# Chapter 2

# Wastewater management in the river basin context

*This chapter gives an overview of the principal components and features related to the studied system. We will put special emphasis on the relationships between the different components as well as on the actual management of the system (management policies and criteria) and how the different emerging problems are solved or tackled. The main objective of this overview is to point out the complexity and thus, the challenges, of the integrated management of industrial wastewater discharges in the context of river basins.*

## 2.1 Regulations and pollution-prevention policies

Water quality management policies on a river basin scale are of special importance in order to prevent and/or reduce pollution of several human sources into the environment. Industrial effluents represent a priority issue particulary in urban wastewater systems that receive mixed household and industrial wastewaters, apart from rainfall water. In particular the contribution from industry must be properly regulated in order to avoid operational problems at the Wastewater Treatment Plant (WWTP) and transfer of pollutants in the effluent or sludge (87). Hereby it is presented a summary of the principal possible water quality management strategies (§2.1.1). Then, sections §2.1.2 and §2.1.3 give an outline on the current legislative European framework and how it is regionally adopted.

### 2.1.1 Water quality management policies

Several management policies are being developed aimed at maintaining or improving water quality on a river basin level. They can be classified according some constraints imposed on the problem *e.g.* minimum treatment level, ambient water quality standards, effluent standards, total emission caps, *etc.*, either individually or in combination, to model various policy alternatives (102). As follows,

- Effluent standard based strategies (*i.e.* emission-based) (191) such as
  - define the effluent concentration on individual pollutants or groups,
  - set an annual total load standard (based on total emission reductions) or,
  - set technological standards based on the Best Available Technology (BAT).
- Ambient water quality objectives strategies (*i.e.* immission-based) (82) based on setting ecosystem-based quality objectives.
- Economic based strategies, based on economic instruments (89). They can work either by changing prices or by limiting the quantity of an environmental resource that may be used (*i.e.* price-based instruments and quantity-based instruments, respectively).

In practice, the combined use of these policy strategies seems to be the best way to manage water quality since it is in line with the related European Community Directives (§2.1.2) with the main focus on *pollution prevention* and *carrying capacity* principles.

### 2.1.2 European directives for pollution prevention

Several European Directives have a direct or indirect influence on water quality of European rivers (see Figure 2.1). From nineties new directives were introduced to prevent water quality deterioration going beyond the *human health protection* approaches, such as the Directive 91/271/EEC. Some of the other most relevant directives, in line with pollution prevention policies, are the Integrated Pollution Prevention and Control and the Water Framework directives.

**Directive 91/271/EEC concerning Urban Wastewater Treatment** (40) set clear infrastructure targets of wastewater treatment for all European urban settlements according to different classes of receiving waters sensitivity. The directive state that there should be wastewater collection and treatment for all settlements above 2000 Population Equivalent (PE) with biological treatment, plus nutrients removal where the affected waters show an elevated nitrates level and/or eutrophication.

**Directive 96/61/EC on Integrated Pollution Prevention and Control** (from now IPPC) (41) was developed to apply an integrated environmental approach to the regulation of certain industrial activities. This means that, at least, emissions to air, water (including discharges to sewer) and land must be considered together. It also means that regulators must set permit conditions so as to achieve a high level of protection for the environment as a whole. These conditions are based on the use of BAT, which balances the costs to the operator against the benefits to the environment. IPPC aims to prevent emissions and waste production or reduce them to acceptable levels by means of permits based on BAT (41; 191).

**Water Framework Directive (2000/60/EC)**(from now WFD) (43), aims to establish a framework for the protection of water bodies in Europe. It intends to apply to all water bodies, including rivers, estuaries, coastal waters (out to a minimum of one nautical mile), and artificial water bodies (such as docks and channels). The WFD provides for a combined approach of *emission limit values* and *environment quality standards* by setting out an overall objective of good status for all waters as well as supporting source controls. The WFD co-ordinates the application of all European Union water-related legislation (*e.g.* Urban Wastewater Treatment, Nitrates, Integrated Pollution Prevention and Control, Seveso, Habitats Directives, *etc.*; see Figure 2.1) with the aim to provide a coherent management framework, so as to meet the environmental objectives of these instruments and the WFD itself.

Accordingly, its aim is to take a holistic approach to water management by introducing a single system of water management by river basin - the natural geographical and hydrological unit - instead of according to administrative or political boundaries. This supposes a coordinated, supra-national approach to achieve the set of environmental objectives.

### 2.1.3 Regional legislation

Several national and regional efforts are being done in order to improve water quality management as well as to accomplish European regulations.

In this section we summarize the Catalan experience as a realistic example of adapting European guidelines to manage water taking into account the local/regional

| EMISSION CRITERIA | | | | IMMISSION CRITERIA | | |
|---|---|---|---|---|---|---|
| **European (Directives)** | **Spanish** | Description | | **European (Directives)** | **Spanish** | Description |
| 76/464/EEC →<br>2006/11/EC → | RD 995/2000<br>RD 258/89 | Discharges of certain dangerous substances | **WATER FRAMEWORK DIRECTIVE 2000/60/EC** (modified by **Decision 2455/2001/EC**) | 75/440/EEC → | Ord. 15/10/90 | Surface water quality required for the abstraction of drinking water |
| 91/271/EEC<br>98/15/EEC → | RD 11/95 | Urban wastewater treatment | | 80/778/EEC<br>98/83/EC → | RD 140/03 | Quality of water intended for human consumption |
| 80/68/EEC | | Protection of groundwater against pollution caused by certain dangerous substances | | 2006/7/EC → | RD 734/88 | Management of bathing water quality |
| | | | | 91/676/EEC → | RD 261/96 | Protection of waters against pollution caused by nitrates from agricultural sources |
| | | | | 79/923/EEC →<br>78/659/EEC → | RD 345/1993<br>Order 16/11/88<br>RD 927/88 (Annex III) | Quality of selfish waters<br>Quality of fresh waters to support fish life |

Figure 2.1: Water Framework Directive scope

reality.

### The Catalan sanitation plan

During the last 20 years Catalonia has done several efforts in building and maintaining sanitation infrastructures in order to comply with European Directives and to reduce pollution and promote the good quality of water bodies. As a consequence of the Directive 91/271/EEC (40), the Catalan Government approved the *Catalan Sanitation Plan* (7th November 1995). The Plan describes the quality goals for the Catalan rivers. In order to achieve them, the Plan was divided into five programs covering different domains that must be addressed: *(1)* the urban wastewater treatment program, *(2)* the industrial wastewater treatment program, *(3)* the cattle wastewater treatment program, *(4)* the agricultural and diffuse wastewater treatment program, and *(5)* the sludge treatment program.

For the scope of this work, the Urban Wastewater Treatment Program (UWTP) and the Industrial Wastewater Treatment Program (IWTP) take special importance in order to analyse the context of pollution-prevention policies in Catalonia. UWTP consists of two parts: the first one with the aim to define sanitation in communities over 2000 PE (representing an increase up to 300 WWTPs most of them using the activated sludge system); the second one (approved in 2002 and known as PSARU 2002) with the aim to define the most appropriate treatment for the communities with less than 2000 PE (in Catalonia this accounts for approximately 2500 communities). Specific Environmental Decision Support Systems were built to take the most appropriate treatment considering several aspects (5; 51; 157). So lot of progress has been done in Catalonia in order to reduce pollution thanks to high investments in new infrastructures.

More recently, and due to the requirements established by the European Directive 2000/60/EC (43), the ageing of sanitation infrastructures and the bad operation of some treatment plants as a consequence of diverse types of arriving wastewaters apart from domestic *e.g.* industrial, agriculture, pluvial, *etc.*, the Catalan Government approved a new UWTP known as PSARU 2005. It substitutes PSARU 2002 and links directly the urban wastewater treatment program with the industrial wastewater treatment program. Firstly, the Program outcrops the need to execute enlargement, improvement, adaptation and remodelling of the existing treatment plants to reach the new quality goals. Secondly, it pays special attention to the industrial component of urban WWTPs in order to facilitate the connection to the public system of those industries and/or industrial parks that accomplish the requirements[2]. The program establishes two temporal scenarios to achieve the new requirements (2006-2008 and 2009-2014) and prioritizes two elements: planning (according to the timetables of the mentioned Directive 2000/60/EC) and economic instruments.

The high investments in sanitation infrastructures have been able to break the link between growth (measured in terms of urban and industrial development) and environmental degradation. But the economical consequences are undeniable: the operation, maintenance, preservation and improvement of these infrastructures generate more and more investments. In this way, it is necessary to establish an equilibrium point among the will of guaranteeing the quality of treatment and environment, with a suitable repercussion of costs that should be self-contained through water canons and other economic taxes.

Accordingly, PSARU 2005 together with the IWTP (known as PSARI 2003) decidedly aim to regulate wastewater discharges, according to their impact into the water bodies (emission and immission based strategy) through some economic instruments imposed to industries (economic based strategy)[3].

## 2.2 Integrated wastewater management in river basins

Currently, when studying industrialized basins, there are at least three principal components of the system that one must take into consideration: the sewer system, the WWTP and the receiving water (*e.g.* the river) (37; 38; 68; 81; 125; 163; 176; 203). These elements are only a part of the global water system which comprises other natural (*i.e.* atmosphere, groundwater, runoff, sea, *etc.*) and anthropogenic (*i.e.* drinking water production, agriculture, households, system administration, *etc.*) components; the integration of these components comprises the so called Urban Wastewater System (UWS).

As the focus of this thesis lies on the effect and management assessment of industrial discharges, apart from these three subsystems, we will make special emphasis and include in the discussion the industrial component. Naturally, some of the other elements of river basins, although not directly included in the scope of the following

[2] In Catalonia the Decree 3/2003 - consolidated text of 6/1999 Law - imposes the connection to public system unless the competent organisms considers and authorizes the discharge into the receiving media claiming more safety, that is to prevent damage to the WWTP and consequently to the river.

[3] The Administration Agent depicted in Chapter 5 intends to exemplify this combined policy.

sections, they are inherently present when describing the components' interactions.

### 2.2.1 Components

#### Sewer system

The main issues that the sewer systems address are

- drainage and sanitation, and
- flood protection (60; 163).

For the purposes of this thesis, we only discuss hereby the drainage and sanitation function. This functions entails the transport of both the rain water and the wastewater directly to the receiving media or to a WWTP.

Fundamentally, there are two types of sewer systems:

1. *Separate sewer systems* have two net of pipes for transporting the water, one for the rain water and one for wastewaters. The main advantages of this kind of system are:

    - the wastewater is not diluted during rain so it can be treated more efficiently, and
    - no combined sewer overflows can occur, reducing the amount of pollution leaving the sewer system.

    Some of their disadvantages are the higher construction costs, the risk of misconnection, sudden and strong hydraulic impact to rivers, and higher heavy metal load to the receiving water (125).

2. *Combined sewer systems* have only one pipe that collects and transports together the stormwater and the different types of wastewater (*e.g.* industrial, household, runoff, *etc.*). The advantage is that only one pipe needs to be constructed. During dry weather only sewage from households and industry is transported to the WWTP. During a light rain event the capacity of the sewer allows the transport of stormwater and wastewater to the WWTP. However, one disadvantage can arise since, considering that the hydraulic capacity of the system is not surpassed, during rain events the flow to the treatment plant is increased while the pollutants are diluted, which reduces the efficiency of the treatment plant. Another problematic situation of combined sewer systems

occurs when the flow in the sewer system becomes higher than the hydraulic capacity of the pipes or the WWTP (*i.e.* during heavy rain events the hydraulic capacity of the sewer system and the WWTP is exceeded). In these cases, the water leaves the system *via* emergency exits, or Combined Sewer Overflows (CSOs) and enters the receiving water without treatment, causing acute pollution periods at the discharge point. In order to reduce the amount of combined water spilled at the CSOs, storm tanks are built in the system, to store a certain volume of storm water before the CSOs start to spill. In this way, both the frequency and the volumes of spilling can be reduced.

Thus, the construction of pluvial or storage tanks in the sewer system is not rare, with main functions of:

- Laminating the inflow to the WWTP, that is, to retain the flow during the maximum production of wastewater and releasing the flow when minimum production.
- Retaining punctual polluting episodes and laminating them in order to reduce the impact to the WWTP.
- Decreasing overflows when rain episodes (retaining the peaks during rain periods and releasing them during dry weather).

#### Wastewater treatment plant

As mentioned previously, one of the main functions of the sewer system is to transport wastewater into a treatment plant. The type of treatment will depend on several factors: the characteristics of arriving wastewater, weather conditions, level of treatment to be achieved, costs, *etc.* Besides the type of treatment, the objective is to treat wastewater before arriving to the receiving media in order to prevent ecological damages.

Urban wastewaters are mostly treated using the *activated sludge system* in which the main treatment is performed by several types of bacteria (189). The treatment performance of these bacteria depends directly on the type and fluctuations of the inflow wastewater. The quality and variability of wastewater received at the sewer and then transported to the WWTP depends mainly on the percentage and composition of industrial wastewaters that are discharged in the combined sewer system together with domestic wastewater; for this reason industries are an important part of the urban wastewater system to be considered when proposing an integrated management of the system.

Figure 2.2 shows a schematic overview of a simple activated sludge plant composed by a pre-treatment, primary treatment and secondary treatment (*i.e.* biological) in which the removal of nutrients and organic matter occurs, and the sludge is separated from the effluent in a secondary clarifier or settling tank (189). As shown in Figure 2.2 part of the sludge (Recycle Activated Sludge –RAS–) settled in the clarifier is recycled into the treatment system to preserve an optimum concentration of micro-organisms, while the rest (Waste Activated Sludge –WAS–) exits the system.

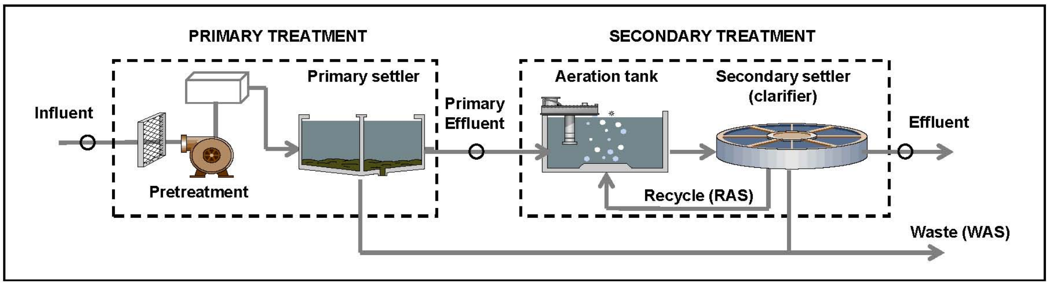


Figure 2.2: Conventional WWTP scheme: *activated sludge system*

The most common WWTP operational states are classified in Figure 2.3. Operational problems at the secondary treatment, specially those with a biological origin, particularly bother WWTP managers. They involve complex microorganisms communities whose dynamics is quite unpredictable.

These problems are briefly described in (54); for a full description of the biological operational problems see (118). The available quantitative (on-line, off-line) and qualitative data permits to characterize and evaluate the WWTP operation and thus to diagnose the abovementioned problems[4]. Table 2.1 list the information available at WWTPs, briefly described as follows:

***Quantitative data*** (118):

- *On-line data* provided by sensors: flow rates (influent, primary effluent, effluent, aeration, recycle, recirculation and wasting) and physical parameters *i.e.*

[4]The information hereby summarized conforms the data bases that can then be used to infer knowledge for environmental decision support (see Chapter 6).

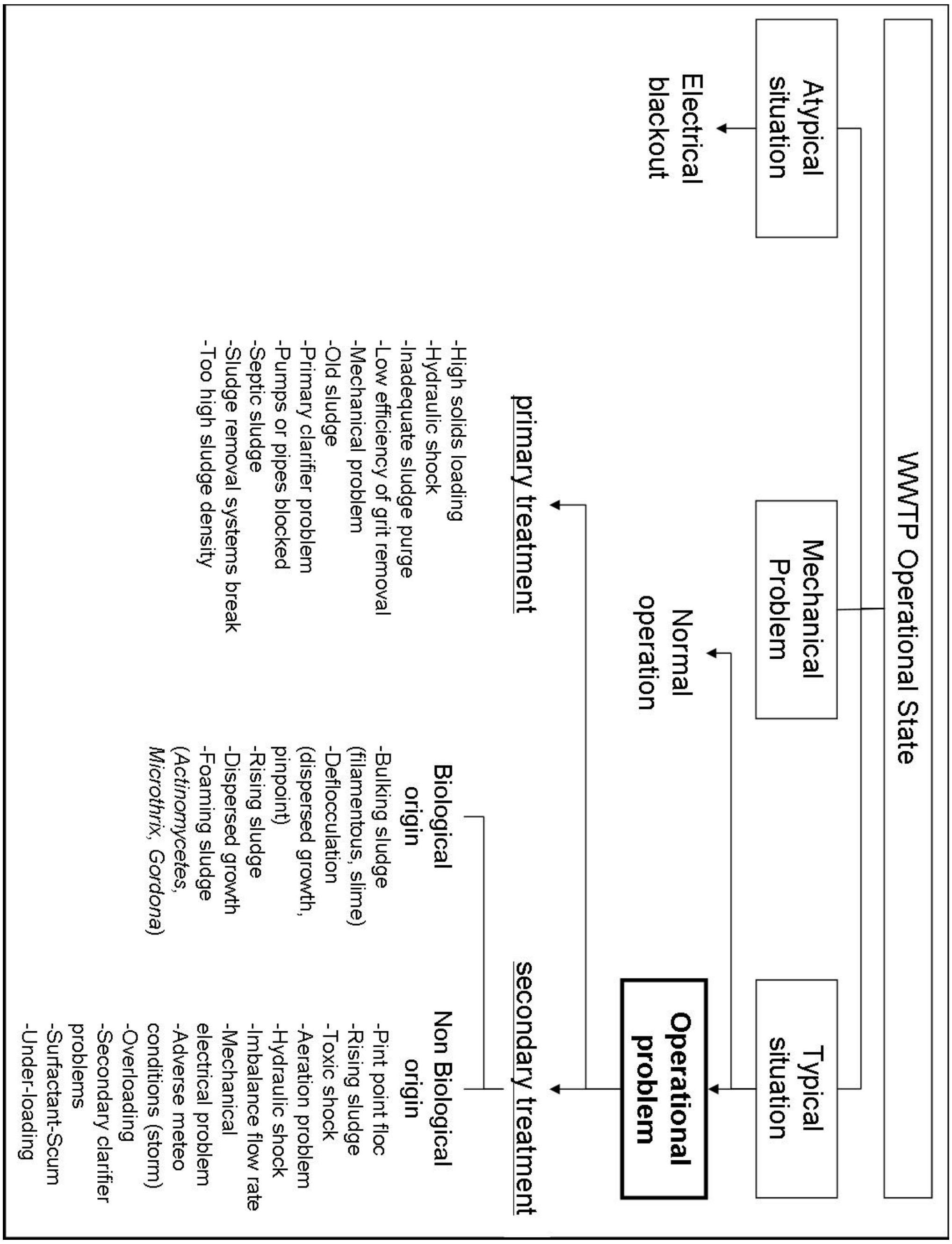


Figure 2.3: List of WWTP operational problems

pH and Dissolved Oxygen (DO).

- Quantitative data provided by the *analytical determinations* of samples collected daily from different locations in the plant: organic matter (Chemical Oxygen Demand – COD – and Biochemical Oxygen Demand –BOD–), Suspended Solids (SS), turbidity, Nitrogen (N) and Phosphorous (P), Temperature (T), conductivity, greases and oils, metals or other inhibitors, V30 and biomass concentration (in terms of Mixed Liquor Suspended Solids –MLSS– and Mixed Liquor Volatile Suspended Solids –MLVSS–). For a good monitoring four sample points are defined: influent, primary effluent or secondary influent, aeration tank and final effluent.

- Combinations of quantitative data which allow calculating *global process state variables*: residence time, Hydraulic Residence Time (HRT), Sludge Volume Index (SVI), % of COD, BOD and SS removal of primary, secondary and overall treatment.

***Qualitative data*** (118):

- *Microscopic determinations*: are usually measured once a week and consist of floc characterization (morphology, average floc size, effect of filaments on the floc and overall evaluation of the floc quality), microfauna (protozoa and metazoa) identifications and counting, and filamentous bacteria identification and counting.

- *Macroscopic observations*: refer to observational information obtained in-situ about plant performance, quality of biomass and settling characteristics (V30 test) (usually a daily quality report is available at WWTPs).

### Receiving water (river)

Although several types of receiving waters can be distinguished at river basins (*i.e.* lakes, sea, streams, rivers, *etc.*), rivers are the most frequently sinks for urban wastewater. Rivers provide a mean of transport, recreation, fishing, drinking water production, irrigation and are an habitat for aquatic fauna. For all of these reasons water taken from these sources must be returned in the river maintaining an *acceptable* quantity and quality. The quality required depends on the expected use of water; since a combination of water uses can coexist in the receiving water,

Table 2.1: Quantitative data measured in the WWTP

| **Source** | **Variable** | **Sampling location** |
|---|---|---|
| Analytical (off-line) | COD, BOD, TSS and Turb<br>Ammonia ($NH_4^+$), TKN,<br>$NO_2^-$, $NO_3^-$, P, T, Cond,<br>greases and oils,<br>metals, inhibitors | Influent, primary effluent and effluent |
| | MLSS, MLVSS, V30 | Aeration tank and recycle |
| Sensors (on-line) | pH | Influent and effluent |
| | DO | Aeration tank |
| | Flow rates (Flow) | Influent, primary effluent, effluent, aeration, recycle, recirculation and wasting |
| Global (calculated) | SRT, SVI, F/M,<br>HRT, % COD, BOD and SS<br>removal of primary, secondary<br>and overall treatment | – |

it is desirable that the minimum quality is determined by the most rigorous water use.

Apart from the inputs received, the river water quality depends on the physical transport and exchange processes (*i.e.* advection and diffusion/dispersion) and biological, biochemical or physical conversion processes between the water column and the sediments.

Water quality is often characterized according to the following parameters (164):

- Physical: temperature, turbidity, conductivity.
- Chemical: DO, BOD or COD, hardness, pH, alkalinity, nutrients (N and P), toxic compounds, organic volatile compounds.
- Biological/Ecological: biocenosis of bacteria, plants and animals, coliform bacteria and variety and complexity of the food chain.

It is clear that all these parameters influence each other and that several factors should be looked at when judging the water quality. The combination of several criteria leads to a classification of the river as having *very good*, *good*, *mediocre*, *deficient* and *bad* ecological quality (which is a combination of physical, chemical and biological parameters) (43).

### 2.2.2 Interactions and most common problems

Several relations and interactions exist between the system components. The multiple effects that emerge due to the existent relations between the components can be related to:

- The *flow* of water (with both quality and quantity being important), such as the effect of CSO spilled on water quality of the receiving media, or the effect of WWTP effluent into the river, or the effect of the quality and quantity of sewer system wastewater variability delivered to the WWTP.

- The *quality* of water, that is every change of quality in an upstream compartment (*i.e.* sewer system or WWTP) will have a more or less pronounce effect on downstream compartment (*i.e.* WWTP or river). Table 2.2 summarizes some of the most important impacts related to water quality on the receiving media according to the most important kind of pollutants they can receive from upstream compartments of the urban wastewater system. It is important to note that there is still lot of research to be done in order to describe the feedback effects between the components (*e.g.* such as the several pollutants and the receiving media).

- *Backwater* effects, that is, the reduction of some infrastructures capacity (*e.g.* pluvial tanks, pipes, *etc.*) due to the water held or pushed back by or as if by a dam or current.

Obviously, apart from these relations between chemical and physical processes of several UWS components, many other connections exist arising from the human behaviour component, technical and legal measures, economic instruments and many other indicators (104).

The interrelations of the presented three subsystems lead to some particular problems. The most frequently modelled problems which are referred in the literature (37; 81; 162; 163) are summarized in Table 2.3. Table 2.3 go over the main processes involved at each subsystem and the state variables most commonly studied. As follows:

- *Toxic peak loads through unionized ammonia*: ammonia is, depending on pH and temperature, in chemical equilibrium with unionized ammonia which is toxic to fish. Therefore, the discharge of ammonia from the UWS is often decisive when the oxygen concentration in the river is not a problem (162). The

Table 2.2: Effect of key pollutants as a result of the interaction with the receiving media. Adapted from (33; 162; 163)

| Contaminant | Environmental effects | Ecological Impacts[a] | Affected water use[b] |
|---|---|---|---|
| **OXYGEN DEMAND:** | | | |
| COD from CSOs and WWTPs | DO reduction<br>Biomass accumulation | 3, 4<br>1, 2, 7 | A, B, D, E<br>A |
| $NH_4$ from CSOs and WWTPs | DO reduction<br>Biomass accumulation | 3, 4<br>1, 2, 7 | A, B, D, E<br>A |
| **NUTRIENTS:** | | | |
| $N_{tot}$ from CSOs and surface runoff | Enrichment | 1, 2, 4, 7 | A, B, C, D, E |
| $P_{tot}$ from CSOs and surface runoff | Enrichment | 1, 2, 4, 7 | A, B, C, D, E |
| **TOXICANTS:** | | | |
| $NH_4$ (+ pH + T) | Toxicity | 2, 3, 4 | D |
| Metals | Toxicity | 2, 3, 4, 7 | D |
| Acute | Toxicity | 2, 3, 4, 7 | D |
| Cumulative | Toxicity | 2, 3, 4 | D |
| Organic micropollutants (cumulative) | Toxicity | | |
| **HYGIENE:** | | | |
| Faecal bacteria | Public health<br>Biomass | 1, 2, 7 | A, B, D |
| **PHYSICAL:** | | | |
| Temperature | T rise + long term change | 1, 2, 5, 6 | D |
| Suspended Solids | Blanketing + harm to fish | 4, 6 | A, B, C, D, E, F |
| Flow | Washout; morphology changes | 2, 4, 7 | D |
| Conductivity | Excess dissolved solids | 2, 5, 7 | A, D, F |

[a]The ecological impacts are referred to ecosystem characteristics: 1.Energy dynamics; 2.Food web; 3.Biodiversity; 4.Critical species; 5.Genetic diversity; 6.Dispersal and migration; 7.Ecosystem development

[b] Beneficial receiving water uses affected by contamination are coded as follows: A.Water supply; B.Bathing; C.Recreation; D.Fishing; E.Industrial water supply; F.Irrigation

Table 2.3: Typical problems modelled: processes and state variables involved (163)

| **Goal function** | | **Sewer system** | **WWTP** | **Receiving water** |
|---|---|---|---|---|
| Toxic peak loads ($NH_3$) | P | Rainfall-runoff, hydrodynamics, advection/dispersion | Transport, mixing, nitrification | Mixing |
| | SV | $N_{tot}$(=$NH_4$, "worst case") | $NH_4$, $X_{BA}$ (autotrophic bacteria) | $NH_4$, pH (measured) |
| Hygienic impact (Faecal Coliforms) | P | Rainfall-runoff, hydrologic analogy, mixing | - | Transport, mixing, "decay" incl. Various removal processes |
| | SV | FC | $FC_{effluent}$=constant | FC |
| Oxygen depletion | P | Rainfall-runoff, hydrol.analogy, mixing, sedimentation in CWRT | Transport, mixing, conversion with ASM1, sedimentation in SST demand | Transport, mixing, conversion, aeration, sediment oxygen |
| | SV | COD, BOD | COD-fractions | BOD-fractions, DO |

P: Processes; SV: State Variables
FC: Faecal Coliforms, SST: Secondary Settling Tank, CWRT: Combined Water Retention Tank

peak load in the CSO discharge is caused by short-term hydrodynamic effects in the sewer system, whereas maximum concentrations in the receiving water are induced just after the inflow to and the mixing with the receiving water. Since the rainfall-runoff process in the natural catchment area is significantly slower than in the urban area, the peak load in the CSO discharge and the minimum dilution capacity at minimum flow rate in the river coincide in the initial phase of the overflow event. The WWTP processes become only significant when the nitrification process or the secondary clarifier is overloaded.

- *Hygienic impact (Fæcal coliforms)*: *Fæcal coliforms* are an indicator for hygienic deficiency in the river. For the receiving water the impact matters if the area is a bathing, water extraction or fishing place.

- *Oxygen depletion* in the receiving water is important (both for the water body and the sediment) since affects the activity of all aquatic fauna and life (*e.g.* fish cannot stand oxygen depletion below critical levels for longer periods of time; oxygen depletion progress can lead to *hypoxia*).

To sum up, wastewater discharges' impacts, in which industries are an important source of nutrients and pollutants, can be grouped into chemical, bio-chemical, physical, hygienic, aestethic, hydraulic and hydrologic, and further classified in terms of duration as acute, delayed or accumulating (162). Accordingly, the *flow* of water can reveal problems like infiltration, exfiltration, WWTP overload, hydraulic stress to receiving waters, *etc.* Organic matter, by means of BOD and COD, may indicate organic pollution, hence oxygen depletion and $CO_2$ emission. Finally, nutrients (N and P) can reveal potential eutrophication in receiving waters. Moreover, the biggest complexity relies on the synergetic effects to aquatic organisms and to identify the critical combination of receiving water properties and urban catchment characteristics (33).

Accordingly, in the following section a brief description of the trends in modelling for water quality management is explained.

### 2.2.3 Current approaches and challenges

Mathematical modelling in the IUWS has a long tradition, especially the modelling of the separate subsystems. Traditionally, wastewater treatment facilities and hydraulic infrastructures have been managed individually by taking into account the characteristics of water before and after the treatment at a particular facility. Up to the date, there is a long modelling tradition of sewers, treatment plants and receiving water, describing the performance according to the individual needs and objectives. The individual elements of the system have been typically build using deterministic descriptions of the fundamental mechanisms and processes (*e.g.* rainfall-runoff, hydraulics in sewer systems, water quality and pollution transport in sewer systems, wastewater treatment and modelling of quality changes in rivers and other receiving waters) (163).

The enforcement of the WFD by European countries (§2.1.2), which claims for the reconsideration of a river basin scale to manage water and wastewater resources, has induced the movement from such individual consideration of system performance to an integrated management of the urban wastewater system. Integrated mathematical modelling approaches have been used to allow the wastewater system to be considered one single system. The components of the system (*i.e.* sewer, treatment plant and river) are often modelled using complex mechanistic models. The complex equations used to model the system have to be solved using advanced numerical integration algorithms with a high computational burden (203), so in most of applications, these models result to be impractical for use in long-term simulation or in optimization problems. Furthermore, the WFD explicitly mentions the ecological integrity as an important goal, whereas ecological modelling and predictions of ecosystems behaviour are still a problematic issue. Whereas systems have been designed for static/stationary loading, real systems are operating under dynamic loading. Immission-based Real Time Control (RTC) has been suggested as a proper instrument to help fulfilling the WFD requirements (37; 176; 203) by means of building integrated mathematical models for control and evaluation.

Several problems are encountered when creating such models and some solutions such mechanistic surrogate models and model reduction has been proposed, all of them with the purpose to simplify the models to be more operative. To mention only some examples, the integration of the sewer system, WWTP and river has been applied in different catchments *e.g.* (37; 38; 68; 125; 155; 176; 203) using sequential or simultaneous integration of the models.

The majority of the authors mentioned before recognized some problems and/or disadvantages when building these numerical tools:

- Interface problems between submodels, ranging from the different time resolution between different processes to multiplicity of variables used. The range of time constants in the system goes from tens of seconds for oxygen and flow dynamics in treatment plant and sewer, respectively, and up to months for population dynamics in treatment plants and rivers. The latter needs further development of consistent sets of model parameters in the various subsystems in order to dynamically run them without external definition of conversion at the interfaces (163).

- Testing of integrated models: measuring campaigns to support such individual and holistic identification of integrated models may become huge as there is both a temporal and a spatial dimension to consider. The development of mechanistic models and their calibration requires a lot of data making campaigns very costly.

- Uncertainty: the results of individual models have an error threshold *w.r.t* reality as they are built principally using deterministic models and default variables. This uncertainty increases when integrating the models. Moreover, there is an inherent uncertainty in modelling these large complex systems (mainly if they imply natural ecosystems).

- Problem oriented modelling: it is vital to analyze carefully what the problem of the system or the receiving water is and based on this formulate the goal of numerical modelling. The complexity of the model will depend on the goal to be achieve, and it is important to formulate it properly as the complexity of the model is a limiting factor for the simulation time.

A step forward in the integrated management of wastewaters is the construction of DSS. DSS are based on the integration of these numerical models (taking into account the knowledge they can provide) with heuristic knowledge (157). Since now DSS have been applied on individual treatment plants (168) designing different control strategies and helping the decision making process at specific situations that may arise in the facility. More concretely, EDSS can play a key role in the interaction of humans and ecosystems, as they are tools designed to cope with the multidisciplinary nature and high complexity of environmental problems (157).

EDSS have to tackle as well with several problems or bottlenecks such as the integration of several sources of data and knowledge, the improvement of knowledge acquisition methods, the sharing and reuse of knowledge, the development of benchmarks of validation and last but not least the involvement of end-users.

This latter approach reflects the current trend of building combined models which integrate the ecological and socio-economic dimensions of common-pool resources management in terms of their dynamics and interactions (86). A scientific paradigm that go towards this direction is *intelligent agents* research area (see Chapter 4).

## 2.3 Conclusions

The conclusions of the above sections can be summarized as follows:

- UWS are an important part of (urbanized) river basins. They are composed by several interconnected elements. One important issue to be tackled by water managers in river basins is water pollution caused by the several sources in the system.

- Among several other sources of pollution (briefly analyzed in this chatper), an outstanding water pollution source, both for their quality and quantity variability, are industrial wastewater discharges. To deal with them, means to understand all the relations, from the sources to the final receiving media. In this way, it is possible to observe how the activities upstream affect water quality downstream, and why an integrated management of the system components is required.

- Several management policies exist *i.e.* immission-based, emission-based, economic-based and combinations of two or more of them. These strategies are formulated under some legislation and regulations. The WFD intends to be a unifying framework with the main focus on *pollution prevention* and *carrying capacity* principles. However, deciding pollution thresholds is not a simple task since there is often a disagreement among whether a toxic or a wastewater substance is or is not safe for the final receiving media.

- Mathematical modelling of UWS has a long tradition. The individual elements of the system (*e.g.* sewer, WWTP and river, principally) have been typically built using deterministic descriptions of the fundamental mechanisms and processes within these elements. The problems of this approach are reported in this chapter. Some of them are being solved while others require complementary and/or different approaches to be overcame. In the field of artificial intelligence the area of *intelligent agents* offers a promising paradigm with a high potential to overcome some of the current complex systems bottlenecks.