts that precipitate sulphide; and

- caustic substances: generally sodium hydroxide.
- adsorption on activated carbon, sand, soil or compost beds;
- biological stripping towers, filled with plastic media on which biological growths can be maintained;
- combustion at temperatures over 650 ºC of the air carrying the odorous chemicals;
- treatment plant control: In order to attain an effective treatment plant, design, management and maintenance are crucial. Some "good practises" should be conceived in order to minimize the problems derived from the liberation of odoriferous gases;
- solids processing control: Odours liberated during the solids and biosolids treatment processes must be controlled. For this purpose several techniques are available, like turbulence reduction, addition of chemical substances, etc.;
- discharge of treated gases into the atmosphere through high stacks; and
- masking agents. Perfume scents sprayed in fine mists near offending process units.

Final comments on odours

There is an increasing need to control odours, mainly because of the increasingly high number of wastewater treatment plants being installed near inhabited areas. Specific planning is needed in order to establish facilities capable to cope with odour problems. Assessment and management of odour problems in relation to sanitation systems need further studies, especially in respect to odour sampling, detection and elimination.

To select the most adequate treatment some aspects should be considered:

- characteristics of the effluent;
- odour reduction efficiency; and
- necessary investment and the expected cost-benefit relationship of the process.

Once the most suitable treatment has been selected, quality control must be implemented in order to ascertain that the system works adequately.

d) Pathogens

Waterborne diseases are those infections that may be spread through a water supply system (see Table 5). Water acts exclusively as a passive vehicle for the pathogen that causes the diseases. Examples of some of these diseases include: typhoid fever, cholera, giardiasis, dysentery, leptospirosis, tularaemia, paratyphoid, and infective hepatitis (Rowe and Abdel-Magid, 1995).

Obviously, the appearance of such diseases is related to the ingestion of water. Although there is usually not a voluntary ingestion of wastewater in a wastewater treatment plant, sometimes there are unnoticed ingestions of such water or indirect ingestions through the hands, clothes and similar. Workers, visitors or other people entering the facility can inadvertently ingest droplets of water or inhale aerosols in several parts of the plants where there is aerosolization of wastewater. Other possible ways of infection are through the skin, mucous and skin discontinuities (small wounds). The risks are greater depending on the hygienic state of the population served.

Not all the indicated pathogens can be "distributed" by all the means indicated above. It is not the objective of this part of the document to undertake an epidemiological study of pathogens. In any case, the list of possible pathogens is really extensive and can be found in any microbiology handbook.

Table 5

Types of waterborne pathogens

Types of waterborne pathogens	**Indicators**	**Observations**
Bacteria	*E. coli*, Faecal coliforms, Total coliforms, *Enterococcus fecalis*, *Staphylococcus aureus*, *Salmonella* spp., *Clostridium perfringens*, *Pseudomonas aeruginosa*, *Legionella pneumophila.*	Faecal coliform determination is the more usual; *E. coli* determination is slowly substituting it. Other bacteria are used for bathing waters, groundwater, etc.
Viruses	Enterovirus. Hepatitis A virus. Bacteriophages.	An accepted indicator still does not exist. Bacteriophage is being studied in this sense.
Helminth - Nematode	Nematode eggs (*Ascaris*, *Trichuris*, *Ancylostoma* as indicated by WHO).	Discouraging: a lot of negative results in a lot of countries. Eggs viability is not re quested.
	Not known.	In some cases important for risk related to animal health.
Protozoa (include *Giardia*, *Cryptosporidium*, Amoeba, *Balantidium*, etc.).	Not known. The presence of one could indicate the presence of the other.	Analytical tools not well developed until now.
Fungi, algal toxins	Not known.	Very few cases detected.

e) Pests/vectors

The pests present in wastewater treatment plants appear in several places of the facilities. The type and number, and the dissemination from the plant depend on the type of facility, its size and containment.

Although in non-tropical climates they are not usual, it is important to know that water-related insect vectors are the cause of infections that are spread by insects which rely on or live near a surface water system (Rowe and Abdel-Magid, 1995). Examples of the water-related insect vector diseases include trypanosomiasis (sleeping sickness), yellow fever, dengue, onchocerciasis and malaria. Rowe and Abdel-Magid (1995) indicate a number of insects that can transmit diseases from animals to man: flea, mosquito, tick, sand fly, mite, tsetse fly, and triatomid bug. Several of them can be found in a lot of wastewater treatment plants. Among the animals acting as hosts, the same authors describe the roof rat, Norway rat, squirrel, wild rodents, rabbit, wild birds, domestic hen, small wild birds, dog, house mouse, cat, field rats and mice, etc.

In intensive systems, flea, rats and seagulls are found usually in the facilities; the last ones in the vicinity of the coastline and sometimes hundreds of kilometres in the interior.

For extensive systems, mosquitoes are described as the main problem, although more insects, rodents and others can be found. Seagulls and other birds cause problems when installed in the free waters of lagoons and similar.

Metcalf and Eddy (1991) indicate that wetlands, particularly FWS systems provide an ideal breeding habitat for mosquitoes. The issue of vector control may be the critical factor in determining the feasibility of using aquatic treatment systems. The objective of mosquito control is to suppress the mosquito population below the threshold level required for disease transmission or the nuisance tolerance level. Strategies that can be used to control mosquito populations include:

- stocking ponds with mosquito fish (*Gambusia afinis*);
- more effective pre-treatment to reduce the total organic loading on the aquatic system to help maintain aerobic conditions;
- steep feed of influent waste stream with recycle;
- more frequent plant harvesting;
- water spraying in the evening hours;
- application of chemical control agents (*larvicides*);
- diffusion of oxygen (with aeration equipment); and
- biological control agents (e.g., *BT/israelensis*).

Sludge facilities are also mentioned as sources of vectors. WEF (1992) states that health considerations in sludge management include minimizing vector breeding. WEF (1996) indicates that vector attraction reduction can be achieved by a 38% volatile solids reduction through aerobic or anaerobic digestion. There are other promulgated methods of vector attraction reduction, such as termophilic aerobic digestion, reducing the specific oxygen uptake rate (SOUR) to less than 1.5 mg of oxygen per hour per gram of total solids at 20ºC, raising the pH to 12 or higher for two hours using alkali addition and remaining at pH > 11.5 for 22 additional hours without the addition of more alkali.

For the control of rodents, there are several systems, mainly the use of poisons. For seagulls, difficulties arise when trying to discourage them. Sudden noise seemed to be a solution for some time, but later on the birds became accustomed to it; therefore, other solutions need to be found. Sounds of predators attacking birds, and the screams of the “victims” seem to be effective, although some people refuse to do it on the grounds of cruelty (Nieto 2002).

f) Aerosols/air contaminants

In a wastewater treatment plant there are usually two types of contaminants emitted into the air; volatile ones (studied under odours) and aerosols, which usually include biological elements and are called bioaerosols. The science which studies bioaerosols is called aerobiology. In this science, bacteria, fungi, free-living parasites, viruses, pollen and algae potentially hazardous for human health are studied. It is also important to study the small fragments of microbial agents and its metabolites (Pascual, 1999). Bioaerosols can be found in closed systems or in the open air, where they can be generated in several activities inside a wastewater treatment plant (CEMAGREF, 1987). Untreated wastewater contents an important number of pathogenic micro-organisms which can affect the health of the wastewater treatment facility workers. Among the possibilities for infection is the atmospheric route, through bioaerosols.

During wastewater treatment, bioaerosols can be generated due mainly to the movement of wastewater and the equipment used for treatment. The main areas and equipment in a wastewater treatment plant where bioaerosols can be generated are:

- water elevation by pumping;
- any water jet (stream) flowing “against” a surface;
- any device for water spraying (e.g., scum elimination using treated effluent);
- any system intended to create bubbles inside the water, afterwards rising to the surface, especially the aeration systems for activated sludge; and
- sludge dehydration devices (mainly the belt filter press systems).

Therefore, the areas in a wastewater treatment plant more likely to generate aerosols are:

- pre-treatment;
- places where water impacts against any solid site;
- aerators, blowers and similar devices;
- turbines; and
- waterfalls.

Pascual (1999), in a study on three different wastewater treatment plants, indicates that:

- there is a different amount of bioaerosols emission related to size of the facility. Higher concentrations are obtained in larger facilities;
- the places where a higher concentration of fungus, moulds, aerobic bacteria, total and faecal coliforms could be found are the pre-treatment and the primary settlers; and
- the aeration tanks are not the areas where higher amounts of aerosols are formed in a facility.

g) Traffic increase

It is necessary here to raise the issue of truck traffic, which receives adverse public reaction due to concerns for public safety, disruption of neighbourhood activities and aesthetics. Because such concerns are expected to be voiced during the construction and operation of treatment plants, designers should try to anticipate all possible conflicts between public expectations and the needs of the facility and take steps to reduce these conflicts as much as is practically possible.

4.3 Internal and external impacts

It seems obvious that a wastewater treatment plant is a more or less closed facility whose association with the outside world must be managed carefully. However, the EU policy on communication indicates that such facilities need to have a relationship with the outside world. In order to achieve this, it is extremely important for the wastewater treatment facility to undertake a policy of communication which includes visits (schools, citizens' organizations, etc.), leaflets (propaganda) and the like. Wastewater treatment plants have impacts which, depending on the site where they occur, can be classified as internal and external. In both cases, these impacts can affect human beings and the environment (see Table 6).

Table 6

Wastewater treatment plant impacts

IMPACTS	Internal	Man	Workers and related persons	P[1] +, N 2+
			Visitors	N +
			Commercials	N +
		Environment	Air	N 2+ to 3+
			Waters Soils/Subsoil	N + N +
			Landscape/aesthetics	P[2] 2+, N up to 4+
			Flora/fauna	P +, N 2+
	External	Man	Workers	N +
			Passers-by	N +
			Neighbours	N +
			Properties value	N 3+
		Environment	Air	N +
			Waters	P 3+, N 2+
			Soils/Subsoil Landscape/aesthetics	P +, N + P 2+, N 3+
			Flora/fauna	P +, N 2+
			Ecosystems	P 4+, N 2+
			Energy-related	N 2+

Legend: P: Positive. N: Negative. L: local. R: Regional. N: National Importance: Graded from 4+ (maximum) to 0 (negligible); the importance is graded depending on the severity of the impact and the probability of occurrence.
1: Employment.
2: Depending on the type (extensive or intensive) location (underground, surface).

Impacts are clearly positive and negative. Negative impacts are mainly internal or in the vicinity of the facility, while positive impacts are mainly related to the region. (Note: sludge and treated water are not included in this part).

4.4 Social aspects

As indicated above, there is a need for communication amongst the wastewater treatment facility and the people it serves. This can be handled through an institution (the water agency) or locally by the municipality or the facility itself. Schools or other academic institutions are a good basis for such programmes because children exert an important influence on the family; they can convey the message that such plants are needed in the community.

In addition, the NIMBY[3] syndrome appears as soon as the planners decide upon the location of the facility. It is up to the authorities to demonstrate that the location has been chosen in a sound and clear way, without external influences on the technical and decision-making staff. Therefore, some initiatives must be taken to compensate residents for "hosting" the facility.

[3] NIMBY: Not In My Back Yard

If the social aspects are considered from the planning phase, specific procedures are established to involve the parties concerned, mainly the stakeholders. Among the stakeholders are:

- NGOs (Non-Governmental Organizations, including environmental associations);
- citizens pressure groups;
- municipal authorities (in the event the facility is not built by the municipality);
- regional and national authorities; and
- future neighbours of the facility.

These procedures are expanded for reclamation and reuse projects.

5. HEALTH IMPACTS

Wastewater treatment plants can affect the health of several types of people, as described below.

5.1 Workers, visitors and relative people

As untreated and treated wastewater contains a certain number of pathogenic micro-organisms, people involved with the facility face the related hazards. The greater part of such pathogenic organisms is of intestinal origin; therefore, the most usual method of human or animal infection is by ingestion (digestive pathway). Transmission can be direct (hand to mouth) or indirect (through food or drink). There are, however, other methods of transmission: through the skin, direct contact with water (skin discontinuities, mucous membranes) or respiring, through bioaerosols (Pascual, 1999).

Sometimes problems are caused by people (mainly workers) falling down the water bodies into the wastewater treatment facility. Clear working procedures and protection in the more dangerous places are of vital necessity, and actuation protocols for such cases should be posted in the facility. Other cases described are equipment-specific, for example the affect of looking at UV radiation, which affects both workers and visitors.

Concerning school trips to wastewater treatment facilities, special care must be taken to safeguard children when visiting unprotected water bodies, e.g., lagooning systems.

5.2 Neighbours

Two types of impact should be considered with reference to the neighbours of a wastewater treatment facility: temporary (before and during construction); and permanent (before and during construction). There are also several impacts afterwards, derived from operation, maintenance and the very presence of the facility itself. Permanent impacts may be health-related and landscape/property-related (loss of value of the properties located near the wastewater treatment plant from the time decision to build is implemented). Temporary impacts are related to the problems derived from the construction, which are similar to any other such work. Impacts experienced afterwards, when the plant is operational, are a result of the “by-products” generated. Aerosols, droplets, runoff, odours, noise, vectors and traffic increase are the main impacts associated to the vicinity of the facility. With respect to the aesthetics, the impact on the landscape, especially on the “view” from the houses, could be important.

5.3 General

When a wastewater treatment facility is installed in a municipality, the general benefits overwhelm the particular disadvantages. The impact on the environment is mainly reduced (wild wastewater disposal) or disappears, but the facility remains. Sometimes, after several years of operation, the plant is surrounded by new town developments. There are two solutions, either to try to isolate the facility with barriers, or close it down and rebuild the system far away from the original location. In other instances, when there is no room available for a new facility or the transportation of raw wastewater is too expensive because of pumping costs to long distances and large heights, the solution is to build the facility underground (e.g., Marseilles and Barcelona).

It should be noted that a special relationship exists in systems with large water bodies (e.g., lagooning), and this is because of the ecologists, who tend to consider the wastewater treatment plant as a wildlife refuge, forgetting the role of the facility. As a consequence, problems and interferences with normal operation can occur.

6. REMEDIATION TOOLS

Now that the problems related to wastewater treatment plants have been outlined, the possibilities for remediation should be dealt with. Solutions to some of the main problems are listed below. Other solutions have been included in the text.

- With respect to <u>bioaerosols</u>, it can be indicated that (Pascual, 1999):

  For workers

  a) it is important that the workers are adequately educated in the characteristics of the material they work with (wastewater, sludge, etc.);
  b) vaccinations must be offered to the workers when appropriate;
  c) there is a need to implement special hygiene measures (no smoking, no consumption of food or drink in hazardous areas, while leaving the plant …, etc.);
  d) the same clothes should not be used inside and outside the facilities. Clothes used inside the facility must remain there;
  e) protective clothing should be worn when necessary. In the pre-treatment, unless the head and face are covered, masks could be necessary; and
  f) wounds should be disinfected immediately.

  For the facility:

  a) it is necessary to provide the workers with periodic information updates (there is a need for them to know the importance of the biological hazards existing in the facilities and the importance of the prevention measures);
  b) there should be adequate signposting indicating the biological risks in areas where hazards exist;
  c) the number of workers exposed to hazards must be the minimum possible;
  d) there is a need to carry out health checks on the workers in relation to the biological hazards. Check-ups must be performed periodically and at different times, (before, during and after exposure) and also when there is evidence of a hazard/risk in a similar, neighbouring facility;
  e) pests (flies, mice, etc.) in the plant must be eradicated, or at least controlled as much as possible; and
  f) persons having a history of immunodepression or lung diseases must not be allowed to work in the facility.

- The effects of wastewater treatment equipment generating air pollution must be minimized by providing scrubbers, filters, covers, electrostatic precipitators, afterburners, proper location of sources relative to prevailing wind direction, and isolation.

- With respect to external noise, mitigation strategies focus on equipment selection, acoustical architectural techniques, and the use of barriers or other sound wave attenuation measures within buildings, surrounding structures, and plant grounds. Noise impacts of construction and operation can be significant. Additional truck traffic must, if possible, be restricted to day hours. Facilities that produce noise must be located as far away as possible from potential receptors. Erection of sound walls, berms, trees and heavy landscaping in the surrounding area contribute towards mitigating noise.

- To reduce the sound level at the plant boundary, enclosing blowers, compressors, large pumps or other similar equipment in sound-attenuating buildings could be a good solution.

- Personnel must have access to and be obliged to wear protective masks (against air pollution) and equipment against noise in accordance with regulations for 8 hours of continuous exposure.

- Solutions for the problem of odour are different. They can be the addition to reactive into the sewerage systems (e.g., permanganate) or covering the main odour focuses and managing polluted air with adequate systems (e.g., chemicals, biofilters, etc.). In any case, such problems should be anticipated from the very outset, during the planning phase when deciding on a location for the facility.

- Truck traffic problems can be solved by, for example, establishing service schedules that do not coincide with rush-hours, establishing specific truck routes to the plant thus avoiding residential streets and neighbouring commercial centres and other areas where school children may be present on the streets. The size of the trucks utilized must also be considered.

7. CONCLUSIONS

Undoubtedly, wastewater treatment facilities exert impacts on the environment. The impacts can be positive or negative.

Positive impacts exist mainly at the regional level while negative impacts are mainly at local level.

With respect to the type of impacts, we refer to:

- impacts on humans; and
- impacts on the environment.

The most significant impacts are related to:

- the loss of value of properties located near facilities;
- odour expansion from the facilities; and
- possible health problems related to workers (not associated with the mechanical problems of the facility). More precisely, the typical safety procedures for almost all industrial facilities.

When considering impacts globally, the positive impacts of wastewater treatment facilities outnumber the negative.

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