Management of storm sewage discharges at coastal locations in Europe

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ABSTRACT

The study gives an overview of the British experience concerning sea outfall management in coastal areas. Consequences of the application of European Directives are observed on British legislation as well as the technical conception of treatment and discharge of urban wastewaters in coastal areas. Eleven British case studies have been analysed, in addition to seven case studies implemented in other European countries. The aims of these projects and technical details are presented, and the consequences for bathing water quality are assessed. The results show a general improvement of the quality of bathing waters following the implementation of the projects. Other European countries, in particular France, will have to carry out investments in order to achieve compliance with European Directive requirements. These countries could benefit from the experience acquired by the UK.

Key words | bathing waters, coastal area, European Directive, storm discharge, UK legislation, wastewater management

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INTRODUCTION

This paper presents an expert review of UK coastal sewerage practice and experience. The report focuses on the planning, management and operation of storm sewage discharges from combined sewer systems, in particular those measures necessary to achieve compliance with relevant European Commission (EC) Directives.

During the 1990s the UK water industry was obliged to substantially revise its policy for the planning, treatment and disposal of urban wastewaters at coastal locations. The French wastewater sector could benefit from the wealth of experience acquired by the UK wastewater sector. This is particularly appropriate as France prepares to make huge investments on schemes to ensure its designated bathing beaches comply with EC standards. This paper presents the consequences of the EU legislation, specifically for treatment and management in coastal locations, results and costs, and two detailed case studies: Brighton and Hove (UK), and Costa de Estoril (Portugal).

Impact of EU legislation

The desire to improve the environment has led to the production of a number of important EC Directives intended to cover all EU countries. EC Directives have had a major impact on wastewater treatment methods at coastal locations, through the prescription of quality and treatment level requirements for the effluent prior to discharge to the marine environment. The most important of these are:

- The Bathing Waters Directive (76/160/EEC) (CEC 1976), which in an Annex lists 19 physical, chemical and microbiological parameters and lays down numerical Imperative and/or Guideline standards for certain of them, and also outlines minimum sampling frequencies, sampling methodologies and analytical techniques.
- The Urban Wastewater Treatment Directive (UWWTD) (91/271/EEC) (CEC 1991), which

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essentially adopts a 'precautionary' approach by specifying minimum treatment requirements rather than quality objectives that should be achieved.

- The ShellFish Directive (79/923/EEC) (CEC 1979), which lays down in an Annex the Imperative values for bacteriological and physico-chemical parameters of water quality which must be attained in designated waters.

Box 1 Summary of the key developments

1976 The Bathing Water Directive (76/160/EEC) required member states to identify relevant bathing waters in order to protect the environment and public health. The Directive lays down Mandatory values for certain parameters which must be attained as well as guidance values which member states must endeavour to observe.

1979 The ShellFish Waters Directive (79/923/EEC) required member states to designate shellfish waters which they consider require protection or improvement. The Directive lays down the Imperative values for certain parameters of water quality which must be attained in designated waters. It also sets Guideline values which member states must 'endeavour' to observe.

1979 27 bathing water beaches were identified by the UK government to be designated bathing waters, none of these was in Scotland.

1986 It was concluded that sewage disinfection would be an interim method for achieving compliance with the 1976 Bathing Water Directive.

1987 A further 377 designated bathing beaches were identified, 23 of these beaches were in Scotland.

1991 The Bathing Water Directive was implemented in the UK by the Bathing Waters (Classification) Regulations (HMSO 1991). Bathing waters are identified in England and Wales by the DoE, now DETR, based on proposals from groups such as the general public, interest groups or district councils as well as the Environment Agency.

1991 The Urban Waste Water Treatment Directive (91/271/EEC) superseded the Municipal Wastewater Treatment Directive (91/27/EEC). The main objective of the Directive is to ensure that all significant discharges of sewage are treated, whether the discharge is to inland surface water, groundwaters, estuaries or coastal waters.

1993 The Commission's report says that certain parameters in the 1976 Bathing Water legislation need to be simplified and adapted to new scientific knowledge.

1994 Proposal to amend the BWD, proposed changes include increased incentives to attain the Guideline values, changes to the parameter requirements: greater emphasis on the enterovirus standard, Mandatory standard for faecal streptococci of 400 $100\ ml^{-1}$ and removal of the total coliform parameter.

1994 Regulations to implement the UWWT Directive in England and Wales and Scotland came into force in the form of the Urban Waste Water Treatment (England and Wales) regulations (HMSO 1994*a*), the Urban Waste Water Treatment (Scotland) regulations (HMSO 1994*b*) and the Urban Waste Water Treatment Regulations (Northern Ireland) (HMSO 1995). The regulations reproduce many requirements made in the Directive.

1995 By 1995 there were 459 bathing waters designated throughout the UK, 420 of these were in England and Wales, 23 in Scotland and 16 in Northern Ireland.

1997 The Surface waters (ShellFish) (classification) Regulations and the Surface waters (ShellFish) (classification) Directions formally transposed the ShellFish Waters

Directive into legislation in England and Wales. The Regulations set minimum Mandatory standards equal to the values of the Directive's Imperative values (HMSO, 1997*a*,*b*,*c*).

1997 The Environment Agency wrote to all the water and sewerage companies in England and Wales outlining the standards it expects new coastal sewage treatment plants to meet in order to protect bathing waters. Under the new policy, treatment plants will have to use either high standards of conventional treatment and discharge from outfalls well away from bathing waters, or use very high standards of treatment followed by disinfection with ultra-violet light if an outfall near bathing water is to be used.

1998 Commission Directive 98/15/EC. Amends Council Directive 91/271/EEC (Urban Waste Water Treatment) with respect to certain requirements established in Annex I thereof. The Directive defines the concentrations of phosphorus and nitrogen that may be discharged to areas subject to eutrophication as annual averages.

1998 The Government issued a consultation paper proposing additional designations of shellfish waters in England and Wales and making proposals for setting operational standards for faecal coliforms as well as setting numerical standards for certain organohalogenated substances and metals which are required to be controlled under the Directive.

Box 1 summarises the impact of EU legislation in the UK in the last 25 years.

Marine treatment

The UK used marine treatment at coastal resorts on a wide scale until the adoption of the UWWTD (*Water Bulletin* 1985; *Water and Sewage* 1994; WRC 1990). This treatment consisted of a very limited preliminary treatment (maceration and screening) and discharge into the sea by a long sea outfall pipe.

After the adoption of the UWWTD, this system had to be changed, mainly by the construction of new urban wastewater treatment plants (UWWTP) and by modifying the management of the storm flows. Box 2 describes the principle of marine treatment.

Box 2 Principles of marine treatment

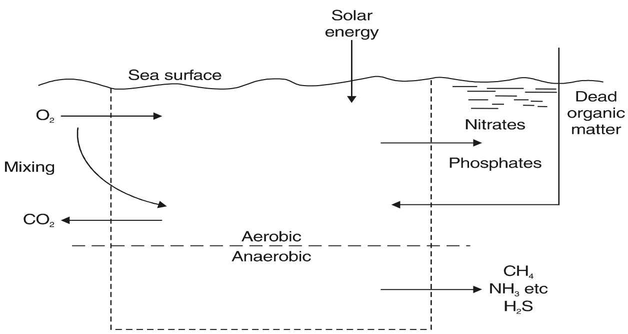
Marine treatment involves the passing of wastewater effluent, usually following a minimum of preliminary treatment, through a long outfall pipe which extends several kilometres offshore.

A diffuser section at the seaward end of the outfall is designed to maximise initial dilution, in order to ensure rapid assimilation of the sewage into the marine waters without a discernible environmental impact beyond a small mixing zone.

How does it work?

The mechanisms which determine the fate of bacteria discharged from a storm sewage outfall can be separated into several stages:

- Initial dispersion: rising of sewage from the outfall to mix with denser ambient sea water;
- Spreading: spreading of the discharge over the surface until density difference between the two water bodies is so small that that the large-scale movements of the ambient waters dominate;
- Plume dispersion: vertical mixing of the water column spreading the plume downwards;
- Decay: enteric bacteria such as faecal coliforms become less viable as a result of UV exposure, starvation, salinity, and low temperatures thus reducing the overall concentration.



Principle of marine treatment

What are the results?

Marine treatment is capable of reducing bacterial concentrations by several orders of magnitude and has the benefit of producing no sludge and localising the environmental impact. Implementation of a marine treatment scheme can have high capital costs and is also only suitable for certain sites around the coast, active coastal currents parallel to the sea shore being vitally important to ensure dispersion and mixing.

A specific design

When designing a marine outfall it is important to recognise the differing characteristics of the receiving waters, the tidal currents regime and coastal morphology which are highly site specific, and to tailor the treatment scheme accordingly to achieve compliance with the appropriate standards. The required level of treatment of the wastewater can be balanced against the assimilative capacity of the receiving water and the length of the outfall pipe used to discharge the effluent.

The main problems

Bacterial contamination of 'identified' bathing waters is the main concern with regard to the water quality impact of intermittent discharges to marine waters. Bacterial concentration following a storm discharge is therefore the problem for the implementation of EU legislation.

Implementation of sewerage management at coastal locations

After the adoption of the UWWTD, the UK authorities decided to abandon marine treatment and to install activated sludge treatment plants for secondary treatment (Water Facts 1993–1996). This treatment is well developed in the UK but has to be adapted to the specific conditions of coastal areas and to the existing sewerage systems. Box 3 presents the difficulties encountered in the improvement of UWWTP.

Box 3 Difficulties of improving UWWTP in coastal areas

Building a treatment works in the heart of a coastal community, often a popular holiday resort, comes with many inherent problems, for example the availability of space, visual impact, odours and noise. In order to gain public acceptance for a new treatment works scheme, high aesthetic standards must be attained in order to preserve the attractiveness of the area.

Limited space

The limited space available at coastal locations is usually a major consideration when planning the works. More space is required for secondary treatment compared with preliminary treatment, even using compact processes (e.g. lamella settlement, biological aerated filters). Two solutions have been implemented in the UK:

- Transferring the wastewater treatment plant to a more convenient remote location, inland or along the coast with a costly modification of the transport of sewage (usually involving pumping against gravity).
- Construction of an enclosed works on site. It is an expensive solution which creates a set of new considerations to minimise operator discomfort inside the works: aerosols, toxic and flammable gases, temperature control, oxygen deficiency, fire and smoke, lighting, condensation, odours and noise.

Salinity

Saline intrusion of the works may also be a problem due to the resulting corrosion. This can be reduced by relining sewer networks to reduce intrusion. Sea water with available sulphides can be an additional problem at coastal sites, as these can be converted to hydrogen sulphide, which can represent an odour problem.

Concept of the treatment

The treatment plant and the sludge treatment at a coastal works must be carefully considered. Any problem of odour and noise is more acute. Onsite dewatering can be used to reduce the volume if the sludge is to be transported elsewhere for treatment and disposal but transport in coastal resorts is more difficult.

During the planning and design of a treatment works it is important to maintain a degree of flexibility for future additions/modifications to the works to allow for future population increase and therefore volume of sewage to be treated, or tighter effluent standards.

An integrated approach is necessary at coastal resorts to take into account the interactions between the sewer system, the treatment plant and the receiving waters (Wright 1995). This increased understanding of the system allows the identification of bottlenecks and gives a greater confidence that upgrading schemes will adequately protect the receiving waters. Implementation times of capital schemes are also reduced and investments are more cost effective. Box 4 summarises the techniques used in the UK.

Box 4 Design assessment and management techniques

The Urban Pollution Management procedure

The Urban Pollution Management (UPM) procedure is defined as the management of wastewater discharges from sewers and sewage treatment schemes under wet weather conditions such that the requirements of the receiving water are met in a cost effective way.

Computer modelling

Computer modelling is used to simulate the complex physical and chemical processes that occur in the urban catchments and the receiving waters (river, estuary or coastal).

Supervisory control and data acquisition (SCADA)

The SCADA system is a sophisticated data collection and processing system that is a prerequisite for Global control. The data obtained are used for model calibration and verification.

Real time control

Real time control (RTC) is the active operation of flow regulators based on information about the

Table 1 | Overview of coastal wastewater management projects by water companies

				EC standards compliance	
Water company	**Population (million p.e.)**	**Bathing waters**	**Cost (£ million)**	**Project commencement (%)**	**1999 (%)**
Southern Water 'Operation Sea Clean'	4	79	1,000	42	93.7
North West Water 'Sea Change'	7	34	500	72.3	67.6
Anglian Water 'Project Clearwater'	9	37	266	81.8	94.4
Yorkshire Water 'Coast Care'	4.6	22	120	77.3	90.9
Welsh Water 'Green Sea'	1.2	70	650	91.2	98.6
South West Water 'Clean Sweep'	1.5–2	141	1,000	68.1	90.8
Northumbrian Water 'Clean-Up Campaign'	2.6	34	150	85.3	97.1
Wessex Water 'Coastal Sewerage Scheme'	2.5	43	143	78.9	93
West Scotland Water Authority	2.4	17	500	69	64.7
East Scotland Water Authority	1.43	27	160	69	80.8
North Scotland Water Authority	1.2	16	400	69	80
Northern Ireland Water Services	0.65	16	77	93.8	93.8

system state such as levels, flows and rainfall. RTC typically improves the overall performance of the existing infrastructure and minimises the extent of new works required.

RESULTS AND DISCUSSION

General overview of UK programmes

In the last 15 years, the UK Water Utility Companies have been building important works for coastal resorts (see Childs 1997; Gibson 1987; Gilling 1994; Haywards 1995; *New Civil Engineer* 1993; Shepherd 1997; Southern Water 1997; Water Sewerage 1994; 1995*a*,*b*,*c*,*d*, 1996, 1998; Whitelaw 1995). Table 1 describes these investments. The population served by these companies is 38 million and they had to consider a total of 536 Designated Bathing Waters in 1999. The total cost of all these projects is approximately £5 billion (FF50 milliards).

Table 2 shows details of some projects, giving the size of population concerned, the cost of the project and the results in term of compliance with EC Standards. These results show an improvement in the quality of bathing waters for these sites.

Table 3 shows the change in bathing water quality in the UK since 1992. The total number of designated bathing beaches (i.e. subject to EU legislation) has increased from 445 in 1992 to 536 (+20%) in 1999. Over the same time period, the percentage of bathing waters which comply with EC mandatory values increased from 77% to 90%. The percentage of bathing waters which comply with EC guide values, which are stricter, has also increased. However, it was still less than 50% in 1998. This reflects the

Table 2 | Summary of case studies

			Compliance with EC Standards										
			Years before completion						**Years after completion**				
Location	**Population size**	**Cost of scheme (£ million)**	**5**	**4**	**3**	**2**	**1**	**0**	**1**	**2**	**3**	**4**	**5**
Ryde (IOW)	26,000	100				Poor	Poor	Good	Good	Good	Good	Good	Good
Swansea Bay	165,000	82	Poor	Poor	Good	Poor	Poor	Poor	Poor	Good			
Fylde Coast	330,000	150											
Blackpool			Poor	Poor	Poor	Good	Poor	Good	Poor	Poor	Poor		
Fleetwood			Poor	Poor	Poor	Poor	Good	Poor	Poor	Good	Good		
Bispham			Poor	Poor	Poor	Good	Good	Good	Good	Good	Good		
Cleveleys			Poor	Poor	Poor	Good	Poor	Good	Poor	Good	Good		
Southport	110,000	75	Poor	Poor	Poor	Good	Poor	Good	Poor	Good	Poor		
Morecambe	53,000	32											
Heysham			Poor	Good	Good	Poor	Poor	Poor	Good	Good			
Morecambe N			Poor	Poor	Poor	Poor	Poor	Good	Good	Good			
Morecambe S			Poor	Poor	Good	Poor	Good	Good	Poor	Good			
Isle of Thanet													
Broadstairs	37,000	7.3			Poor	Good	Good	Poor	Good	Good	Good	Good	Poor
Margate	53,900	5.1			Good	Good	Good	Good	Good	Exc.	Good	Exc.	Good
Ramsgate	99,100	9.6	Poor	Poor	Poor	Poor	Poor	Poor	Exc.	Exc.	Good	Good	
Whitburn	37,500	14	Poor	Poor	Poor	Poor	Poor	Good	Exc.	Good	Good	Good	
Brighton	244,000	36											
Brighton			Poor	Good	Good	Poor	Poor	Exc.	Good	Good	Good	Exc.	
Hove			Poor	Poor	Poor	Good	Poor	Good	Exc.	Good	Exc.	Good	
Herne Bay	48,000	24	Poor	Poor	Poor	Good	Poor	Good	Good	Exc.	Exc.	Good	

Poor, fails to meet EC mandatory standards; Good, meets EC mandatory standards; Excellent, meets EC Guideline standards.

usual policy of designing coastal schemes to comply with the mandatory, rather than the guideline, standards. The reduction in the percentage of bathing waters which do not comply with mandatory values or which are not sampled is indicative of the progress made. Indeed, this percentage decreased by about half from 1992 to 1999. No prohibition of bathing in designated waters occurred between 1992 and 1999. However, it is difficult to interpret this statistic, as it was exceptional to prohibit bathing prior to the implementation of the UWWT Directive.

Table 3 | UK bathing water quality results since 1992

Year	Total number of sites	NI (%)	NG (%)	NF (%)	NC (%)	NB (%)
1992	445	77.1	35.6	1.3	21.5	0
1993	457	79.9	30.6	0	20.1	0
1994	457	82.3	33.7	0	17.7	0
1995	464	89.0	49.6	0	11.0	0
1996	472	89.4	46.0	0	10.6	0
1997	486	88.3	43.4	0	11.7	0
1998	496	88.7	44.2	0	11.3	0
1999	536	90.1		0.37	10.1	0

NI, % of bathing waters sufficiently sampled which comply with EC Mandatory values.
NG, % of bathing waters sufficiently sampled which comply with EC Guide values.
NF, % of bathing waters insufficiently sampled.
NC, % of bathing waters which do not comply with Mandatory values or which are not sampled (no data available).
NB, % of sites where bathing was prohibited for the duration of the bathing season.

Management of storm sewage discharges has been promoted in many European countries. Table 1 presents selected cases where sea outfall technology has been used to protect water quality, for bathing waters and for sites of specific interest.

Costa de Estoril Wastewater System

What is the Costa de Estoril project?

The Estoril Coast wastewater system serves an area of 22,000 ha located on the west side of Lisbon (Milleron 1994). The Estoril Coast is a popular area due to the beauty of its beaches. The increase in population, which has been occurring since the 1940s, has had a strong impact on the quality of both inland and coastal waters of the area, due to the existing inadequate sanitation systems. In the 1950s, only the towns of Estoril and Cascais had a sewerage system and this discharged raw wastewater directly into the streams flowing into the sea. Twenty years later, the streams were heavily polluted and the quality of the water in the Estoril Coast beaches was not meeting EC standards and was causing a public heath problem.

The forecasted population in 2025 is 920,000 p.e. The SANEST company has set up a project which aims:

- to improve the water quality of the beaches to the level of compliance with the bathing water quality Directive 76/160/EEC;

Table 4 | Presentation of European cases

Name	Pop. (1,000s)	Treatment activity	Targeted area	Results (March 2000)
Turkish Black Sea coast	1,500	Adaptation of simple marine treatment in difficult topographic conditions	50 agglomerations, 1,500 km coast length	Turkish legislation compliance
Costa de Estoril (Portugal)	920	Outstanding sea outfall	15 bathing waters	Compliance with standards 95%
Barcelona (Spain)	1,500	RTC management of storage and treatment	4 km beaches	Compliance with standards
Genoa (Italy)	220	Meteorological events prediction	Old Port protection	Not available
Venice (Italy)	127	Flooding and eutrophication control	Lagoon protection	Not available
Helsingborg (Sweden)	205	Network optimisation	Coastal eutrophication	Not available
Halmstad (Sweden)	100	Integrated modelling of the system	Coastal eutrophication	Not available

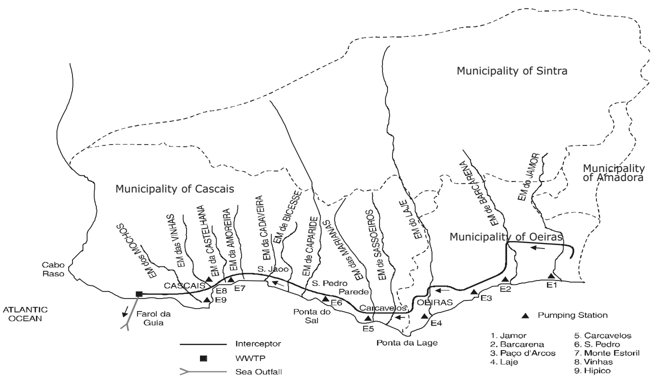


Figure 1 | Costa de Estoril sewer map.

- to improve the water quality in the streams of the Estoril Coast area by reducing the point source pollution from the discharge of raw wastewater;
- to assist the municipalities in their effort to upgrade the municipal wastewater drainage systems.

What does the project involve?

Several options were considered when planning the new sewerage network.

1. The construction of a gravity interceptor sewer which would collect wastewater from four municipalities and transport it to the headworks located in Guia. After primary treatment, water would be discharged into the sea through a 2,750 m long outfall. Wastewater from sewers located at the lowest level would have to be pumped by the existing pumping stations, with complementary adjustments.
2. A single treatment plant in Guia, carrying out complete biological treatment. The network described in (1) would supply this plant. Treated effluent would be discharged near the coast.
3. Divide the system into two sectors. For the municipality of Cascais, the same facilities as in (1) would be built but only for local sewerage. Oieras wastewater would be treated in a second plant and discharged into the Tage estuary.
4. The construction of several treatment plants in the valleys for Oieras wastewater, which would then be discharged at various points in the Tage estuary. Option 3 would be used for Cascais.

As outlined above, the major objective of the Estoril System is to improve the quality of bathing water on the beaches. Moreover, the Estoril coast has several small hydrographic catchments that make it difficult to treat the wastewater discharged in each one. These were the main reasons for selecting the chosen solution: to carry all the wastewater away from the coast by means of an interceptor trunk sewer and to dispose of the effluent in the open ocean after suitable treatment (see Figure 1). This solution combines options 1 and 2.

The project was implemented in two phases:

Phase 1, initiated in 1994

- interceptor trunk sewer from Ribeira da Laje to Guia (Cascais) 14.6 km long;
- five pumping stations;
- wastewater treatment plant;
- sea outfall.

Phase 2, initiated in 1998

- interceptor trunk sewer from Ribeira do Jamor to Ribeira da Laje 10.2 km long;
- four pumping stations.

The gravity trunk sewer begins near the stream in the valley of Jamor with an 800 mm diameter pipe and ends near the Guia lighthouse with a 2,500 mm diameter pipe. The total length is 25 km. Of the intercepting trunk sewer 19 km were built in a tunnel and 6 km in a trench. The interceptor sewer was constructed from concrete.

Raw wastewater flows along the interceptor sewer for 25 km, hence releases of hydrogen sulphide are likely, especially on hot days. Three oxidation chambers were installed, aiming to reduce hydrogen sulphide production thus preventing the corrosion of the concrete pipe and offensive odours. Oxidation is provided by the addition of hydrogen peroxide to the wastewater. The sewer pipes are protected against corrosion with appropriate lining materials.

Figure 2 | Barcelona sewer map.

Seventeen municipal trunk sewers are tributaries of the general interceptor sewer and collect urban wastewater from the cities and towns in the area of the Estoril Coast. The trunk sewers run almost parallel to the streams for a total length of approximately 140 km. The system includes nine pumping stations that pump wastewater from lower points that are not able to have a gravity connection to the interceptor.

The preliminary treatment plant, built entirely underground, is located at Guia (Cascais). The grit chambers are designed to remove sand with diameter less than 0.2 mm. The removed grit is separated and washed to remove any organic content before disposal to landfill.

The effluent of the preliminary treatment plant is disposed of in the Atlantic Ocean by means of a 2,750 m sea outfall. The initial stretch is 950 m long, with a diameter of 1,800 mm and is made of wrought iron internally lined with mortar cement. This stretch is fixed in a trench excavated in the rocky shallow part of the sea bottom. This rigid pipe is connected to a derivation box made of wrought iron with a concrete cover where the pipe splits into two parallel branches 1,850 m long, made of HDPE, with a diameter of 1,200 mm. This flexible part of the sea outfall was ballasted with concrete pieces at 5 m intervals. The effluent is discharged into the sea by diffusers at a depth of 40 m. The diffusers in each branch are 400 m long and have 80 windows of 100 mm diameter. The diameter of the final stretch of the two branches of the sea outfall decrease to 1,000 mm and 800 mm along the last 300 m of the pipe. The distance between the diffusers of both branches ranges between 165 m and 250 m.

The design of the Estoril Coast Wastewater System was initiated in the 1970s, although construction did not commence until 1985. The first phase of the construction

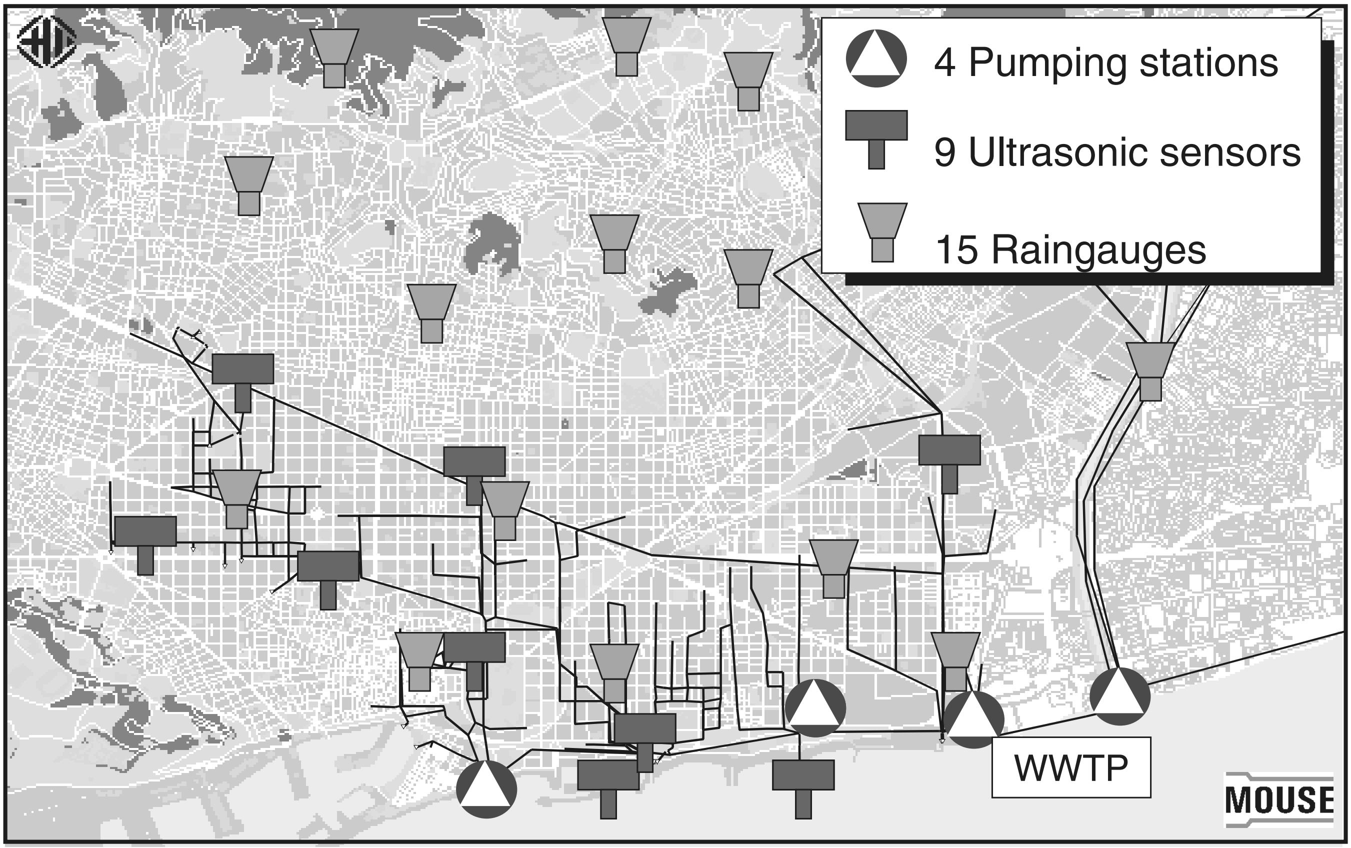


Figure 3 | SCADA and RTC in Barcelona.

begun in 1985 and finished in 1994, the second phase was completed in 1998.

The total capital cost of the Estoril Coast Wastewater System was 35 billion escudos or Euro 175 million.

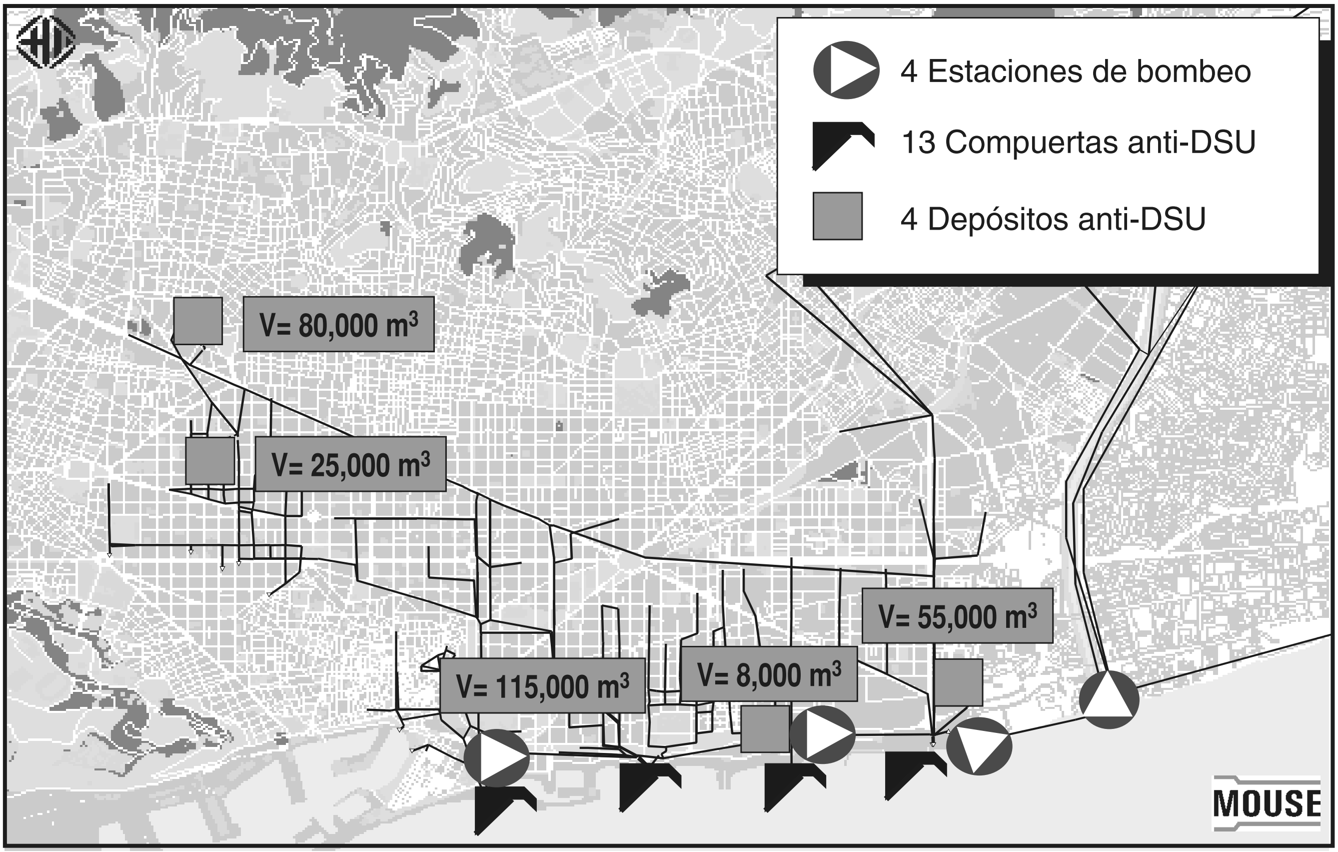
What is the environmental effect?

Before the project was fully in operation in 1994, no beaches in the area had good bathing water quality and most had faecal coliforms greater than the Imperative value. Since 1995, conditions have improved. In 1998, 95.3% of the bathing waters complied, 41.7% with the guide values, 53.6% with the Imperative values. In 1999, 76.3% complied with the guide values and only 0.7% were of unsuitable quality.

Barcelona

The Barcelona wastewater system (Figures 2 and 3) serves an area of 102 km^2. The combined network of Barcelona is 1,500 km long with 35,000 pumping stations. There are four direct discharges on 4 km of beach. The network depends on Ayuntamiento de Barcelona, Agencia Catalana del Agua. It is a popular tourist area with 8 million bathers in 1999. The population concerned is 1.5 million inhabitants. The project aims to improve the water quality of the beaches in the area and also establish the ancient port as a recreation park (Congresso Internacional GADU 2000).

Hydraulic modelling has been carried out on the study area and on the whole Besos river watershed. Some chemical parameters have been integrated into the model (e.g. ammonia). An integrated model has been



Estacion de bombeo: Pumping station
Compuertas anti-DSU: Overflow gate
Depósitos anti-DSU: Storage tank

Figure 4 | Storage capacity and overflow regulation in Barcelona.

implemented which gives information on retention time within the network and assessment of the efficiency of the UWWTP (Figures 4 and 5).

The works were implemented from 1992 to 1998. Figures 6 and 7 show the results obtained on the Barcelona coast after implementation of the project.

Venice

The Venice Lagoon has a surface area of 55,000 ha and was formed nearly 6,000 years ago. In order to preserve the lagoon and adapt it to existing needs (port, fish farms, land reclamation, transport and industry), humans have undertaken important works to achieve hydraulic regulation important over the past five centuries. This has mainly been by diverting the principal rivers from the Lagoon into the Adriatic Sea, and building numerous reclamation systems on the lower lands to use them for agricultural purposes. In the last 50 years, this has resulted in a large reduction in wetlands area and an increased pollution load to the Lagoon (Congresso Internacional GADU 2000).

The contributing catchment has a total area of 185,000 ha and includes 90 municipalities with a population of 127,000 inhabitants. The greatest challenge to be faced is to provide measures that avoid the flooding of Venice during storm surge and tidal events and to complete the cleaning plan for the Lagoon. The Lagoon is subject to adverse ‘algae bloom’ phenomena due to excessive nitrogen loads. In the last 50 years the city of Venice

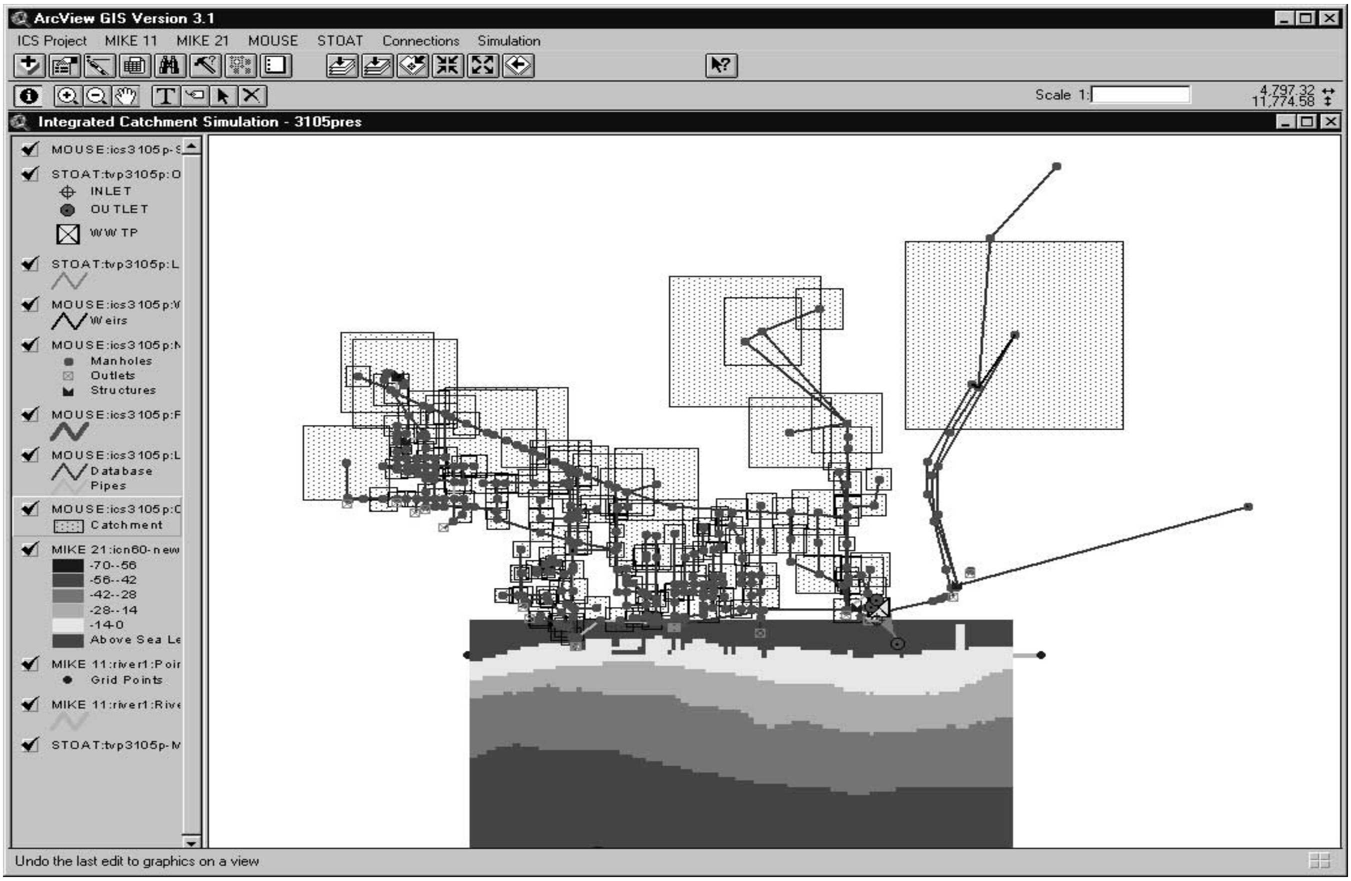


Figure 5 | Barcelona network modelling.

has subsided by 24 cm, due in part to natural sea level rise but mainly because of man-made water abstraction to meet the needs of the Fusina industrial area. In addition, the frequency of extreme tidal events (higher than 80 cm) has risen significantly through this century, varying from five high tides per year in the 1920s to the present 80 annual events.

One of the proposed solutions under assessment by the national authorities over the past 10 years is represented by the euro 2.6 billion Mose project. This would form a flexible seawall with a series of flap gates that would stretch along the Lagoon and block tides from flooding the city. The current solution to the sinking of Venice is based on the traditional dredging and cleaning of its ancient canals, combined with the upgrading and

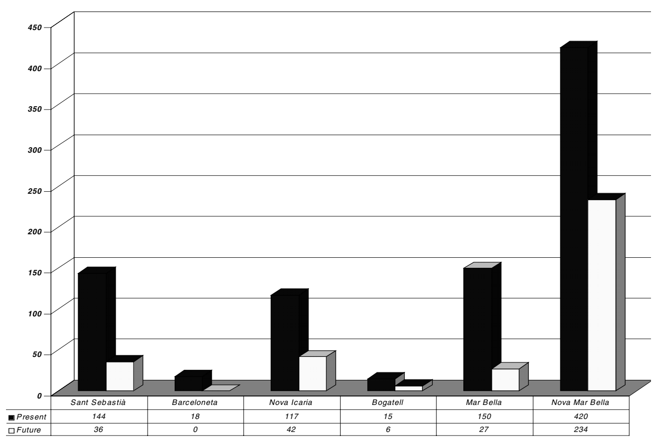


Figure 6 | Mandatory levels compliance in Barcelona (expressed in hours of implementation of imperative levels, from 1997).

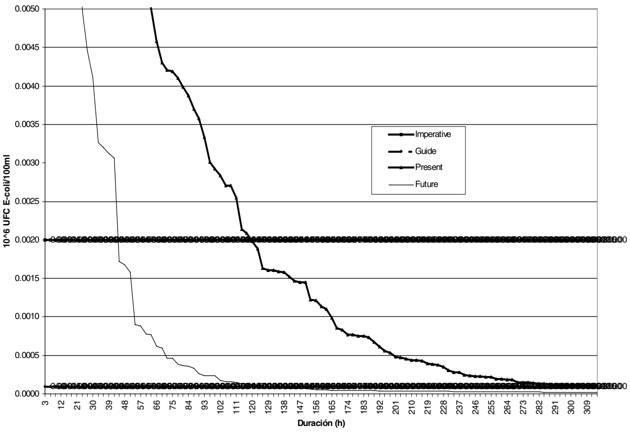
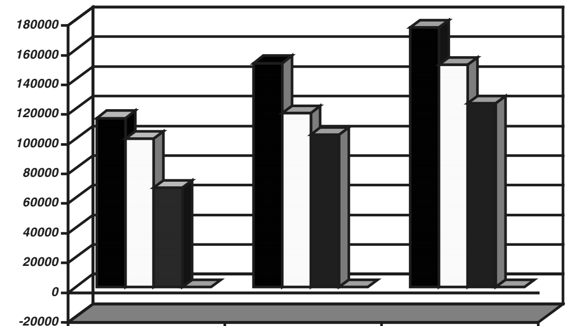


Figure 7 | Concentration/time curve for Nova Icaria beach, Barcelona (1997).



	Tr=5y	Tr=10y	Tr=20y
Present Situation	114000	151000	175000
Tanks - Local control	100000	117100	150000
Tanks - Global RTC	67000	102800	124000
reduction-Global RTC	-42%	-32%	-30%

Figure 9 | Total volume discharged into lagoon in Venice (total computed volumes, m^3).

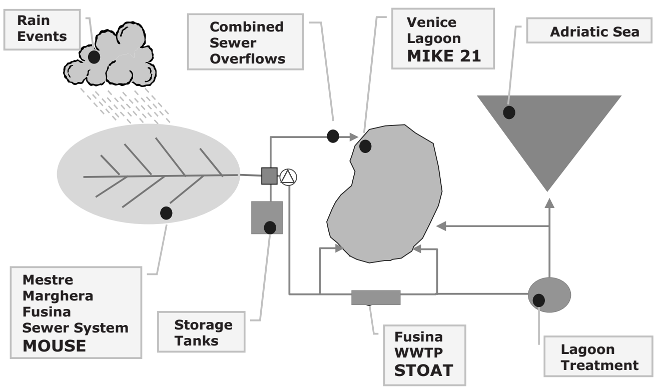
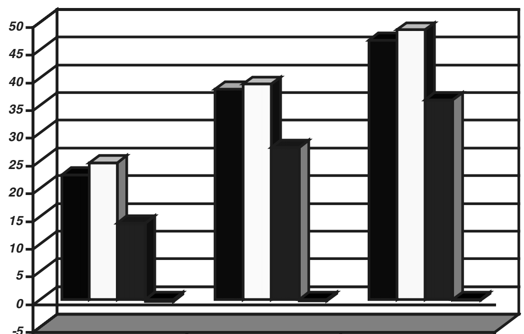


Figure 8 | Venice project schema.



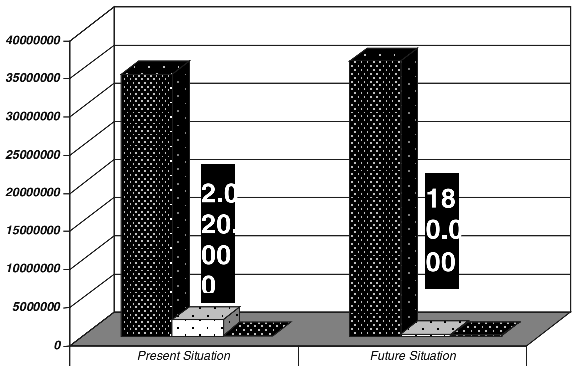
	Tr=5y	Tr=10y	Tr=20y
Present Situation	22.45	37.89	46.7
Tanks - Local control	24.58	38.82	48.61
Tanks - Global RTC	13.73	27.36	35.99
Reduction Global RTC	-39%	-28%	-23%

Figure 10 | Scenarios for flooding in Venice (total computing flooding, m^3).

renewal of its infrastructure services: sewerage, water supply, electricity, etc.

As regards the pollution status of Venice Lagoon, it is estimated that of the 9,000 tonnes of nitrogen produced each year in the basin, about 7,000 tonnes is disposed of in the receiving waters. This represents an excess of 4,000 t yr^{-1} since the tolerability limit for the Lagoon has been calculated at 3,000 t yr^{-1}. The pollution has caused heavy eutrophication due to the replacement of eelgrass on the bed of the Lagoon with green macroalgae. As a result, both the biological and physical state of the Lagoon have been affected, since the loss of eelgrass coverage has enhanced the erosive processes.

In view of the fragility of the Lagoon and the complexity of its ecosystem, an integrated simulation and control system is required in order to allow the simultaneous monitoring and regulation of the processes affecting the Lagoon. The Integrated Wastewater Project, funded under the European Commission Innovation Programme, is intended to develop this integrated solution. The three year project (started in 1997) involves six Member States of the EU and intends to provide an integrated tool formed by a calibrated model representing the real performance of the urban catchment–sewer network–WWTP and receiving Venice Lagoon. This model is to help in the assessment of engineering solutions to optimise the existing system and future works. The works began in 1997 and were completed in 2000 (Figure 8).



	Present Situation	Future Situation
WWTP Fusina	34202688	35935196
Overflows	2026991	180083
Outflow to Ext. System	25719	114400

Figure 11 | Comparison of water flows for the present and future situation by destination (distribution of sewer load in long-term simulation, m^3).

Figures 9–11 show the results expected of the project in Venice. Figure 9 shows the results of modelling of discharges into Venice Lagoon. This modelling has been performed for three periods of time (5, 10 and 20 years) under three different scenarios of implementation of the project (unchanged present situation, with storage and local control, with storage and RTC control).

Figure 10 presents modelled flooding for three periods (5, 10, 20 years) under three different scenarios of implementation of the project (unchanged present situation, with storage and local control, with storage and RTC control). Figure 11 shows the differences in overflow to the Lagoon for the present and future situation, from 2 million m^3 to 180,000.

CONCLUSION

Many engineering projects have been undertaken in Europe with the objective of maintaining or improving the quality of bathing waters (Soyupak 1994). In this study, 11 British and seven mainland Europe projects were analysed in terms of their cost, size of population served and compliance of the bathing waters with the EC Bathing Waters Directive before and after the project. Results show that bathing water quality is improved following the implementation of the schemes and particularly so if storm sewage discharges are included. The European Commission has launched a process for a thorough revision of the Bathing Waters Directive in 2001. Many European countries, including France, will have to make significant investments to ensure compliance. Countries could benefit from the experience acquired by the UK and the other countries described in this study.

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