ENVIRONMENTAL ASSESSMENT
OF
MUNICIPALITIES OF SPLIT/SOLIN, KAŠTELA/TROGIR
WASTE WATER DISPOSAL INFRASTRUCTURE PROJECT

DRAFT

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THE COUNTY OF SPLIT AND DALMATIA
ENVIRONMENTAL ASSESSMENT

OF

MUNICIPALITIES OF SPLIT/SOLIN, KASTELA/TROGIR WASTE
WATER DISPOSAL INFRASTRUCTURE PROJECT

DRAFT

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PREFACE

This document was prepared in the accordance with Contract made on the one hand, "Hrvatske vode" as the Client and, on the other hand the Consultants. Document have been prepared in accordance with terms of reference prepared by World Bank.

The Client, according to the provisions of Contract, provided all available documentation to the Consultant.

The assessment of environmental impacts was made using the available data, an estimation based on the most likely conditions prevailing at the project area and based on similar predictions at other areas previously evaluated by the Consultants.
INTRODUCTION

At the request of the Croatian Government, the World Bank and the European Bank for Reconstruction and Development, in close cooperation with HBOR, are developing the project "Municipal Environmental Infrastructure Investment Program".

The nature and size of the investment part of the project, as well as its potential environmental impacts require, according to the Croatian environmental regulations and those of the participating banks, to carrying out of an environmental assessment. The project has been ranked as category "A" for the purpose of the World Bank Operational Directive O.D. 4.01, which means that a full environmental assessment study is required before banks can approve the project for its financing.

The study area for the assessment consists of the drainage area to be serviced by the wastewater collection system; the tracts of land on which effluent to be applied in reuse systems; marine and estuarine waters which could be influenced by effluent discharge; remote sites identified for disposal of solid waste generated in the treatment process, and watershed which might be affected.

OBJECTIVES OF THE STUDY

The environmental assessment study is being developed to: (i) assess potential environmental consequences of the potential project alternatives; (ii) help guide the design of the proposed project's alternative to minimize any potential negative environmental impacts which might occur during construction and operation, and (iii) to formulate recommendations concerning measures that should be undertaken in order to maintain conditions for the protection of the marine environment in the area.

This study with its recommendations will be the basis for applying for an environmental permit from the regional authorities.
1. DESCRIPTION OF THE PROPOSED PROJECT

1.1. INTRODUCTION

This study deals with the wider area of the Kaštel Bay that covers the municipalities of Split, Solin, Kaštel and Trogir. This region represents a unique economic and territorial complex whose segments are closely bound to each other and to the city of Split as a dominating center which is why it is referred to as the region of Split. This region is situated in the central part of the Croatian littoral and the entire region belongs to the County of Split and Dalmatia (Fig. 1.1.). The city of Split is the main center of the wider area of the Kaštel Bay and also the capital of the mentioned County. Within the system of industrial centres within the Republic of Croatia Split is referred to as a category 2 centre while within the system of tourist activities it bears a category 1 title.

In the year of 1981 the region of Split had a population of 466,567. The estimated population until 2015 is approx. 530,000. In 1991 Split, Solin, Kaštel and Trogir had a population of 266,118, and the estimated population in 2015 is 355,000. This region covers an area of approx. 14,500 hectares.

It has been known for a rather long time that the area of Kaštel Bay has been one of the most polluted areas in the Adriatic. It has also been known that efforts have been made in trying to solve this problem. The problem, however occurred as a result of intensive construction and industrialization on a rather small area. Within all this, through a long period of time, the basic municipal infrastructure - sewerage system was omitted. Therefore, the solution to this problem cannot be expected so soon. This problem has become wider by scope, more complex in the technical way, and too heavy economically which are the reasons why it cannot be solved quickly and easily.

The region of Split that covers towns such as Solin, Kaštel and Trogir greatly developed and became urbanized in the post-war period. In the last forty years the population grew three times as much so that in 1953 it had about 109,000 inhabitants, presently about 300,000. Along with the increase of population, industry, traffic and trade developed as well. Split is the largest traffic, industrial, commercial and administrative centre of Dalmatia with a strong tendency of growing in the future. Unfortunately, town planning, construction and particularly industry was directed onto the area of Kaštel Bay (Fig. 1.1.) so that this rather small surface with restricted capacities is already greatly devastated and polluted.

Throughout this period, the intensive construction of residential and industrial buildings was not in relation to the construction of the sewerage infrastructure. As a result of this a greater part of this region does not have a unique and complete sewerage system. The area of Trogir, Kaštel and Solin has no sewerage system so that the greatest part of wastewater is collected in septic tanks. The wastewater is either directly or indirectly without treatment drained into the coastal sea. Regarding the sewerage system the area of the city of Split enjoys a somewhat better situation, but even here all the wastewater is either directly or indirectly drained into the coastal sea.
Fig. 1.1. The wider area of the Kafteia Bay
Such level of urban construction, concentration of traffic and industry adds to the pollution of air, land and particularly the sea as a recipient of the entire pollution of the corresponding catchment area. The unexacting necessary infrastructure increases the dangerous environmental impact up to a level where the environment could affect future development or even cause regression of the achieved level of development. It can be said of the wider area of Split that is facing an ecological crisis, because it is experiencing all levels of development and crisis impact, from pollution over negative impact to destruction. Certain environmental elements can still bear this while others are affected to such an extent that their ability to cope is reduced. Unfortunately there are also environmental elements that are destroyed to such extent that they cannot be restored. Year after year, this situation causes an increasing quantity of destroyed natural environment, simultaneously reducing the unaffected elements. It is entirely up to the inhabitants of this area whether this trend will continue in the future, and it is up to them to stop this negative trend of environmental pollution.

One of the main prerequisites for solving this problem is the construction of a sewerage system, a treatment plant and wastewater disposal plant. The topic is very complex, and the ways of solving it are rather hard and confusing. The study brings a description of the solution to the problem, a long-term concept of the sewerage system of the wider area of the Kaštela Bay, phases of its construction as well as part of the system whose construction will be financed by the World Bank and the European Bank for Reconstruction and Development.
1.2. EXISTING STATE OF SEWERAGE SYSTEM

In the studied area, the greatest part of the sewerage system was built only in Split, and approx. 70% of the population is connected onto the sewerage. Speaking in terms of surface, only 55% of the urban area of Split has its sewerage system. The total length of the sewerage system of Split is approx. 202 km. The sewerage system in Solin, Kaštel and Trogir was partly constructed, i.e. the part in the town nucleus. Approximately 25% of the population is connected onto the sewerage system. The total length of the Solin sewerage system is approx. 13 km, Kaštel - 31 km and Trogir - 16 km. Other buildings have their septic tanks.

Neither the entire area nor these towns individually have a unique sewerage system. Not even Split. The existing sewerage system was built mostly in the city nucleus, and as the city grew larger the sewerage system grew accordingly. However, the system did not increase as a unique sewerage system. It may rather be considered as separate subsystems that accumulate wastewater on a smaller area and drain it where the wastewater is drained into the coastal sea. Because of this, the area has more than several hundred of separate outfalls into the sea (Fig. 1.2). This practically means that this area has no wastewater treatment plants, neither partly mechanical ones. Of all the outfalls that were built in accordance with the professional standards, those that should be mentioned are: the Podstrana outfall, the Lav Hotel outfall, the Split airport outfall and the Medena Hotel outfall. The largest outfall in Split is the one at Katalinića brig which has not been in use in the past few years due to the malfunctioning of the pump station. The southern part of Split, i.e. the wider area of Bačvice is connected onto this outfall.

In accordance with the aforementioned it may be concluded that Split has an incomplete sewerage system while other towns practically have none at all. The sewerage system of Split is mostly a combined-type system, while only the segment built in the past ten years was built as a separate one (Fig. 1.3.). The sewerage system of Split is as old as the city itself, i.e. built before 1700 years. In the Diocletian Palace there is a unique sewerage system that remained very well preserved until the present. Presently, works are carried out so that it will be able to function properly. The sewerage system was built as the city grew larger, so that the city nucleus bears remains of cross-sections of the sewerage system, although it was not until the period between the wars that greater sewers were built.

The city saw its most intense development in the post-war years so that it may be said that a more serious construction of the sewerage system did not begin until then. Unfortunately, due to short-term economic interests and an incorrect approach to the assessment of the capacity of the coastal sea, a combined-type sewerage system was foreseen. This was common practice in the Mediterranean that foresaw outfall of part of the wastewater into the sea by means of long submarine outfalls and only partial mechanical treatment. The result of such practice was a concentration of all wastewater and rainwater in the centre of the city, i.e. at Katalinića brig, where the mechanical plant and outfall was foreseen and where the first phase of the outfall was built. All overflow water was supposed to be drained into the coastal sea, the greater part of which (approx. 60%) into the Split port, which makes 80% of the entire annual pollution.
Fig. 1.2. Submarine outfalls of the existing sewerage system
Fig. 1.3. Existing sewerage system of Split/Solin
In accordance with the aforementioned and also with the topographic characteristics of the
region, presently all the wastewater of the southern part of Split and partly the northern part is
concentrated in the city port where it is drained into the sea in the area of Vranjic. This has the
greatest affect on regular mortality of fish during the summer. As the planned sewerage system
did not foresee any plants (except partly mechanical ones) the area near the outfalls became
urbanized so that there are is no way of erecting any quality wastewater treatment plant in these
areas. Altogether this led to a very complicated situation regarding the sewerage system,
treatment plant and submarine outfalls that should be solved on a long-term basis. The present
situation could be solved in a much easier way in Solin, Kaštel and Trogir because a separate
system was partly built and because the sewerage system was not built yet. The newly
constructed one would therefore be much easier to design and it would also be less restricted by
the existing system.

Due to the situation that occurred in the past few years, sewerage systems were built very
intensively. Presently under construction are:

a) the one on the area of the city of Split; the main sewer in the city port, the corresponding
treatment plant (mechanical) and pump station, and a connection onto the existing submarine
outfall as well as the reconstruction of the existing sewerage system on that area.

b) the one on the area of the town of Solin; the main pump station Solin with corresponding
transmission mains bearing in mind that part of the main system has already been built.

c) the one on the area of the town of Kaštel; the sewerage system and pump station of the first
phase of the sewerage system that covers K. Sućurac and K. Gomilica.

As result of such situation a big quantities of pollutant have been discharged in to Kaštel bay
directly from sewerage system or indirectly by hydrological cycle or local water resources. In
accordance with result of the study /3/ total biological oxygen demand load and suspended solids
load of the Kaštel bay was:

<table>
<thead>
<tr>
<th>SOURCE (t/year)</th>
<th>BOD5</th>
<th>SUSPENDED SOLIDS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domestic water</td>
<td>2226.0</td>
<td>2431.0</td>
</tr>
<tr>
<td>Industry</td>
<td>1562.0</td>
<td>954.0</td>
</tr>
<tr>
<td>Storm water</td>
<td>984.0</td>
<td>4920.0</td>
</tr>
<tr>
<td>Air deposit</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Underground water</td>
<td>206.6</td>
<td>88.6</td>
</tr>
<tr>
<td>Surface runoff</td>
<td>27.2</td>
<td>87.4</td>
</tr>
<tr>
<td>Rivers</td>
<td>387.9</td>
<td>1419.1</td>
</tr>
<tr>
<td>TOTAL</td>
<td>5394.0</td>
<td>9900.1</td>
</tr>
</tbody>
</table>
1.3. WASTEWATER

According to the last census in 1991, the population was 266,118 while the long-term estimated population is 361,000. Table 1.1 brings the situation and plans according to specific cities.

### Table 1.1. Population and tourists in Split, Solin, Kaštel and Trogir

<table>
<thead>
<tr>
<th>Year</th>
<th>Split</th>
<th>Solin</th>
<th>Kaštel</th>
<th>Trogir</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1991</td>
<td>203870</td>
<td>17171</td>
<td>29168</td>
<td>15909</td>
<td>266118</td>
</tr>
<tr>
<td>1995</td>
<td>211100</td>
<td>20000</td>
<td>31400</td>
<td>19700</td>
<td>282200</td>
</tr>
<tr>
<td>2000</td>
<td>218000</td>
<td>23500</td>
<td>34600</td>
<td>22400</td>
<td>298500</td>
</tr>
<tr>
<td>2005</td>
<td>224000</td>
<td>27500</td>
<td>37100</td>
<td>25500</td>
<td>314100</td>
</tr>
<tr>
<td>2010</td>
<td>232000</td>
<td>32000</td>
<td>40400</td>
<td>29000</td>
<td>333400</td>
</tr>
<tr>
<td>2015</td>
<td>240000</td>
<td>38000</td>
<td>44000</td>
<td>33000</td>
<td>355000</td>
</tr>
<tr>
<td>2020</td>
<td>245000</td>
<td>41000</td>
<td>48000</td>
<td>36000</td>
<td>370000</td>
</tr>
<tr>
<td>2025</td>
<td>250000</td>
<td>43000</td>
<td>50000</td>
<td>38000</td>
<td>381000</td>
</tr>
</tbody>
</table>

### Estimated population growth (1991-2025)

<table>
<thead>
<tr>
<th>Year</th>
<th>Split</th>
<th>Solin</th>
<th>Kaštel</th>
<th>Trogir</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1991</td>
<td>4500</td>
<td>0</td>
<td>4000</td>
<td>4000</td>
<td>12500</td>
</tr>
<tr>
<td>1995</td>
<td>4000</td>
<td>0</td>
<td>5000</td>
<td>5500</td>
<td>14500</td>
</tr>
<tr>
<td>2000</td>
<td>5700</td>
<td>0</td>
<td>7600</td>
<td>7500</td>
<td>20800</td>
</tr>
<tr>
<td>2005</td>
<td>6800</td>
<td>0</td>
<td>8500</td>
<td>8300</td>
<td>23800</td>
</tr>
<tr>
<td>2010</td>
<td>8000</td>
<td>0</td>
<td>9400</td>
<td>9800</td>
<td>27200</td>
</tr>
<tr>
<td>2015</td>
<td>9500</td>
<td>0</td>
<td>10500</td>
<td>11150</td>
<td>31150</td>
</tr>
<tr>
<td>2020</td>
<td>11000</td>
<td>0</td>
<td>11500</td>
<td>12800</td>
<td>35300</td>
</tr>
<tr>
<td>2025</td>
<td>12500</td>
<td>0</td>
<td>12500</td>
<td>14500</td>
<td>39500</td>
</tr>
</tbody>
</table>

### Estimated number of tourists (1991-2025)

<table>
<thead>
<tr>
<th>Year</th>
<th>Split</th>
<th>Solin</th>
<th>Kaštel</th>
<th>Trogir</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1991</td>
<td>4500</td>
<td>0</td>
<td>4000</td>
<td>4000</td>
<td>12500</td>
</tr>
<tr>
<td>1995</td>
<td>4000</td>
<td>0</td>
<td>5000</td>
<td>5500</td>
<td>14500</td>
</tr>
<tr>
<td>2000</td>
<td>5700</td>
<td>0</td>
<td>7600</td>
<td>7500</td>
<td>20800</td>
</tr>
<tr>
<td>2005</td>
<td>6800</td>
<td>0</td>
<td>8500</td>
<td>8300</td>
<td>23800</td>
</tr>
<tr>
<td>2010</td>
<td>8000</td>
<td>0</td>
<td>9400</td>
<td>9800</td>
<td>27200</td>
</tr>
<tr>
<td>2015</td>
<td>9500</td>
<td>0</td>
<td>10500</td>
<td>11150</td>
<td>31150</td>
</tr>
<tr>
<td>2020</td>
<td>11000</td>
<td>0</td>
<td>11500</td>
<td>12800</td>
<td>35300</td>
</tr>
<tr>
<td>2025</td>
<td>12500</td>
<td>0</td>
<td>12500</td>
<td>14500</td>
<td>39500</td>
</tr>
</tbody>
</table>
Figures for the year of 2000 and up are given on the basis of the trend from the past, while figures for the year of 2015 are taken from revised urban plans of certain towns.

The total water consumption on this area is given in Table 1.2, while facts on certain industries and consumers are given in Table 1.3. Quantity of the wastewater is about 70-80% of domestic water consumption. Quantity of industrial wastewater vary depend on industry type. Estimation for 1995 on the bases of study /24/ and other data results in overall a flow of around 10600 m3/day. Only part of this quantities will be collected by sewerage system, about 8500 m3/day, because part of it will be lost (shipyard, cement industry, construction industry, etc.).

Table 1.2. Water consumption and forecast of water consumption (average flow in max. day in l/s)

<table>
<thead>
<tr>
<th>Year</th>
<th>Population (l/s)</th>
<th>Tourism (l/s)</th>
<th>Industry (l/s)</th>
<th>Agriculture (l/s)</th>
<th>Public fac. (l/s)</th>
<th>Net water demands (l/s)</th>
<th>Total demands (l/s)</th>
<th>Water losses (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1991</td>
<td>825</td>
<td>53</td>
<td>864</td>
<td>154</td>
<td>26</td>
<td>1923</td>
<td>2634</td>
<td>27</td>
</tr>
<tr>
<td>1995</td>
<td>808</td>
<td>61</td>
<td>833</td>
<td>146</td>
<td>37</td>
<td>1886</td>
<td>2583</td>
<td>27</td>
</tr>
<tr>
<td>2000</td>
<td>926</td>
<td>88</td>
<td>467</td>
<td>157</td>
<td>39</td>
<td>1677</td>
<td>2266</td>
<td>26</td>
</tr>
<tr>
<td>2005</td>
<td>999</td>
<td>100</td>
<td>467</td>
<td>160</td>
<td>41</td>
<td>1768</td>
<td>2326</td>
<td>24</td>
</tr>
<tr>
<td>2010</td>
<td>1088</td>
<td>115</td>
<td>489</td>
<td>160</td>
<td>44</td>
<td>1896</td>
<td>2431</td>
<td>22</td>
</tr>
<tr>
<td>2015</td>
<td>1191</td>
<td>132</td>
<td>515</td>
<td>160</td>
<td>46</td>
<td>2044</td>
<td>2555</td>
<td>20</td>
</tr>
<tr>
<td>2020</td>
<td>1272</td>
<td>150</td>
<td>539</td>
<td>160</td>
<td>49</td>
<td>2170</td>
<td>2679</td>
<td>19</td>
</tr>
<tr>
<td>2025</td>
<td>1347</td>
<td>167</td>
<td>563</td>
<td>160</td>
<td>51</td>
<td>2289</td>
<td>2791</td>
<td>18</td>
</tr>
</tbody>
</table>

Total water demands - SPLIT, SOLIN, KAŠTELA, TROGIR
maximum day (l/s)
In the past few years, on the area of Split, the quality of wastewater has been measured and the results of last years results are given in Table 1.4. Since this is a combined-type sewerage system the intensity of wastewater varies greatly and is affected by rainwater and infiltration water in the system. Therefore, all level of pollution and the quantity of specific materials that are introduced into the environment are calculated on the basis of expected production of waste material and not on the basis of the concentration in wastewater.

Within the system of industrial centres within the Republic of Croatia Split and his region is referred to as a category 2 centre.

Industry of the Split region is mostly located in the northern part of the community around north part of the Kaštelan bay (Vranjic basin). This region around north port in Kaštelan bay is industrial zone of the community Split, Solin and Kaštel. In this area we have general port, oil port, railway, Split shipyard, Vranjic shipworks, and most of industry. In the Trogir area the most significant industry is shipyard located in the Trogir bay.

The region of the Kaštelan bay accommodates a whole variety of industry. Some of them has strong organic wastewaters and high flow like several food and drink processing plants, including a large brewer, a winery, two soft drink plants, dairy and one big and several small slaughter house. This industry highly contribute to pollution of the Kaštelan bay because all of this industry have been discharged wastewaters into eastern part of the bay. Other industry are: metal finishing, metal construction, chemical processing, PVC factory, shipyard and shipworks, machinery production, building industry and other typical industry associated with urbanized area.

Table 1.5. brings figures on quality of industrial wastewater in accordance with a survey of industrial discharges carried out during 1990 /24/. Some of industries had appropriate wastewater treatment plant. However, due to current industrial restructuring processes, economical fluctuations, bankruptcy and liquidation of certain industries and the development of new ones, these figures are given rather as a reference and apply to industry that is foreseen to exist in the following period. Most of big industry not operate in full capacity or not operate at all. In same time small industry have been establishing. Existing states of industrial wastewaters, treatment plants and other characteristics are not known and appropriate study have to be developed in the next stage of the project.

Most of these industry from Split and Solin will significantly contribute both flow and strength organic waste water which will be biodegraded in the treatment plant, especially food and drinking processing plants. Organic load from such industry have been estimated about 89000 equivalent people. Discharges from other industry like chemical processing and metal finishing may contain materials dangerous for treatment processes or pass through treatment works and polluted the sea water at the outfall.

As it is presented in table 1.3. industrial water consumption in community Split drop from 13.262.000 in 1987 to 10.707.000 in 1995. and will continue to decline as was projected to 5.874.000 in 2010 year. Major reason for this is better water economy with industrial works.

Information about present condition is not available because changes are frequent and considerable. For example, the largest industrial plants of INA-Vinil and Adriachem in Kaštel Sucurac with around 1500 employees haven't been operating for 4 months. Frequent and considerable changes can be expected during following few years. After that period stabilization and the end of restructuring of industry can be expected. Therefore it is necessary to prepare and
conduct the program to analyze industry, circumstances and needs in reference to protection of environment and wastewater treatment plant. Because of the circumstances it is not recommended to haste with planning of secondary treatment plant because input data is subjected to frequent changes.

In order to protect the sewerage system and wastewater purification plant Directive /25/ (Chapter 2) on Trade Effluent Discharge Standards for sewerage system in communities Split, Solin and Kaštela was issued.

Today the majority of industrial wastewaters have been discharged into Kaštela bay because of its position along the coastline. Planned sewerage system will deliver industrial wastewater to wastewater treatment plant and then discharge it into Brač Channel. During the initial phase of the treatment plant development removal of solids and suspended materials will be limited. Therefore the majority of wastewater will be discharged into sea water of Brač Channel. In order to protect Brač Channel the Trade Effluent Discharge Standards should be strictly carried out and strict trade effluent monitoring controls instituted. It is also necessary to begin the process of greening of industry.

Study carried out in 1990. /24/ involving industry that existed in that period established measures that industry had to take (treatment level) in accordance with the Trade Effluent Discharge Standards in order to be connected to the sewerage system of Split/Solin area. Same measures are still valid for industry that exists today and should be strictly carried out.

Similar study hasn't been carried out for Kaštela and Trogir area. However industry is not well spread in this area or its influence on urban wastewater characteristics is insignificant (e.g. shipyard in Trogir, cement factory in Kaštel Sućurac etc.). The only factories that, if working, will have significant influence on quality of urban wastewater of the Kaštela sewerage system are INA Vinil and Adriachem situated in Kaštel Sućurac.
Table 1. Water consumption according to sectors and consumers (Ribarevča)

<table>
<thead>
<tr>
<th>Sector</th>
<th>Consumers</th>
<th>Water Consumption (m^3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industrial</td>
<td>1</td>
<td>30.12</td>
</tr>
<tr>
<td>Domestic</td>
<td>2</td>
<td>19.2</td>
</tr>
<tr>
<td>Agricultural</td>
<td>3</td>
<td>12.34</td>
</tr>
<tr>
<td>Commercial</td>
<td>4</td>
<td>8.9</td>
</tr>
</tbody>
</table>

Note: Water consumption data is reported in cubic meters (m^3).
<table>
<thead>
<tr>
<th>Year</th>
<th>JANUARY</th>
<th>FEBRUARY</th>
<th>MARCH</th>
<th>APRIL</th>
<th>MAY</th>
<th>JUNE</th>
<th>JULY</th>
<th>AUGUST</th>
<th>SEPTEMBER</th>
<th>OCTOBER</th>
<th>NOVEMBER</th>
<th>DECEMBER</th>
</tr>
</thead>
</table>

*Note: The table continues with data for subsequent years.*
Table 1.4. Characteristics of the Split wastewater

<table>
<thead>
<tr>
<th>COMPOSITION (1995)</th>
<th>LOCATION</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BANOVINA</td>
</tr>
<tr>
<td>Suspended total</td>
<td>52.65</td>
</tr>
<tr>
<td>COD</td>
<td>48.9</td>
</tr>
<tr>
<td>BOD-5</td>
<td>50.3</td>
</tr>
<tr>
<td>Total - N</td>
<td>100.0</td>
</tr>
<tr>
<td>Total - P</td>
<td>5.6</td>
</tr>
<tr>
<td>MPN 10^3 col/100ml</td>
<td>40123</td>
</tr>
<tr>
<td>Mineral oils</td>
<td>369</td>
</tr>
<tr>
<td>Anion detergents</td>
<td>1287.5</td>
</tr>
<tr>
<td>Phenol</td>
<td>1.75</td>
</tr>
<tr>
<td>Total - Hg</td>
<td>0.5</td>
</tr>
<tr>
<td>Total - Cd</td>
<td>5.8425</td>
</tr>
<tr>
<td>Mn</td>
<td>99.2</td>
</tr>
<tr>
<td>Cr</td>
<td>9.7775</td>
</tr>
<tr>
<td>Pb</td>
<td>38.15</td>
</tr>
</tbody>
</table>

| X_MIN | X_MAX | X_AVG | X_MIN | X_MAX | X_AVG | X_MIN | X_MAX | X_AVG | X_MIN | X_MAX | X_AVG |
|--------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| X_MIN | X_MAX | X_AVG | X_MIN | X_MAX | X_AVG | X_MIN | X_MAX | X_AVG | X_MIN | X_MAX | X_AVG |
Fig. 1.4. Plan of measurement stations within the sewerage system.
**Table 1.5. Industrial wastewater**

**AVERAGE VALUES FOR 1989.**

<table>
<thead>
<tr>
<th>COMPOSITION</th>
<th>KBC (Hospital)</th>
<th>Dijkom (Plastic pl.)</th>
<th>Dalmacijavino (Drink bottling)</th>
<th>Hrv. željeznic (Railway)</th>
<th>Mjekara (Diary pl.)</th>
<th>DC 10. kolovož (Cement plant)</th>
<th>Salonit (Cement-zrčast. pl.)</th>
<th>Salonacop (Slaughter house)</th>
<th>Pivovara (Brewery)</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>8.37</td>
<td>7.56</td>
<td>7.49</td>
<td>7.75</td>
<td>6.67</td>
<td>8.37</td>
<td>11.5</td>
<td>7.33</td>
<td>6.62</td>
</tr>
<tr>
<td>Suspended total</td>
<td>73.2</td>
<td>11.9</td>
<td>40.19</td>
<td>447</td>
<td>279</td>
<td>0.775</td>
<td>52</td>
<td>323</td>
<td>238</td>
</tr>
<tr>
<td>COD</td>
<td>273</td>
<td>113</td>
<td>2430</td>
<td>51</td>
<td>471</td>
<td>142.1</td>
<td>54.2</td>
<td>289</td>
<td>1983</td>
</tr>
<tr>
<td>BOD-5</td>
<td>86.9</td>
<td>28.9</td>
<td>1045</td>
<td>20.5</td>
<td>118</td>
<td>2.45</td>
<td>2.34</td>
<td>141</td>
<td>441</td>
</tr>
<tr>
<td>Total - N</td>
<td>2.95</td>
<td>3.49</td>
<td>12.4</td>
<td>13.76</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Organic - N</td>
<td>1.61</td>
<td>0.903</td>
<td>6.53</td>
<td>7.19</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NH₄-N</td>
<td>1.76</td>
<td>11.25</td>
<td>2.25</td>
<td>7.2</td>
<td>8.58</td>
<td>0.035</td>
<td></td>
<td></td>
<td>18.17</td>
</tr>
<tr>
<td>NO₂-N</td>
<td>0.03</td>
<td>0</td>
<td>0.038</td>
<td>0.001</td>
<td>0.009</td>
<td>0.204</td>
<td></td>
<td></td>
<td>0.001</td>
</tr>
<tr>
<td>NO₃-N</td>
<td>0.788</td>
<td>0.688</td>
<td>0.65</td>
<td>1.1</td>
<td>0.86</td>
<td>0.416</td>
<td></td>
<td></td>
<td>0.56</td>
</tr>
<tr>
<td>PO₄-P</td>
<td>3.45</td>
<td>0.396</td>
<td>0.396</td>
<td>8.03</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3.22</td>
</tr>
<tr>
<td>Grease</td>
<td>4.39</td>
<td>0.088</td>
<td>0.444</td>
<td>27</td>
<td>0.523</td>
<td>0.911</td>
<td>4.013</td>
<td>0.975</td>
<td></td>
</tr>
<tr>
<td>Mineral oils</td>
<td>1.38</td>
<td>0</td>
<td>0.164</td>
<td>0.696</td>
<td>0.344</td>
<td>0.294</td>
<td>2.01</td>
<td>0.241</td>
<td></td>
</tr>
<tr>
<td>Phenols</td>
<td>0.015</td>
<td>0.002</td>
<td>0.014</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.001</td>
</tr>
<tr>
<td>Detergents</td>
<td>8.3</td>
<td>0.107</td>
<td>0.188</td>
<td>0.01</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.906</td>
</tr>
<tr>
<td>MPN 10⁵. coli/100ml</td>
<td>7.8</td>
<td>23</td>
<td>33</td>
<td>6.6</td>
<td>11.6</td>
<td>0.000022</td>
<td>6700</td>
<td></td>
<td>990</td>
</tr>
</tbody>
</table>
1.4. THE SEWERAGE SYSTEM SOLUTION - CONCEPT

1.4.1. Methodology of solution selection

If wishing to exploit the coastal sea, i.e. the coast as it is foreseen, wastewater should be accumulated at several locations, treated to a certain extent and disposed into the sea far enough so that it will not affect the quality of the coastal and also open sea. Solving wastewater disposal should meet required standards and also prevent undesired long-term effects. The question is how to do it in the most useful way.

The sewerage system is always designed in accordance with certain water and sanitary standards that set the legal framework for a certain solution. Departing from the existing situation, and also taking into consideration its usage, water and sanitary conditions require that all wastewater from the area of Split, Solin, Kaštel and Trogir be disposed into the Brač Channel and the Split Channel far enough along with previous corresponding treatment that will ensure a permanent protection. This means that the Kaštel and Trogir Bay cannot be permanent recipients of wastewater from towns that surround them /2/, /3/ and /8/. With such requirements with a determined recipient, the basic prerequisites for solving the problem of sewerage system in this area have been set. The engineers were to find the best technical solution that would meet the required sanitary and environmental standards.

Choosing the location for the treatment plant was the next crucial step in solving this problem. It was desirable that the plant be close to the recipient and that the greatest part of wastewater reaches it by means of gravity. Bearing this in mind the entire area of the Brač and Split Channel would be appropriate locations for the plant. However, this coastal area is extremely valuable and is primarily intended for housing, tourism and recreation and as such is not suitable for a wastewater treatment plant. Apart from that, the greatest part of the coastal area is already populated. On the other hand the plant should be located in such a way that it takes the advantage of most of the existing sewerage system thus requiring as less reconstruction as possible. Unfortunately, as it is presently the case, all the wastewater is concentrated in the very centres of towns where there are no facilities for building wastewater treatment plants. Such situation did not provide any simple solution.

In order to reach the most suitable solution, a detailed analysis of potential locations for the treatment plant was worked out /1/. Considering the plant features (capacity, dimensions, environmental impact, necessary infrastructure etc.), the potential locations were determined. Each location was completed with corresponding technical, sanitary, town planning and other requirements on the basis of which a conceptual design of the plant was worked out. The solutions were evaluated and ranked. A conceptual design for the three most favorable locations was worked out accordingly as to make the final decision and taking into consideration the recipient, plant and outfall features and the sewerage system in general. The solutions were studied in detail bearing in mind the stipulated criteria /1/. The results obtained were presented to experts, town planners, representatives of all interested institutions, government representatives and others who were welcome to express their opinion and propose the most suitable solution. On the basis of the aforementioned the most suitable solution for the Split, Solin, Kaštel and Trogir sewerage system was chosen.

1.4.2. Sewerage system concept

On the basis of detailed analysis it have been concluded that protection of the sea environment have to be implemented by: treatment of wastewater at the sewerage treatment work, disposal of
effluent by long submarine outfall, treatment of industrial wastewater at production site and green industry.

The long-term solution for the Split, Solin, Kaštela and Trogir sewerage system foresees the construction of two separate sewerage systems, that of Split - Solin and the one of Kaštela - Trogir. (Fig. 1.5). These systems are separate-type systems. Each one would have its central wastewater treatment plant and a corresponding submarine outfall. All the wastewater from Split and Solin would be united at the central plant Stupe in Stobreč, to the north of the commercial and transport terminal (TTTS). Treated water would be drained into the sea of the Brač Channel in front of Stobreč. All the wastewater from Kaštela and Trogir would be united at the central treatment plant on the Island of Ćiovo, to the south of the village of Žedno. Treated wastewater would be drained into the Split Channel in front of Mavašćica. In order to unite all this wastewater into the treatment plants, appropriate sewerage collectors would need to be built, as well as a number of pump stations and facilities.

In order to protect the sea and performance of sewerage treatment works, treatment of industrial wastewater at the production site will be instituted. The trade effluent policy will be established and strict trade effluent monitoring controls instituted.

1.4.3. The Split - Solin sewerage system

1.4.3.1. Treatment plant and submarine outfall

Treatment plant

The crucial element of this system is the wastewater treatment plant (15). Analyses have shown that on the area of the Split peninsula there is not a suitable area where a plant of 8 hectares could be located. The Stupe site was chosen as the most favorable solution. This site is north of the TTTS and south of the city landfill Karepovac. This area is not suitable for any other purposes and it is at the same time far enough from the city and is not in collision with the purpose of the nearby land.

Hydraulic load of the plant:

<table>
<thead>
<tr>
<th></th>
<th>Qave., day</th>
<th>Qave., day-summer</th>
<th>Qmax, hour</th>
<th>Qrain</th>
</tr>
</thead>
<tbody>
<tr>
<td>m³/day</td>
<td>128736</td>
<td>161568</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>m³/hour</td>
<td>5364</td>
<td>7732</td>
<td>8352</td>
<td>15804</td>
</tr>
<tr>
<td>m³/s</td>
<td>1.49</td>
<td>1.87</td>
<td>2.32</td>
<td>4.39</td>
</tr>
</tbody>
</table>

The organic load of the plant is as follows:

<table>
<thead>
<tr>
<th>concentration</th>
<th>average load</th>
<th>summer load</th>
</tr>
</thead>
<tbody>
<tr>
<td>(mg/l)</td>
<td>(kg/day)</td>
<td>(kg/day)</td>
</tr>
<tr>
<td>BOD₅</td>
<td>235</td>
<td>30252</td>
</tr>
<tr>
<td>COD</td>
<td>470</td>
<td>60504</td>
</tr>
<tr>
<td>TS</td>
<td>280</td>
<td>36046</td>
</tr>
<tr>
<td>T-N</td>
<td>40</td>
<td>5149</td>
</tr>
<tr>
<td>T-P</td>
<td>10</td>
<td>1287</td>
</tr>
</tbody>
</table>
Long term solution of sewerage systems Split-Solin and Kaštel-Trogir

Fig. 1.5. Concept of the Split-Solin and Kaštel-Trogir sewerage system.
The size of the plant complies with Austrian and German standards and instructions A131 from ATV. It was anticipated that the works would serve a population equivalent of up to 632833, including tourists and industrial contributions. The plant was designed by the Austrian company Scieffe & Forsthuber Consulting from Salzburg in cooperation with the Faculty of Civil Engineering in Split. As the technological process, the two-stepped process with active sludge was chosen (AB process) although satisfying results may also be obtained with a single-stepped process. The process was chosen according to a complex analysis of these processes /12/. The main advantage of the two-stepped process lies in the fact that in accordance with the characteristics of the recipients the water will for a long time only need partial treatment so that the level of treatment provided by phase A of the AB process is in this case completely satisfactory.

The plant was planned in several parallel technological lines, and each line in several technological phases, i.e. treatment levels. The basic elements and construction phases of the plant are adapted to the long-term requirements of the system and are as follows:

<table>
<thead>
<tr>
<th>I phase</th>
<th>II phase</th>
<th>III phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>screens</td>
<td>B process</td>
<td>anaerobic tanks</td>
</tr>
<tr>
<td>aerated grit/grease rem.</td>
<td>settling tanks</td>
<td>sludge digestion</td>
</tr>
<tr>
<td>A process</td>
<td>sludge treatment</td>
<td>RAS process</td>
</tr>
<tr>
<td>settling tanks</td>
<td></td>
<td>P-settling</td>
</tr>
<tr>
<td>sludge treatment</td>
<td>flocculation and settling</td>
<td>disinfection</td>
</tr>
</tbody>
</table>

Efficiency of the plant and characteristics of the effluent obtained in certain phases is as follows:

<table>
<thead>
<tr>
<th></th>
<th>I phase (mg/l)</th>
<th>II phase (mg/l)</th>
<th>III phase (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOD5</td>
<td>94</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>COD</td>
<td>258</td>
<td>47</td>
<td>47</td>
</tr>
<tr>
<td>TS</td>
<td>56</td>
<td>14</td>
<td>14</td>
</tr>
<tr>
<td>TN</td>
<td>32</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>TP</td>
<td>5.5</td>
<td>4.5</td>
<td>5.5</td>
</tr>
<tr>
<td>MPN colib.</td>
<td>10x10⁶</td>
<td>99</td>
<td>99.99</td>
</tr>
</tbody>
</table>

Apart from the mentioned phases, it was foreseen for the beginning of the system construction that the plant operates only with a mechanical level of treatment, i.e. only with the screens and aerated grit/grease removal chamber. With the construction of the plant divided into phases the level of treatment would be adapted to the real needs and there would be a possibility for the third level of treatment in the future should this be necessary.
Fig. 1.6. Scheme - ground-plan of the treatment plant
As the level of treatment increases, the energy consumption increases accordingly, as well as the number of workers, chemicals consumption, required space and the quantity of waste that is separated in the plant, so that the phases are as follows:

<table>
<thead>
<tr>
<th>Phase</th>
<th>Energy (kWh/ep/year)</th>
<th>Persons (g/ep/year)</th>
<th>Chemicals (g/ep/year)</th>
<th>Space (m²)</th>
<th>Sludge (kgDM/ep/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>5</td>
<td>16</td>
<td>70</td>
<td>28000</td>
<td>29</td>
</tr>
<tr>
<td>II</td>
<td>30</td>
<td>32</td>
<td>78</td>
<td>64000</td>
<td>32</td>
</tr>
<tr>
<td>III</td>
<td>32</td>
<td>38</td>
<td>810</td>
<td>73000</td>
<td>31</td>
</tr>
</tbody>
</table>

**Submarine outfall**

In order to satisfy the characteristics of the recipient, primarily regarding the bacteriological pollution, a corresponding submarine outfall was foreseen for each construction phase of the plant. Together with the treatment plant it would operate as a unique system plant - outfall. With regard to this, there will be two submarine outfalls in the final phase of realizing the treatment plant. One of them would be rather long as a result of a phase-by-phase construction and a shorter one depending on the final condition.

At the beginning, the mechanical treatment would require a submarine outfall 3230 m long, with a 400 m long diffuser. Depth at the point of disposal is 42 m. The diameter of the outfall is 1400 mm. Initial dilution will be 250 and secondary 35.

As for the complete biological treatment of wastewater, the shorter outfall can be 931 m long, with a 400 m long diffuser. Depth at the point of disposal is 32 m. The outfall diameter should be 1340 mm. Initial dilution will be 175 and secondary 6.

In the first time period when treatment work will work with ca 50% capacity shorter submarine outfall can be built. In this case total length of outfall will be 2600 m with a 400 m long diffuser. The outfall diameter should be at shallow water in Stobreć bay (956 m) 1000 mm while out of by 700 mm. Depth at the point of disposal is 36.65 m. Initial dilution will be 350 and secondary 34.

The land part begins at the outlet and inlet chamber next to the treatment plant (Fig.17). Accepted route of the land part follows the transport terminal plateau, the access road to the terminal, crossing the access road in the south after the railing of the terminal. The route follows the access road as far as to the Adriatic highway, goes along it and Žrnovnica river estuary, crosses the highway toward Stobrec camp. The submarine part begins at the Stobrec camp, crosses the Stobrec bay in the direction of Brac Island.

The outfall route has a slight fall from the waste water treatment plant to the beginning of the submarine part and even further. Even though this fall is not necessary since the outfall is operated under pressure, depth difference makes possible emptying of the pipeline at a single point as well as collecting of the water after rinsing. The altitude of the land part takes the advantage of natural characteristics of the area, for the most part it requires digging for protection. The submarine part is raised at such an altitude to provide a fall towards the outlet end, Fig 1.8.
The diffuser is located at the end of the submarine part, whereas deaeration manhole is at the end of the land part (or the beginning of the submarine part). Location of diffuser depends on stage of realization of the system (quantity of water and level of treatment, or rate at which the sewerage system is realized). Locations for I phase and final phase is given on Fig. 1.9.

Solid wastes from treatment plant

The solid wastes associated with the operation of the treatment plant will consist of: screenings, grease, oil, grit, sand and biosolids sludge. Screenings will be wash, dewatered and compacted before transport to the landfill site or incinerate on-site. Oil and grease will be burn on small incinerator in first time period and later will be dispose to the digester. Grit and sand after passing through fine screens will be suitable for disposal to landfill or can be used for landscaping purposes. Stabilized biosolids from the treatment plant will be stabilized by anaerobic digestion and dewatered. Sludge will have a long term stability and will be suitable for agricultural or horticultural purposes. Total quantity of sludge which will be produced at the works depend of inflow quantities of waste water and treatment level. In accordance with total capacity of the treatment plant daily quantities of the sludge production can be ca 55 t/day.
<table>
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<tr>
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<td>1000</td>
<td>1000</td>
</tr>
</tbody>
</table>

**Fig. 1.8. Longitudinal section of the submarine outfall "Stobreč" - I phase**

24
Fig. 1.9. Location of the diffuser "Stobret" - I phase
In the first time period (15-20 years) treatment plant will work probably with 50% capacity. Initial wastewater flows will be lower than 50% and will depend on development of sewerage system. Increase capacity of the works will be necessary when wastewater from Katalinic Brig (existing submarine outfall) will be transferred to the central treatment plant.

1.4.3.2. Sewerage system of Split and Solin

In order to bring all the wastewater to the plant, large sewerage collectors and pump stations should be built. As already said the existing Split sewerage system collects all the wastewater in the city port and the Sjeverna luka (commercial harbour), 4 km from the site of the future plant. In order to connect the northern Split area (Dujmovac) and the town of Solin onto the central plant, a hydrotechnical tunnel approx. 2.4 km long should be built beneath Karepovac which would transfer all the wastewater of the northern Split area and Solin onto the southern area of the Split peninsula. Fig. 1.5, Fig. 1.10.

Such tunnel would be necessary for the improvement of Kaštela Bay because of its environmental significance for the protection of the Bay. Approximately 80% of organic pollution that reaches Kaštela Bay comes from the northern Split area and the town of Solin so that if transferred into the Brač Channel, the pollution of Kaštela Bay would considerably be reduced. Several pump stations would be required for connecting the southern Split area onto the central plant. Fig. 1.10. The southern Split area does have a sewerage system by means of which the wastewater is concentrated in the Split port. Two collectors - the one at Bašvice and the other along the railroad onto which the collector in the Domovinskog rata St. is connected, form a complex scheme of the Split sewerage system by which the wastewater is collected in the city port. All other zones at higher elevations are connected onto the aforementioned collectors by gravitation, while the zones at lower elevations are pumped by means of a number of pump stations. However, the direction of all the wastewater should be changed into the opposite direction (southwards) and brought to the Stupe plant. In order to rationalize the costs of repumping part of the system will be altered from a combined to a separate one, and the whole new system will be built as a separate system in which the transmission mains will be directed towards the wastewater treatment plant.

Improvement costs of the existing system and bringing all the wastewater onto the central plant will be very high, and the construction of the system would last rather long even in the event should the financial means be provided (over ten years). Operation costs would also be very high due to often repumping of wastewater.

Basic concept of the proposed sewerage system design

The sewerage system covers the Split/Solin area in accordance with the General urbanistic plan (GUP). Wastewaters of this area (industrial wastewater as well as domestic wastewater) are collected by a system of canals and pumping stations and delivered to the wastewater treatment plant situated in Stupe area. Purified water is then disposed into the Brač Channel through submarine outfall situated in Stobreč, Fig. 1.10.
Fig. 1.10. Sewerage system Split/Solin
The sewerage system is partially combined but mostly separate sewerage system. A combined sewerage system covers the area of already existing combined sewerage system. It will be still in use but the tendency is to eliminate it in the future. Combined sewerage system covers the major area of already existing sewerage system of Split Peninsula. That is the sewerage system that tends toward city port with the trunk sewer alongside the railroad, trunk sewer Šetalište Bačvice and a series of smaller trunk sewers situated in old part of the town as well as a part of already existing sewerage system that tends toward Vranjic basin. Higher zones are covered with combined sewerage system while coastal areas will be covered with separate sewerage system no matter if it already exists or it is only proposed. The rest of the area will be covered with separate sewerage system.

A storm water will be disposed into coastal sea area on certain locations, directly or indirectly, by means of existing springs and torrents. In the combined sewerage system storm water will be disposed into the sea at initial ratio of sanitary sewer and storm water of 1:3. An outfall position (depth and distance from the shore) should satisfy the required sea standards at each outfall site.

Considering the topography and urbanisation of the area as well as the location of the wastewater treatment plant, the entire sewerage system can be divided into few separate catchment areas, Fig. 1.10. They are: the South catchment area, the Dujmovača catchment area, the Solin catchment area and the Stobreč catchment area. A construction of series of smaller and bigger pumping stations, trunk sewers and other structures is planned in order to conduct wastewater to a singular wastewater treatment plant.

The South catchment area covers the area of Split Peninsula from Žnjan in the south then following the peninsula watershed to Domovinskog rata street in the north and a shipyard in the west. Wastewaters of this area are delivered to the central pumping station of this catchment area PS Katalinića Brig. Its dry weather capacity is 2,097 m³/s while its rain weather capacity is 9,24 m³/s. This pumping station is situated on the hill Katalinića Brig nearby existing submarine outfall. The purpose of this pumping station is to pump wastewater from the South catchment area to the central wastewater treatment plant Stupe. Three main trunk sewers of the South catchment area are connected to this pumping station. They are: the city port trunk sewer, trunk sewer alongside the railroad and trunk sewer from Šetalište Bačvice street. Second biggest pumping station is PS Žnjan. Its capacity is 2,1 m³/s. It is a pumping station situated on rising main of the pumping station Katalinića Brig.

The Dujmovača catchment area covers the area of Dujmovača: in the north following the line of Mravinački potok to existing Jadranska cesta and than following river Jadro to the sea; in the south following the peninsula watershed to the Pujanke district; in the west Pujanke district and the area below Domovinskog rata street to the shipyard. Wastewaters of the area above existing Jadranska cesta are delivered by gravity to the collecting chamber of the tunnel from where wastewater drains by gravity to the wastewater treatment plant Stupe. Wastewaters of the area below existing Jadranska cesta are delivered to the main pumping station Dujmovača situated west from the crossroads Solinska cesta and Put mostina. This pumping station pumps wastewater to the collecting chamber of the tunnel from where wastewater drains by gravity to the wastewater treatment plant Stupe. Dry weather capacity of Dujmovača pumping station is 0,630 m³/s while its rain weather capacity is 0,963 m³/s.

The Solin catchment area covers the area of town of Solin; in the south to Mravinački potok and in the west to the boundary of Kaštel county. Its north boundary is formed by suburban districts. It also includes wastewater coming from solinska zagora (area over the mountain). Wastewater...
of this area is delivered to the pumping station Solin. Wastewater is then pumped to the trunk sewer situated above existing Jadranska cesta and then to the collecting chamber of the tunnel. Dry weather capacity of this pumping station is 0.650 m³/s.

Wastewater of Dujmovca and Solin catchment area is delivered to the collecting chamber of Stupe tunnel from where it drains by gravity to the wastewater treatment plant Stupe.

The Stobreč catchment area covers the rest, mainly south, area of city of Split. Wastewater of this area is partially by gravity and partially by means of pumping stations drained to the main wastewater treatment plant. The biggest pumping station of this area is the pumping station Šibe. Its dry weather capacity is 0.188 m³/s while its rain weather capacity is 0.240 m³/s.

It can be observed that capital structures of the sewage system are: the wastewater treatment plant Stupe and its submarine outfall, tunnel Stupe, the wastewater treatment plant Katalinica brig and its outfalls, main pumping stations: Katalinica brig, Žnjan, Solin-Japirko, Dujmovca, Šine and main trunk sewers of several catchment areas.

Interim solution of the first phase of the sewerage system construction will be the wastewater treatment plant Katalinica brig and its outlet.

Hydrotechnical tunnel “Stupe”

In order to connect wastewater of the town of Solin area and wastewater of northern part of Split (Dujmovca, Ravne Njive, Pujanke and other) with a common wastewater treatment plant situated in Stobreč area, construction of the hydrotechnical tunnel between Duje and Stobreč (TTTS) is planned, Fig. 1.10. and Fig. 1.11.

Hydrotechnical tunnel is chosen as the most acceptable technical and long term economic solution. A major part of water catchment area of northern and southern part of Split as well as part of the town of Solin area can be delivered by gravity to the wastewater treatment plant. Pumping height of lower zones is considerably decreased as well as the cost of works.

Tunnel is 2436 m long. Its cross section is 15.39 m². The elevation of tunnel entrance is 14.36 m above sea level while the elevation of tunnel exit is 11.93 m above sea level. Two sewer pipes of 1300 mm diameter are situated in the tunnel. Tunnel is big enough to lay other infrastructure (electricity, telephone) out of which the most important is water supply system that connects northern part of Split and Solin area with planned water intake situated at Žrnovnica well. Total volume of excavated material is 38500 m³.

1.4.3.3. Characteristics of the wastewater treatment plant site

Microloctational characteristics of the wastewater treatment plant site in reference to the entire area

Considering the city organisation and development, the most appropriate wastewater treatment plant location would be the north side of Split peninsula. It is the area intended for small businesses. It is obvious that the basic ecological requirements for every urban location must be fulfilled. Elevation (10-15 m above sea level) and partially built operational area are the limitations. Therefore the only suitable location will be the one situated north from the planned railroad junction Solin-TTTS, Fig. 1.12.
Fig. 1.11. Longitudinal section of the tunnel-plant-outfall system; Split - Solin sewerage system.
Fig. 1.12. Location of the treatment plant "Stupe"
Location is situated in the far north of the Commercial-Transport Terminal area, in the foothill of Mosor, between proposed railroad junction Solin-TITS in the south and proposed highway Split-Zagreb in the north. The area is 8.4 hectares. Ground surface elevation is mainly 15.0 m above sea level. According to the General urbanistic plan (GUP) one part of this area is planned to be used for transportation activities. The other part of the area is situated in the corridor of Split-Zagreb highway. A solid waste dump Karepovac is situated approx. 550 m to the west.

The Split-Zagreb highway corridor is still not defined because its route is moved beyond Mosor (according to the Area plan of the Split Municipality - adopted in 1982).

A residential area of low density is planned north from the highway corridor. A small number of residential buildings is already constructed north-east from the wastewater treatment plant location. Significant forest zone is also situated in this area. A Commercial-Transport Terminal contents are situated south from the wastewater treatment plant location, Photograph 1.

Considering the purpose of the area: large traffic areas, solid waste dump, forests (Mosor hillsides), the collision between proposed wastewater treatment plant location and proposed purpose of the surrounding area is the smallest.

Site location in reference to the city infrastructure

Traffic

A track and a switching yard of TTTS-Solin railway junction are planned in the south of Stupe-TTTS site. A proposed highway corridor is situated north from the plant complex.

Water supply system

Water supply of Stupe-TTTS area is planned from the water supply system of Žrnovnica well that delivers water of the entire area south of Korešnica by gravity.

Electricity supply system

According to the General Urabanistic Plan (GUP) TS 110/35 kV “Meterize”, TS “Sućidar” and TS 110/35 kV “Centar” will be connected to the main city transformer station TS 220/100 kV “Vrboran”. TS “Vrboran” is connected to the main transformer station 380/22/110 kV situated in Konjsko. TS 110/10 “Split-3” was built to supply the middle part of Split peninsula. Transformer stations: 110/10 kV “Split-4” and 110/35 kV “Split-5 - Korešnica” will be built to supply the area of Stobreč. Stupe-TTTS site will be supplied with electrical energy from planned TS 110/35 kV Korešnica.

Telecommunication system

The main telephone exchange situated in Split covers the area of middle Dalmatian municipalities. According to GUP telephone network of the Split area contains: transit and main telephone exchange Split, centre ATC Kaštel and seven district TS telephone exchanges situated in following city areas: Split Centre, Sućidar, Visoka, Sirobuja, Stobreč, Mravinci and Solin.

Stupe-TTTS site will be connected to ATC Split (Sirobuja).
Proposed Site

Photograph 1. Location of the wastewater treatment plant "Stupe"
Microlocation characteristics of the site and usage conditions

Layout and available area

Treatment plant site is situated in far north of the Stobreč field. Available area is 8,4 ha. Ground surface elevation is approx. 15,0 m above sea level in the east. Ground level elevates toward west. This site is relatively favourable in reference to the planned facilities of the surrounding area. The distance between wastewater treatment plant and TTTS operational area is approx. 100 m. The distance between wastewater treatment plant and planned residential area of low density is approx. 120 m.

According to the conceptual design of TTTS (Civil Eng. Institute, Split) it is necessary to move the switching yard building south from railroad-junction. It is possible to place it as a part of central boiler group building complex.

Lithographic, engineering geological and hydrogeological characteristics of the area

Surface area is made of prolluvial sediments (youngest Quarternary sediments Qpr), composed of silty-clay material with some gravel. Eocenic flisch (E2,3) mostly built of marls was deposited under prolluvial sediments.

Prolluvial sediments are poorly compacted and heterogeneous. Limestones are degraded but as the depth increases they have better physical and mechanical characteristics.

Silty-clay material with some gravel has intergranular porosity; it is hydrogeological collector. These sediments are saturated. Water table was observed immediately under the ground surface. Marls form impermeable base. Drainage must be well designed in order to secure functionality of the structure. Foundations must be built on marl base.

According to the Seismic map of Croatia, this area is situated in the zone where maximum earthquake intensity of 7°MCS for recurrent period of 200 years is expected.

If shallow foundations are built on prolluvial sediments higher level of seismic risk should be taken into account because of soil composition and high underground water level.

General hydrological characteristics

Civil Engineering Institute, Faculty of Civil Engineering, Split produced hydrogeological base plans and detailed design for regulation of one part of water courses Bekavac and Vrbovik (according to “General solution of drainage and stream regulation of TTTS area” and general design “Regulation of water courses Bekavac and Vrbovik” produced in 1981. and 1987). Regulation wasn’t done till today.

The same principle should be used for regulation of the upper part of stream Bekavac and one of its tributaries. It must be done because they either intercept or are situated near the wastewater treatment plant site.

Microclimate characteristics

General climate characteristics are given in the begging of the Study (General plan of Split 1978.). It will be possible to define microclimate characteristics of the area after one year measurements and monitoring. This must be done in the next design phase. Climate elements are very important factors in wastewater treatment plant design.

Existing and planned infrastructure

Traffic

Existing traffic infrastructure consists of partially built TTTS with traffic routs and junction road to Jadranaka cesta (MC-2) at Stobreč area. Water purification plant complex can be connected
with urban transportation network through previously mentioned access road for TTTS and further with separate access road that passes under the planned track. This road is 7,0 m wide. Parking lot of 224P/M capacity is planned in the east of the complex.

If a new urban freeway is built within the highway corridor (route placed behind Kozjak), plant complex should be accessed from it.

**Water supply**

Existing pipe line of 500 mm diameter coming out of reservoir Visoka I is situated north from Jadranška cesta. Another pipe line of 300 mm diameter is buried in TTTS access road.

Commercial-Transport Terminal Split (TTTS) as well as the wastewater treatment plant site will be connected to existing pipe line during the first phase. As the ultimate solution they will be connected to Žrnovnica water supply system.

**Electricity**

Electricity facilities and installations are not present in this area. Therefore, according to the project, wastewater treatment plant will be connected to TS 110/10 Korešnica.

If wastewater treatment plant is built before TS 110/10 Korešnica it should be connected to existing TS 35/10 Miljevac with 10 kV cable extending from TS 10/0,4 at the plant site, following the TTTS road to TS Miljevac.

**Telecommunications**

Telecommunication facilities are not present in this area. Therefore it is necessary to lay 50-pair cable between wastewater treatment plant site and planned ATC Split-4.

**Spatial disposition of the site and use of the area**

Taking into consideration the site position in larger urban area as well as purpose of the surrounding area (operational area, highway corridor that is still not defined) limitation factors of this site for wastewater treatment plant construction are the least.

It is necessary to cover preliminary physical treatment objects (racks and possibly sand traps, grease traps and primary sedimentation tanks).

There are no special requirements concerning building outlines. Administration building should be placed in the east facing existing residential zone. Access road passes through the tunnel under planned track. Surrounding area should be planted out of security and aesthetic reasons. It is also possible to build all necessary installations. Railroad junction can also be used.

**1.4.4. The Kašte - Trogir sewerage system**

1.4.4.1. Treatment plant and submarine outfall

As already mentioned the central plant of this system is located on the Čiovo Island, at the site south of Žedno (Photograph 2.) This site is visually remote from the coastal part and is naturally well protected by a depression so that its location cannot affect the coastal sea. This site that is rather close to the sea of the Split Channel (400 m) is practically the only area of minor importance where the treatment plant could be located according to the long-term needs of Kašte and Trogir. Collecting the wastewater from Kašte and Trogir at this particular site is the most suitable solution in the environmental, economic and technical point of view /147/ and /5/.
Photograph 2. Location of the wastewater treatment plant "Človo"
The greatest disadvantage of this location is the same as for Split - it is rather far from present locations for collecting the wastewater in Kaštela and Trogir and the need for building a tunnel through the Čiovo Island because the wastewater needs to be transferred from Kaštela and Trogir into the Split Channel. The situation here is, though somewhat more simple because there is not a significant sewerage system in this area so that the problem should be approached from the very beginning.

The wastewater treatment plant has the same characteristics as the one in Split, but its capacity is much smaller. It was anticipated that the works would serve a population equivalent of up to 150000, including tourists and industrial contributions.

The hydraulic load of the plant is:

<table>
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Mechanical wastewater treatment would require a 2400 m long submarine outfall, and a 400 m long diffuser. The outfall would be at a depth of 52 m and the outfall diameter 900 mm. Initial dilution will be 705. Biological wastewater treatment would require a 650 m long submarine outfall, and a 400 m long diffuser.

In the first time period when treatment work will work with ca 50% capacity shorter and smaller submarine outfall can be built. In this case total length of outfall will be 2050 m with a 400 m long diffuser. The outfall diameter should be 500 mm. Depth at the point of disposal is 52 m. Initial dilution will be 394.

The outfall route has a slight fall from the waste water treatment plant to the beginning of the submarine part and even further. Even though this fall is not necessary since the outfall is operated under pressure, depth difference makes possible emptying of the pipeline at a single point as well as collecting of the water after rinsing. The altitude of the land part takes the advantage of natural characteristics of the area, for the most part it requires digging for protection. The submarine part is raised at such an altitude to provide a fall towards the outlet end, Fig 1.13.

The diffuser is located at the end of the submarine part, whereas deaeration manhole is at the end of the land part (or the beginning of the submarine part). Location of diffuser depends on stage of realization of the system (quantity of water and level of treatment, or rate at which the sewerage system is realized). Locations for I phase and final phase is given on Fig. 1.14.
Fig. 1.13. Longitudinal section of the submarine outfall "Čiovo" - 1 phase
Fig. 1.14. Location of the diffuser Čižovo - 1 phase
The solid wastes associated with the operation of the treatment plant will consist of: screenings, grease, oil, grit, sand and biosolids sludge. Screenings will be wash, dewatered and compacted before transport to the landfill site or incinerate on-site. Oil and grease will be burn on small incinerator in first time period and later will be dispose to the digester. Grit and sand after passing through fine screens will be suitable for disposal to landfill or can be used for landscaping purposes. Stabilized biosolids from the treatment plant will be stabilized by anaerobic digestion and dewatered. Sludge will have a long term stability and will be suitable for agricultural or horticultural purposes. Total quantity of sludge which will be produced at the works depend of inflow quantities of waste water and treatment level. In accordance with total capacity of the treatment plant daily quantities of the sludge production can be ca 21 t/day.

In the first time period (10-15 years) treatment plant will work probably with 50 % capacity. Initial wastewater flows will be lower than 50% and will depend on development of sewerage system.

1.4.4.2 Sewerage system of Kaštela

The sewerage system for Kaštela would be rather easy to solve. The greatest part of wastewater of this area (approx. 70%) is collected by gravity by the main collector which is located in the old Kaštela road, i.e. the entire area above this collector. The wastewater from the area between this collector and the sea is transferred onto the main collector by means of a number of pump stations. At the end of the main collector is the main pump station that will transfer all the wastewater from the Kaštela area into the tunnel on the Čiovo Island and through the tunnel bring it to the treatment plant. The wastewater from the plant is by gravity drained into the sea by means of submarine outfall.

The sewerage system covers the area of the town of Kaštela in accordance with the General urbanistic plan (GUP). It is the separate sewerage system. Wastewater is by means of a special sewer network delivered to the wastewater treatment plant. A storm water will be disposed into the coastal sea area on certain locations directly or indirectly by means of existing springs and torrents.

Considering the topography and proposed urbanisation of the area as well as the location of the wastewater treatment plant, the entire sewerage system can be divided into few separate catchment areas, Fig. 1.15. They are: the area above Kaštelanica cesta that can be connected by gravity with the wastewater treatment plant and the area below Kaštelanica cesta that is by means of several pumping stations connected to the trunk sewer situated in Kaštelanica cesta. A wastewater is conducted through a main trunk sewer situated in Kaštelanica cesta to the wastewater treatment plant situated on Čiovo Island. Every pumping station forms a separate smaller catchment area. Several pumping stations connected in series form a bigger sewerage system that is connected to a main trunk sewer situated in Kaštelanica cesta.

Larger pumping stations are: P.S. Gomilica II of 114.4 l/s capacity, P.S. Lukšić II of 48.8 l/s capacity and several others.
Fig. 1.15. Sewerage system of Kaštela
The biggest pumping stations of ultimate phase are: P.S. Jadro of 370 l/s capacity and P.S. Pantana-Divulje of 421 l/s capacity that partially collects wastewaters of Trogir. The pressure pipeline of P.S. Pantana-Divulje is 1600 m long. It connects wastewater of Kaštela with wastewater of Trogir at the entrance of the Ciovo tunnel, Fig. 1.5. This pipeline is situated mostly under the water in Kaštela Bay. In case of final phase construction it is necessary to construct hydrotechnical tunnel through Ciovo of 1900 m length as well as one part of the Ciovo Island sewerage system.

It can be observed that the capital structures of the final solution of the sewage system are: the wastewater treatment plant Ciovo and its submarine outfall, Ciovo tunnel, main pumping stations: P.S. Jadro of 370 l/s capacity and P.S. Pantana-Divulje of 421 l/s capacity and its submarine rising main and the main trunk sewer situated in Kaštelska cesta.

1.4.4.3. Sewerage system of Trogir

The concept for the Trogir sewerage system is similar, except that there are three main sewerage systems: the land sewerage system, the Ciovo Island sewerage system and the sewerage system of the old part of the town located on a small island between the mainland and the Ciovo Island. The land sewerage system of Trogir is mostly by gravity united onto one pump station by means of which it is transferred to the Ciovo tunnel. Zones at lower elevations are repumped into main collecting sewers. The wastewater from the northern area of the Ciovo Island is by means of a number of pump stations transferred into the Ciovo tunnel, while the wastewater from the southern and western part of the island are united on the western part of the island at the wastewater treatment plant. Wastewater from the old part of the town is connected with the land system. (Fig. 1.16.)

Planned sewerage system of Trogir is separate sewerage system. Wastewater is delivered to the wastewater treatment plant situated on Ciovo island through single sewerage system. A storm water is delivered through separate storm sewerage network to the sea. It is then disposed into the sea in accordance with the local requirements.

The wastewater sewerage system network consists of three main catchment areas: the land catchment area and sewerage system, the Ciovo catchment area and sewerage system, and old part of the town (small island) catchment area and sewerage system. The sewerage system of each catchment area consists of several smaller catchment areas. Each smaller catchment area is formed by a pumping station that delivers water to the central wastewater treatment plant situated on Ciovo island, Fig 1.16. Total number of required pumping stations is more than 16.

The coastal sewerage system consists of 7 pumping stations. The biggest ones are: Lokvice (Q=283 l/s, H=24 m, P=111 kW) and Medena (Q=134 l/s, H=24 m, P=53 kW). The main pumping station of this part of a sewerage system is pumping station Lokvice that pumps wastewater from the land over the bay to the hydrotechnical tunnel Ciovo.

Sewerage system of the old part of the town consists of a single catchment area formed by pumping station “Stari grad” that pumps wastewater to the sewerage system of the coastal area.
Fig. 1.16. Sewerage system of Trogir
Sewage system of Čiovo island consists of 9 pumping stations. The biggest ones are: Čiovo (Q=25 l/s, H=25 m, P=15 kW), M. Draga (Q=43 l/s, H=8 m, P=6 kW) and Okrug G (Q=144 l/s, H=30 m, P=71 kW). Pumping stations of northern part of the island: Čiovo, Miševac and Arbanija pump wastewater to the north entrance of the tunnel. Pumping stations of the west side of the island: M. Draga, Okrug G., Okrug D. and Okrug D.-Recetinovac pump wastewater to the south side of the island into trunk sewer of the wastewater treatment plant. Pumping stations Fumija and Mavarštica are situated in the south of the island.

Sewage system of Trogir is very complex and expensive as it can be observed from its description.

Sewage system of Trogir is designed on a study level. Only central part of the town and part of the main trunk sewer of the land catchment area are designed on a higher level.

1.4.4.4. Hydrotechnical tunnel Čiovo

In order to connect wastewater of the Kaštela area and major part of Trogir (northern part of Čiovo island and land part of the city of Trogir) with the common wastewater treatment plant situated in the southern part of Čiovo island, a construction of hydrotechnical tunnel through Čiovo island is planned, Fig. 1.16. and Fig. 1.17.

Hydrotechnical tunnel was chosen as the most acceptable technical and long term economic solution. Construction of this tunnel decreases the cost of pumping. Construction of a very expensive trunk sewer through Saldun Bay is also avoided.

Tunnel is 1851 m long. Its cross section is 10,52 m². The elevation of tunnel entrance is 17,0 m above sea level. The tunnel exit is situated in the south of Čiovo island, and its elevation is 15,0 m above sea level. One sewer pipe of 1000 mm diameter is situated in the tunnel. The tunnel is big enough to lay other infrastructure (electricity, water, telephone). Total volume of excavated material is 20500 m³. Material is mostly limestone.

1.4.4.5. Characteristics of the wastewater treatment plant site

Conceptual design of the sewerage system of Kaštela anticipated two construction phases; the construction of wastewater treatment plant near the airport as transition phase and the construction of wastewater treatment plant on Čiovo island as the ultimate phase. The environmental study will treat Čiovo plant because only ultimate works will be performed.

Microlocaotional characteristics of the site in reference to the entire area

The wastewater treatment plant Čiovo is a common plant for sewerage systems of Kaštela and Trogir. It is situated in the south of Čiovo island in the middle of the valley that extends from village Žedno to Mavarštica Bay, Fig. 1.18. This valley is not residential area or intended for any other activity. Therefore as a less valuable area it was left to be the “green” area. Site situated in the middle of the valley is far away from the coast (more than 800 m), inaccessible, closed and it can’t be seen from surrounding urbanised area. The wastewater treatment plant is situated far away from the town centre, residential areas of Trogir and main infrastructure facilities and close by the holiday village Mavarštica. Therefore it is the best site for the wastewater treatment plant.
Fig. 1.17. Longitudinal section of the tunnel-plant-outfall system; Kaštel-Trogir sewerage system
Fig. 1.18. Location of the treatment plant "Čiovo"
The sewerage system Kaštela and Trogir study (Faculty of Civil Engineering, 1990) analysed several sites. Site situated in Kaštela Bay and Trogir Bay as long term common solution wasn’t accepted because it is very valuable and attractive area. According to water management authorities Split Channel that is situated across from Čiovo island and is not a part of Kaštela and Trogir Bay is water recipient. The only logical solution was the treatment plant site situated on the south side of Čiovo island. Out of all available sites in that area, that is already considerably built and also intended for construction, site situated in the cove below village Žedno was considered to be the best.

The wastewater treatment plant is situated 15 m above sea level. It is a very rational solution considering that wastewaters of Kaštela and Trogir area (except for part of villages on Čiovo island) must be permanently multiple times repumped to the plant.

The wastewater treatment plant Čiovo was worked out only on prefeasibility study level, hence detailed information about the treatment plant and its characteristics don’t exist. Therefore we can’t give its precise position in reference to the urban infrastructure. Plant is situated far away from the town centre, residential areas of Trogir and main infrastructure facilities. It is situated close by the holiday village Mavarštica.

Plant can be accessed by road from the area of Mavarštica Bay. Infrastructure connection (water, electricity, phone) is also possible in Mavarštica village but only in the beginning while the plant is still not working with its full capacity. For the ultimate works suitable infrastructure must be built in order to meet the requirements of the plant with its capacity and characteristics.

Lithographic, engineering geological and hydrogeological characteristics of the area

The area is made of limestone beddings of Upper Cretaceous (Senonian) with infrequent dolomite lenses.

This area is part of Primosten-Trogir-Split tectonic unit. Its north boundary is reverse fault Kozjak. The rock mass is well jointed because of intense tectonic activity.

Sandstone and limestone are brittle, jointed, very hard rocks of shell-like and irregular fracture. Joints are of “dm” aperture, empty or infilled with degradation products such as terra rossa and silty clays.

Hydrogeologically speaking these beddings have secondary jointed porosity that is more distinct in the surface area. Precipitation water can be infiltrated relatively fast through the surface zone to the sea level. During rainy season a temporary surface runoff toward the valley can be expected. Therefore treatment plant site must be protected from it.

According to the Seismic map of this area, the wastewater treatment plant is situated in the zone where maximum earthquake intensity of 6°MCS for recurrent period of 200 years and of 9°MCS for recurrent period of 500 years is expected.

General hydrological characteristics

Hydrological layout of this area is very simple. Site must be protected from rainfall water only. Depending on the feasibility project of the plant it is possible that only one small stone canal that collects water coming from the boundaries will be sufficient. Surfaces of the plant should be mildly inclined toward the sea. Therefore the removal of runoff can be done by gravity.
Existing and planned infrastructure

Traffic
Only the road that leads to Mavaričica village is built near planned treatment plant complex. Treatment plant site is connected to the road of the holiday village Mavaričica.

Water supply
Treatment plant can be connected to the water supply system of Mavaričica village.

Sewerage
Sewerage system doesn't exist in this area.

Electricity, Telecommunications
Detailed information about electricity and telecommunication system is not available.

Spatial disposition and use of the area
As it was earlier mentioned, the wastewater treatment plant was designed on prefeasibility study level. Therefore detailed information about spatial disposition and use of the treatment plant area can not be given.

As it is evident from the indented coast and town of Trogir, collecting wastewater is very complex and expensive and requires a construction of a larger number of pump stations and several underwater crossings and the construction of two tunnels. The Kaštela area requires similar facilities, even though the Kaštela sewerage is somewhat more simple and cheap. Due to all the aforementioned, the construction of the Kaštela-Trogir sewerage system is a high-cost, complex and long-lasting solution.

1.4.5. Phases in the construction of the sewerage systems
Such solution for the Split-Solin and Kaštela-Trogir sewerage systems is very expensive both regarding the construction as well as maintenance/operation. It is therefore foreseen that it will not be realized in the near future. We must bear in mind that because of the standard of the population in these areas, the people will not be able to finance the sewerage system and to repay the loans in according to the foreseen final solution that provides a high standard protection of the sea. This mostly applies to construction, maintenance and operation costs of the plant.

Because of this we have foreseen solutions by phases by means of which the long-term solution would be completed. As to provide such type of construction the solutions by phases should meet the technical and technological requirements of the long-term solution, but also improve the present environment protection, and function as a unique technical and technological whole.

Phases in the construction regarding the capacity of the plant and pump stations are provided by building several separate operation lines: plant, outfall and other sewerage facilities. Depending on the level of treatment each operation line will be built at several treatment levels i.e. technological treatment processes. The following is foreseen: complete mechanical wastewater treatment (screen, sediment chamber), partial biological treatment (A phase of AB biological treatment and sludge processing), complete biological treatment (B phase of AB procedure with appropriate sludge processing, de-nitrification, de-phosphatization and disinfection. Each treatment level would be accompanied by a corresponding submarine outfall that together with the plant forms a unique technical and technological whole both in the sense of treatment and wastewater disposal into the sea.
Construction by phases would also be necessary because the largest part of this area has no sewerage system, the construction of which would, apart from substantial financial means, require a long time. This practically means that a complete and unique sewerage system would require a very long time. As each construction phase should improve the environmental protection, it was foreseen that a corresponding treatment plant and submarine outfall be built for each construction phase. This means that certain construction phases will be accompanied by building treatment plants and outfalls. However, as the long-term solution foresees a unique treatment plant, these so-called “phase-plants are temporary because as the construction of the sewerage system advances towards a unique sewerage system and plant they lose their function. Therefore, these phase-plants should be the least expensive as possible or to be used long enough as to depreciate the investment. Therefore only two levels of temporary plants have been foreseen: complete mechanical treatment and A phase of AB biological process. The sludge treatment plant was foreseen strictly at the site of the plant, i.e., it should be permanent. Mechanical wastewater treatment would meet aesthetical standards of the sea and by long submarine outfalls they would meet the sanitary standard of the sea. The environmental protection of the sea would start with A phase of AB plant, and it would be more significant with the completion of B phase of AB plant. De-nitrification and de-phosphatization and disinfection would provide high quality effluent and a long-term protection of the sea. Sites for the plant were chosen taking into consideration the fact that they be used as long as possible so that the investments be most depreciated.

Bearing in mind the town-planning and environmental features of this region as well as the existing state of construction of the sewerage system and outfall, we have come to three phases of the sewerage system (Fig. 1.19.). Within them there are several smaller systems and significant facilities. Technological phase A, final solution with two separate systems; technological phase B with four separate systems and an A-AB level of biological wastewater treatment at each of them; technological phase C with six temporary sewerage systems and corresponding mechanical treatment plants. It is evident that as the sewerage systems become more complete, the level of treatment increases because only in such a way is it possible to improve the environmental protection, i.e., reduce the pollution of the sea. The technological and economically acceptable transition from one phase of the system into the other is provided by temporary plants that would be built at the sites of the main regional pump stations that need to be built in accordance with the long-term concept of the sewerage system. Therefore, the temporary plants are conceived in such a way that they be used in the following phase for the final pump stations and functioning in incidental situations when the unique sewerage system breaks down. The transition from one sewerage system of construction phase into the other requires some major facilities that would enable smaller systems to be united into larger ones (C into B, B into A). In this case these are two hydrotechnical tunnels Stupe and Ciovo. In order to connect the Solin sewerage system to the one of Split it is necessary to built the Stupe tunnel, and in order to connect the Kaštel sewerage system and part of that of Trogir with the central plant of the Kaštel-Trogir system, the Ciovo tunnel should be built.

Accordingly, the following elements—subprojects of the sewer system construction are possible:

1. Projects of A technological level:

A1 - Split-Solin sewer system with the central plant and full biological treatment and a central outfall

A2 - Kaštel-Trogir sewer system with a central treatment plant and full biological treatment and a central outfall.
2. Subprojects of B technological level:

B1 - Stobrec sewer system with "A-AB" phase of the AB treatment level and the respective outfall
B2 - Sewer system of the Split port with "A-AB" phase of the AB treatment level and the respective outfall
B3 - Kaštela sewer system with one treatment plant with "A-AB" level and the respective outfall
B4 - Trogir sewer system with "A-AB" phase of the AB treatment level and the respective outfall
B5 - The Stupe tunnel as the main structure for connecting the Solin and Split systems
B6 - the sewer system including Solin, Dujmovaca, Stobrec, with the plant "A-AB" phase of the AB treatment level at the location of the central plant and respective submarine outfall.

3. Subprojects of C technological level:

C1 - Stobrec sewer system, treatment plant with full mechanical treatment of waste water and a respective outfall
C2 - Stupe tunnel, Solin, Dujmovaca and Stobrec sewer system, treatment plant with full mechanical treatment of waste water and a respective outfall
C3 - sewer system of the City port catchment, treatment plant with full mechanical treatment of waste water at Katalinić Brig and a respective outfall
C4 - Kastel Sucurac and Gomilica sewer system, treatment plant with full mechanical treatment of waste water and a respective outfall
C5 - sewer system of western part of Kaštela municipality, treatment plant with full mechanical treatment of waste water and a respective outfall
C6 - Trogir sewer system, treatment plant with full mechanical treatment of waste water and a respective outfall
C7 - Čiovo sewer system, treatment plant with full mechanical treatment of waste water at the location of the central plant and a respective outfall.

Thus, fifteen alternative solutions of phase construction were obtained in the wide area of Kaštela Bay, Figure 1.19. Each alternative is specific considering the cost of construction, operation and maintenance and also with regard to its environmental impacts, i.e. the improvement of environmental protection. This protection is improved with the centralization of the system and with higher treatment levels; however, this implies costs of construction, operation and maintenance of the system. The decision makers should solve the following dilemma: which structure should be built with the available funds while simultaneously ensuring better environmental protection.

It is a complex and difficult problem to reach correct decisions since the selection of each phase of the system construction does not include only the consideration of financial means (funds) but also the technological characteristics of the sewerage system. The funds necessary for the system construction certainly represent the most important factor to be considered. Greater amount of funds implies a higher level of purification of the plant and better collection of the waste water, which in turn makes the long-term implementation of the system more efficient and less expensive. If the funds are smaller the system should include lower levels of purification and then it should be decided which is the best of the available alternatives. The selection should not be based on some local interests since then the unique concept of the system should be threatened and hence its most efficient construction. Possible errors can prove very expensive and hazardous for the successful protection of the sea in this area.
Figure 1.19. Sub-projects of the construction of the Split-Solin and Kaštela-Trogir systems.
### Table 1.6. Cost of construction, operation and maintenance for each alternative of treatment work

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Total amount of waste water (m³/day)</th>
<th>Unit operation cost (US$/m³)</th>
<th>Daily operation cost (US$/day)</th>
<th>Sewerage system in use (%)</th>
<th>Yearly operation cost (US$/year)</th>
<th>Cost of the system (US$)</th>
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<td>A1</td>
<td>126 566.60</td>
<td>0.132</td>
<td>16 706.8</td>
<td>90</td>
<td>5488 180.9</td>
<td>52 000 000</td>
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<td>90</td>
<td>1156 320.0</td>
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</tr>
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<td>80</td>
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<tr>
<td>C3</td>
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<td>95</td>
<td>1373 130.0</td>
<td>8 000 000</td>
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<tr>
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<td>90</td>
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<td>6 000 000</td>
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### Table 1.7. Organic load which will be removed in each alternative

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Equivalent number of population (e.p.)</th>
<th>Total quantity of sewage water (m³/day)</th>
<th>Pollution load (BODS/kg/day)</th>
<th>Efficiency of treatment plant (BODS) (%)</th>
<th>Total organic load removed (BODS)</th>
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<td>126 566.60</td>
<td>37 969.98</td>
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<td>34 172.98</td>
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</tr>
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<td>229.47</td>
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1.5. INTEGRATED ENVIRONMENTAL PROJECT - KASTELA BAY

The Project financed by the Bank includes the main elements of the sewerage systems Split-Solin and Kastela-Trogir which ensure a long-term protection of the Kastela Bay, Figure 1.20. This Project makes it possible for all the waste water released into the Kastela Bay to be collected, purified and released outside the Bay into the Brač-Split Channel. This Project also ensures total and long-term protection of the Trogir Bay since all the waste water currently released into the bay will be collected, purified and released outside the Bay into the Split Channel.

The Project includes the following elements of the sewer systems:

a) Split-Solin sewerage system

- main sewer system of Solin (total length of 3800 m, \( \varnothing \) 400-800 mm), with the main pumping station "Japirko-Solin" (Q=0.650 m\(^3\)/s, \( H_{\text{man}} \)=23 m) and the belonging pressure pipeline (length of 800 m, \( \varnothing \)500 mm),

These selected structures represent the most important parts of the Solin sewerage system which ensure that system can function as a unique and complete technological system which ensures environmental protection and high standards for the users of these systems. All waste water from these systems will be transferred by pump station "Japirko-Solin" to hydrotechnical tunnel "Stupe".

- main sewer system for the Dujmovača and Vranjic (total length of 9400 m, \( \varnothing \) 250-1200 mm) with the accompanying main pumping stations, i.e. the pumping stations of the Dujmovača sub-catchment: "Duje" (Q = 0.506 m\(^3\)/s, \( H_{\text{man}} \) = 22 m, belonging pressure pipeline length of 260m, \( \varnothing \)600 mm), and "Dujmovača" (Q = 0.963 m\(^3\)/s, \( H_{\text{man}} \) = 21 m, belonging pressure pipeline length of 831m, \( \varnothing \)800 mm), and the pumping stations of the Vranjic sub-catchment" "Vranjic I" (Q = 0.020 m\(^3\)/s, \( H_{\text{man}} \) = 6 m, belonging pressure pipeline length of 360m, \( \varnothing \)150 mm), "Vranjic II" (Q = 0.090 m\(^3\)/s, \( H_{\text{man}} \) = 13 m, belonging pressure pipeline length of 500m, \( \varnothing \)2300 mm) and "Vranjic III" (Q = 0.180 m\(^3\)/s, \( H_{\text{man}} \) = 12 m, belonging pressure pipeline length of 400m, \( \varnothing \)250 mm).

These selected structures represent the most important parts of the Split north catchment area sewerage system which ensure that system can function as a unique and complete technological system which ensures environmental protection and high standards for the users of these systems. All waste water from these systems will be transferred by pump station "Dujmovača" to hydrotechnical tunnel "Stupe".

- main sewer system of the Strobreč (total length of 2300 m, \( \varnothing \) 300-600 mm) sub-catchment with the main pumping station "Šine" (Q = 0.240 m\(^3\)/s, \( H_{\text{man}} \) = 18 m, belonging pressure pipeline length of 1440 m, \( \varnothing \)500 mm).

These selected structures represent the most important part of the Strobreč sewerage system which ensure that system can function as a unique and complete technological system. All waste water from this system will be transferred by pump station "Šine" to wastewater treatment plant "Stupe".

- hydrotechnical tunnel "Stupe" (length 2436 m, cross section A = 15.39 m\(^2\)
Figure 1.20. Parts of the sewerage systems which will be financed by the Banks which are included in the Kastela Bay Project
The heart of the wastewater collection system Split/Solin is hydrotechnical tunnel "Stupe" by which wastewater which belong to catchment area of Kaštela bay will be transferred out of the bay to the Brač channel. Transferring wastewater out of the Kaštela bay environmental rehabilitation of the sea water of the bay will start.

- "Stupe" treatment plant - Phase I (mechanical treatment) (Qmax = 0.880 m³/s),

The goal of this treatment is to produce an effluent that may be discharged by outfall, producing "no visible slick" and protecting downstream processes. It can be achieved by: coarse and fine screening (holes less than 6 mm), grit removal, grease and oil removal.

- long submarine outfall in Stobreč - Phase I (length 2600 m, Ø1000 - 700 mm, diffuser 400 m, depth 37 m) The outfall diameter should be at shallow water in Stobreč bay (956 m) 1000 mm while out of it 700 mm.

Since the wastewater sewerage system will be realized by stages, the outfall should meet legal criteria for coastal water quality (III class at point of discharge and II class at 300 m from coastline) at any stage of realization including and Phase I of Stupe wastewater treatment plant development.

b) Kaštela-Trogir sewer system

- main sewer system of Kaštela (total length of 16800 m, Ø250-1100 mm) with accompanying 13 pumping stations,

These selected structures represent the most important parts of the Kaštela sewerage system which ensure that system can function as a unique and complete technological system which ensures environmental protection and high standards for the users of these systems. All wastewater from these system will be transferred by pump station "Divulje-Pantana" to hydrotechnical tunnel "Čiovo".

- main sewer system for Trogir (total length of 13900 m, Ø250-700 mm) with accompanying 9 pumping stations,

These selected structures represent the most important parts of the Trogir sewerage system which ensure that system can function as a unique and complete technological system which ensures environmental protection and high standards for the users of these systems. All wastewater from these system will be transferred by pump stations to wastewater treatment plant "Čiovo".

- hydrotechnical tunnel "Čiovo" (length 1851 m, cross section A = 10.52 m²),

The heart of wastewater collection system Kaštela/Trogir is hydrotechnical tunnel "Čiovo" by which wastewater which belong to catchment area of Kaštela bay and Trogir bay will be transferred out of the bay to the Split channel. Transferring wastewater out of the bay's environmental rehabilitation of the sea water of the bay will start.

- "Čiovo" treatment plant - Phase I (mechanical treatment) (Qmax = 0.356 m³/s),

The goal of this treatment is to produce an effluent that may be discharged by outfall, producing "no visible slick" and protecting downstream processes. It can be achieved by: coarse and fine screening (holes less than 6 mm), grit removal, grease and oil removal.

- long submarine outfall on Čiovo I phase (length 2050 m, Ø500 mm, diffuser 400 m, depth 47 m)
Since the waste water sewerage system will be realized by stages, the outfall should meet legal
criteria for coastal water quality (III class at point of discharge and II class at 300 m from
coastline) at any stage of realization including and Phase I of Ciovo wastewater treatment plant
development.

These selected structures ensure that each sewer system can function as a unique and complete
technological system which ensures environmental protection and high standards for the users of
these systems. This system also ensures the use of the coastal sea in accordance with legislation,
Figure 1.21.

The treatment plan includes the plant for the material from the septic tanks which will makes
possible efficient disposal of the waste water.

The proposed configuration of the sewer systems and treatment plants ensures a gradual and
efficient long-term solution of the problems related to the collection, treatment and disposal of
waste water in the area of Kastela Bay and Trogir Bay.

The selected technological level is in accordance with the current practice and experience of the
communal organization engaged in the maintenance and management of the sewerage system, so
that all the problems can be efficiently solved. Almost all the structures which will be built
within the Project already exist within the present sewerage systems. The construction of the
planned structures will result in the employment of a great number of new personnel.

Since these problems related to the collection, treatment and disposal of the waste water have
been dealt with for several years many administrative and technical activities have already been
carried out. Thus, urban plans have been brought into accordance with the proposed solutions of
the sewer systems. Various permissions from the water management authorities have been
obtained as well as construction permits for some structures. It should be borne in mind that one
part of the sewer systems has already been constructed or is being constructed according to the
selected solutions.

The Project documentation has been developed for all systems for different levels, according to
the interest of some cities and the priorities of their construction, starting from preliminary
design to the final designs. The Split-Solin sewer system has, thus, been developed at a higher
level of the documentation and preliminary activities and will be realized before some other
systems. The sewer system in the Kastela area has also been quite well developed, while the
Trogir region is the least well prepared, considering the documentation and construction.

Environmental impact studies have been developed for all sewer systems in accordance with
Croatian legislation. These studies represented essential conditions for obtaining the respective
permits and agreements.

The plan for the construction of structures for the sewer systems primarily includes the proper
disposal of the waste water, i.e. first the operation of the submarine outfalls and plants, and
subsequently all other structures necessary for collecting the waste water and delivering it to the
treatment plants.

The Project also includes, simultaneously with the construction of the structures, the training of
the personnel according to the selected equipment and the purchase of the equipment for the
organizations who will operate these systems according to the expected tasks in the maintenance
of the sewer systems.
Figure 1.21. Categorization of the coastal water in accordance with Croatian standards
1.6. MANAGEMENT AND STAFFING

Vodovod i Kanalizacija is the operating company set up to manage the water and sewage infrastructure on behalf of the Split, Solin, Kaštela and Trogir municipalities.

Currently, approximately 35 staff are employed to operate the sewage system and pumping stations for the whole four municipalities. In addition, approximately 55 technical specialists are employed as mechanical and electrical fitters.

Planed development of sewerage systems Split-Solin and Kaštela-Trogir will require significant additional resources and additional 15-20 operatives will be required to maintain the new assets (sewers, pump stations, telemetric system, etc.).

With two treatment plant the staffing level will increase over an extended period of time. The treatment works operations team will be small in the beginning period (6 -10). A smaller team of chemists and laboratory staff (5-7) will be required for the initial phase. This period will require significant activity, establishing effluent and trade effluent monitoring.

Planing development of the sewerage systems will require new management organization which will be able to operate and maintenance new collecting system assets, treatment plants and submarine outfalls. Main component of that organization should be:
- Administration and finance department,
- Sewerage department,
- Treatment works department,
- Maintenance department,
- Scientific department.

Treatment works team and part of collecting system team should be recruited at the beginning period of systems construction in order to be familiarized with the work and elements of the systems. Planed full automatisation of systems and treatment works will require training for existing and new staff.
2. DESCRIPTION OF THE ENVIRONMENT

2.1. PHYSICAL ENVIRONMENT

The area of concern is the wider area of Kašela Bay and neighboring maritime areas including the Brač and Split channels and the coastal strip bounded by the slopes of the Kozjak mountains to north, the city of Trogir in the west, and the river of Žrnovnica in the east. The topography of the area is shown on the Figure 2.1. The Figure shows the topographic diversity with mountainous land forms, gently inclined fields typical of coastal flatland and the terraced slopes of surrounding hills.

2.1.1. Geology

This area is a part of a large Cretaceous-Tertiary system of outer Dinaric massive and a typical Adriatic structural unit characterized by sediments of Jurassic, Cretaceous, Tertiary and Quaternary time (Figure 2.2.).

Jurassic thick-deposited Eohtic and Lower Cretaceous limestones occupy a very small area northeastern of the Jadro spring towards the Mosor Mountain.

Cretaceous time is represented by the deposits of Upper Cretaceous time: Turonian mainly well stratified limestones very little commingled with dolomites and dolomitic limestones and Cenomanian massive thick-deposited limestones and limestone dolomites except the complexity of plate limestones at the feet of the Biranj Hill on the Kozjak Mountain.

Tertiary is represented by the deposits of eocene time: classical and carbonate Eocene Flysch deposits, breccia, breccia conglomerates, with limestone and marly deposits and foraminiferal limestones.

Flysch deposits of very heterogeneous structure prevail. Petrographically they are mainly sandstones commingled with maries; still limestone breccia, breccia conglomerates, sandy calcarenites and biocalcarenites may also be found.

Such marked stratification points to a rhythmical sedimentation.

Foraminiferal limestones occupy a small area at the margins of Cretaceous-Tertiary synclines.

A large part of Flysh sediments is covered by Quaternary deposits of a very varying structure and thickness. During Quaternary, intensive erosion was a dominant process along with the transport and local settling of material made up of fragments of limestone-dolomitic angular coarse skeleton and soil particles. The ratio of skeleton quantity to soil particles and depth of these deposits determine ecological-productive properties of this land.

Quaternary Pleistocene breccia, counting fragments of Cretaceous and Paleogene carbonate deposits of different size, extends over a small area on the western side of Kašela farmland.

Alluvial deposits adjacent to the rivers of Jadro and Žrnovnica are made up of sandy-gravely layers of Cretaceous and Tertiary sediments.

The continental part slightly rises from the sea, gradually becoming rather inclined and tectonically folded slope, ending in a steep fissure - reverse fissure of Kozjak and Mosor mountains. Pronounced deformities, appearing as folds sloping to the south, as well as transversally and longitudinally split architecture are indicative of high plasticity of Flysch deposits.
Fig. 2.2. Geology of the area

- Upper Cretaceous
  - K^2_1 Turonian limestones with rare layers of dolomites
  - K^2_2 Senonian massive limestones and dolomites
  - Palaeogene
    - E_1,2 Foraminiferal limestones
    - E_2,3 Flysch

- E_3 Breccias and breccia-conglomerates with lenses of limestones

- O.1. Limestones breccias

- Quaternary
  - d Well-cemented breccias
  - a Alluvium
Reverse fissures of Kozjak and Mosor steeply rise from recent Flysch deposits. Other parts of the cretaceous complex also make it a terrain of great energy with a number of karst geomorphologic phenomena.

2.1.2 Soils

The soils in the area are very variable, resulting from the great variation in different soil formatting factors over short distances (Figure 2.3.). Such factors include: the composition of the parent material; topography; and, human use and interference.

The relative position and relationship between topography, geological structures and altitudinal distribution of soil types (soil mapping units) are illustrated in the schematic cross section A-A’ (Figure 2.4.).

There is close relationship between the spatial distribution of the different soil types and the topography: flatland and gently sloping relief are covered by arable, anthropogenic, terraced soils; abandoned terrace soils are found in areas of steeper slope; and, on the very steep slopes, natural, shallow and skeletal soil types are developed on the underlying limestones and dolomites.

Natural soil types include Lithosols, Calco-melanosols, Cambic soils and Rendzinas. Lithosols lack well-developed genetic horizons, and are formed of skeletal limestones. Their appearance is unstratified due to the physical friable nature of the limestone, to the karstic hydrology and to intensive erosion of the smaller particles. On flat ground, these soils are very shallow (10-20 cm); on the steep slopes lithosols are found in combination with calco-melanosols and colluvial soils, which are much deeper but very skeletal. The properties of colluvial soils, which are much deeper but very skeletal. The properties of colluvial soils depend on the quality of the material that is transported, the distance of transport and the physical characteristics of the environment.

Calco-melanosols are shallow soils with well-developed organic horizons that lie above the limestones. Chemically, these soils have a high humus content (mull-type), an excellent soil structure and the Calcium carbonate content is very low. Shallow depth and dryness resulting from low water retention capacity and underlying karst hydrology are the principal limiting factors to potential production of these soils. Calco-melanosols are found in combination with Cambic soils.

Rendzinas are humus-carbonate soils and represent a further stage in the development of the carbonate regisols. These are mostly plateau type soils covered with forest vegetation. Their productivity dependents on the thickness of the humus horizon, depth of the profile and the properties of the parent material. Rendzinas formed on the marl regolites have a deep soil solum, in contrast to rendzinas on marl limestones or sandstones that are in direct contact with the parent rock.

Soils developed on the impermeable Flysh marls, with a high content of silt and fine sand, are particularly prone to physical degradation such as crusting of the soil surface and erosion. The intensity and consequences of erosion processes differ, depending on the geology, topography, climate, soils, vegetation cover and human activities. The area surveyed is made up of two completely different geological substrata, which affect the hydrological characteristics of the soils. In the impermeable Flysh marls, with silty and clayey soils, sparse vegetative cover and montane topography, erosion processes are most obvious.
1. Lithosol and Calco-melanoso complex
2. Regosols
3. Andosols
4. Calco-melanosols and Calco-cambisol complex
5. Calco-cambisols, typical and colluvial
6. Terra Rossa soil, occasionally Calco-cambisol

7. Terraced abandoned soils on Flysch
8. Terraced carbonate soils on Flysch
9. Terraced very skeletal soils on quaternary deposits
10. Anthropogenic skeletal clay-loam soils on quaternary deposits
11. Anthropogenic soils on the alluvial deposits (Fluvisol)

Fig. 2.3. Soil of the area
Cambic soils are formed on Cretaceous limestones and dolomites; and on Palaeogenic foraminiferal limestones, breccia and conglomerates. The ground where they are formed is characterized by a high density of stones and the well-developed karstic sub-soil morphology of the parent material. As a consequence, wide variation in soil depth is a basic feature of these soils affecting their ecological value. In contrast to the erosion processes in the area of Flysh, the Cretaceous limestones have a high infiltration capacity, which reduces or precludes the possibility of surface runoff and hence reduces surface erosion and mass movement. As a result of the conditions affecting soil formation, in particular those relating to the parent rocks of the area and the action of the climate on the limestones, Calco-Cambisols and Terra Rossa soils may also be formed.

2.1.3. Hydrology

Hydrological, Cretaceous and Tertiary sediments are markedly contrasted. On the one hand, limestones and dolomites are very cracked and frequently calcified, porous and therefore arid and without surface waterflows. On the other hand, Paleogene Flysh complex is practically impermeable and liable to erosion and slide.

Quaternary colluvial deposits drape Flysh deposits protecting them from erosion. Hydrological properties of Quaternary colluvium are determined by their texture and skeleton structure as well as by the thickness and properties of the environment and substrates through which they have been brought there.

The geological properties of the coastline control ground and surface drainages creating different hydrological phenomena so that this area is comprised of rivers, smaller surface waterflows, ground water which diffusely and concentrated enters the sea at the sea level or below it (submarine springs).

The catchment area of the Bay watershed is twice that of the Bay itself (about 120 km²).
Intensive urbanization caused this area to change persistently the characteristics of drained area. So, growing quantities of precipitation remain on the surface and are discharged into the Bay through a whole system of small streams and channels (precipitation sewerage). Since water quantities are limited and relatively small, the water input is directly dependent on the intensity and duration of rainfall, varying a lot and being almost completely arid during summer. Hydrological analysis of the coastal watershed has never been completed so that actual quantities have remained unknown. However, the total quantity of surface and ground waters that enter the Bay every year have been estimated at 100 million cubic metres.

The Jadro river and the Pantana stream account for most of the freshwater input into Kaštela Bay. The area they drain does not belong to the surface watercourses of the coastal watershed of the Bay. Flysch geological barrier extending along the coastline causes ground water accumulations in the hinterland wherefrom the Pantana and the Jadro waters sprout out to the ground. The watershed of these small rivers covers an area exceeding 260 km².

Annual average flow rate of the Jadro River is 9.5 m³/s. Its minimum flow is 4.0 m³/s and maximum reaches as high value as 66.0 m³/s. The Jadro River annual run-off amounts to 300 million cubic metres of freshwater.

The Pantana flow rate has not been accurately determined, since the spring is at the sea level where fresh and sea water mix. The average spring capacity has been estimated at 6 m³/s, minimum being 0.5 m³/s and maximum 20.0 m³/s.

The Žrnovica River, discharging into the Split Channel, is of considerably lower capacity than the Jadro River. Winter average flow rate has been estimated at about 5 m³/s and the summer one to be very small.

An essential property of the riverine input of fresh water is great variability affected by the rainfall. About 70% of annual freshwater input is realized during winter.

2.1.4. Climate conditions

A long time meteorological monitoring shows that the study area is with relatively warm conditions, moderate precipitation, and markedly windy. Table 2.1 shows monthly frequency and average wind speed (expressed in Beauforts) based on data obtained over the 28-year period from 1949-1976 at the Split-Marjan station, while Figure 2.5 shows monthly wind rose. The north-east wind ("Bura") is most frequent and this blows 25% of the time with an average force of over 3 B in some autumn and winter months. Generally speaking, except in May and June, the frequency of "bura" wind never drops below 20%. "Široko" or the south-east wind is frequent in February, April and November, so that the local maximum frequency coincides with the local minimum of "široko" and vice versa. The average force of the "široko" exceeds that of the "bura" for much of the year. The "Maestral" is on-shore summer wind, which blows in the afternoon as the consequence of much faster warming up of the land during the day as compared with the sea. Its direction varies, depending on local conditions. In the study area, "maestral" is southwestern wind blowing towards the coast at an angle of about 45°. The mean frequencies of this wind in summer time (June, July, August) are 18.3, 17.3 and 19.4 %, respectively, while in the rest of the year it is negligible. Its force in summer is up to force 2-3 Bf.
Fig. 2.5. Monthly wind rose
Fig. 2.5. Monthly wind rose (contd.)
In the summer period the frequency of the south-west wind is high. In contrast, the frequency of the south-east and north-east winds is at a minimum in the summer months, since the passage of low-pressure systems over this area is minimal during this period. During summer, the frequency of the north-east wind is somewhat greater than that of the south-east wind, since it regularly occurs during the night time as part of the sea-breeze circulation. During the summer period the wind is generally weaker and the greatest changes occur on a daily time scale. These changes are the result of day-night circulation. The wind direction rotates over the 24 hour period in clockwise direction, so that at night a light north-easterly wind prevails, while during the afternoon a south-westerly wind is predominant. The afternoon or south-westerly wind may be stronger than the night wind because it represents the sum of thermally induced sea-to-shore winds. The so-called etesian wind, which form part of the general summer circulation of the eastern Mediterranean region, generally blow from the northwest, although locally their direction may correspond to the direction of on-shore winds connected with the day-night circulation.

Table 2.1. Mean frequency (F) in parts per thousand and strength (J) of wind in Beauforts over the period 1949-1976.

<table>
<thead>
<tr>
<th>Month</th>
<th>N</th>
<th>NE</th>
<th>E</th>
<th>SE</th>
<th>S</th>
<th>SW</th>
<th>W</th>
<th>NW</th>
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<tr>
<td></td>
<td>F</td>
<td>J</td>
<td>F</td>
<td>J</td>
<td>F</td>
<td>J</td>
<td>F</td>
<td>J</td>
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<td>276</td>
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<td>140</td>
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<td>160</td>
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<td>198</td>
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<td>3.2</td>
<td>219</td>
<td>3.2</td>
<td>158</td>
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<td>176</td>
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<td>3.3</td>
<td>216</td>
<td>3.2</td>
<td>149</td>
<td>4.2</td>
<td>197</td>
<td>4.2</td>
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<tr>
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<td>136</td>
<td>3.3</td>
<td>120</td>
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<td>156</td>
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<td>235</td>
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<td>102</td>
<td>2.4</td>
<td>84</td>
<td>2.5</td>
</tr>
<tr>
<td>Aug</td>
<td>149</td>
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<td>229</td>
<td>2.3</td>
<td>88</td>
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<td>101</td>
<td>2.5</td>
<td>84</td>
<td>3.5</td>
</tr>
<tr>
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<td>3.5</td>
<td>305</td>
<td>3.2</td>
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<td>178</td>
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<td>Dec</td>
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<td>3.3</td>
<td>316</td>
<td>3.2</td>
<td>127</td>
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<tr>
<td>Annual</td>
<td>161</td>
<td>3.2</td>
<td>245</td>
<td>3.2</td>
<td>137</td>
<td>3.4</td>
<td>135</td>
<td>2.3</td>
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</tbody>
</table>

With regard to outfalls design the most critical wind are the Southerly winds (SW, S and SE) as these will generate on-shore currents. The mean yearly frequencies of these winds is 34.2% and during the critical summer months (June, July and August) the frequency is 35.5 %.

Surface air temperature is controlled by the wind and other weather processes and reflects the local balance of incoming and outgoing radiation, as well as heat storage in water bodies. Monthly mean air temperature over the annual cycles are presented in Table 2.2. Mean annual temperature is 16.0°C and the annual range (difference in mean temperature between the coldest and warmest months) is 17.9°C. January appears to be the coldest month with a mean temperature of 7.6°C and July the warmest month with a mean temperature of 25.5°C, which is in agreement with changes in global irradiance.

68
Tabl e 2.2. Mean monthly temperature (°C); number of hot, warm and cold days in each month; max ($t_1$), min ($t_2$) and range of mean monthly temperature for the Split-Marjan station, 1949-1988

<table>
<thead>
<tr>
<th>Month</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>June</th>
<th>July</th>
<th>Aug</th>
<th>Sept</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
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<td>13.8</td>
<td>18.7</td>
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<td>25.0</td>
<td>21.5</td>
<td>16.9</td>
<td>12.3</td>
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<td>-</td>
<td>-</td>
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<td>-</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Warm</td>
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<td>-</td>
<td>-</td>
<td>-</td>
<td>0.2</td>
<td>7.6</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Cold</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<td>11.4</td>
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<td>16.9</td>
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<tr>
<td>$t_1$ (°C)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>10.6</td>
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<td>16.9</td>
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<tr>
<td>$t_2$ (°C)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<td>7.1</td>
<td>11.3</td>
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<tr>
<td>$t_1$-$t_2$ (°C)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<td>5.8</td>
<td>4.8</td>
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</table>

The mean annual precipitation in this area is 820.6 mm with a minimum of 613.0 mm and a maximum of 1101.5 mm. Precipitation is, on average, lowest in July and highest in November (Table 2.3). The annual distribution of rainfall reflects both cycnic activity and local topography. Since orographic rainfall is affected by the local topography, a single rainfall recording station cannot be representative of the spatial distribution of rainfall over the entire area. Comparison of the monthly rainfall figures suggests that the mean monthly total precipitation at the Kaštela Airport station is generally higher than that at the Split-Marjan station. The Kaštela Airport station is situated in the vicinity of the highest mountain in the area, which is oriented in an ENE-WSW direction, practically perpendicular to the "široko". This is the wind that carries humid and relatively warm air and therefore usually coincides with rainy weather.

Table 2.3. Monthly total precipitation (mm) for the Split-Marjan station over the period from 1949 to 1988, and for the Kaštela Airport station over the period from 1949 to 1970, and mean number of days with daily precipitation >0.1 mm ($N_1$), >1.0 mm ($N_2$) and >10.0 mm ($N_3$) for the Split-Marjan station

<table>
<thead>
<tr>
<th>Period</th>
<th>Split-Marjan</th>
<th>Kaštela-Airp.</th>
<th>$N_1$</th>
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<tr>
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<td>165</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Minimum values of relative humidity are recorded in the warmer part of the year, while the highest humidity occurs in the winter months (Table 2.4).

Table 2.4. Annual and monthly, mean and minimum values of relative humidity (%) over the period from 1949-1988

<table>
<thead>
<tr>
<th>Period</th>
<th>Mean</th>
<th>Mean Min.</th>
<th>Abs. Min.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>61</td>
<td>25</td>
<td>12</td>
</tr>
<tr>
<td>Feb</td>
<td>60</td>
<td>25</td>
<td>10</td>
</tr>
<tr>
<td>Mar</td>
<td>59</td>
<td>27</td>
<td>15</td>
</tr>
<tr>
<td>Apr</td>
<td>56</td>
<td>26</td>
<td>6</td>
</tr>
<tr>
<td>May</td>
<td>50</td>
<td>30</td>
<td>21</td>
</tr>
<tr>
<td>June</td>
<td>31</td>
<td>28</td>
<td>9</td>
</tr>
<tr>
<td>July</td>
<td>31</td>
<td>27</td>
<td>12</td>
</tr>
<tr>
<td>Aug</td>
<td>58</td>
<td>29</td>
<td>18</td>
</tr>
<tr>
<td>Sept</td>
<td>62</td>
<td>29</td>
<td>19</td>
</tr>
<tr>
<td>Oct</td>
<td>65</td>
<td>29</td>
<td>19</td>
</tr>
<tr>
<td>Nov</td>
<td>63</td>
<td>30</td>
<td>18</td>
</tr>
<tr>
<td>Dec</td>
<td>63</td>
<td>28</td>
<td>15</td>
</tr>
</tbody>
</table>

2.1.5. Oceanography

The oceanographic characteristics of the marine environment of the area, in terms of the currents and distribution of temperature, salinity and density depend upon the characteristics of the wind field, the inflow of freshwater, the insolation and the influence of neighbouring sea. The effects of tidal oscillation are relatively weak and negligible due to the small amplitude of the oscillations of the surface resulting in relatively weak horizontal currents.
**Kaštel Bay**

The Kaštel Bay is a relatively deep basin with an average depth of about 23 m (Figure 2.6.). It covers a total surface of about 60 km². It is deepest at the inlet (an average inlet depth is about 40 m), so that the communication with the adjacent basin (the Split Channel) is good. Its flushing time and changes in the current field are greatly induced by local winds. The tides energy is considerably smaller. Since wind oscillates mostly on the time scale of synoptic disturbance, the current field does the same with some delay.

The estimated flushing time of the Bay is about one month. The eastern, relatively shallow part which represents one fourth of the total body of the Bay water, has the flushing time of 15 days. Some recent current measurements in the Bay inlet have shown that under strong winds the flushing time of the Bay may be considerably shorter, even less than five days. The same is presumably applicable to the eastern part of the Bay as well. This part of the Bay receives the bulk of waste waters entering the Bay.

In the surface layer of the Kaštel Bay, a number of residual circulation types - both cyclonic, anticyclonic, and a combination of the two can be seen at different times. The type of circulation is dependent on many factors, but primarily on the wind. The south-west wind generates incoming currents in the surface layer, while the north-east wind generates outgoing currents. At some time the surface circulation patterns in the Bay are anticyclonic and cyclonic with respect to the two winds.

The temperature and the salinity of the sea water have been measured monthly since the late 1940s at a station located in the center of the Kaštel Bay. In addition, sporadic measurements of these parameters are carried out in other parts of the bay.

Table 2.5 shows the average monthly values of water temperature at the central station in the Bay over the period from 1952 to 1964. These data show a cooling of the sea surface during the period from November to February, when the surface temperature is lower than that of the deeper layers during this period. The surface temperature is at minimum in February and at maximum in August. The water column is most homogenous in March, but in April the existence of a thermocline can be detected in the upper layers. In October the thermocline almost disappears due to cooling of the sea surface and the vertical mixing generated by the wind.

During the summer season the lowest salinity is found at the surface of the eastern section of the Bay, while in spring low salinity water is found in the west. This reflects the impact of freshwater inflow from the Jadro river and submarine springs. As a rule, the influence of the freshwater inflow is not apparent at depth below 10 m.

The surface water of the central part of the Bay is under the direct influence of the Split channel. The eastern portion of the bay is separated from the rest by a quasi-stationary front in the field of mass. The less dense water, which is probably less saline as well, leaves the bay along the coast of the island of Ćiovo. The temperature minimum of the deeper water layers in the central part of the bay during the summer has been explained in terms of upwelling generated by the wind, suggesting that transport from the Split channel into the bay predominates in the bottom layer.
Table 2.5. Month average water temperature (°C) in Kaštela bay

<table>
<thead>
<tr>
<th>Month</th>
<th>Depth 0 m</th>
<th>Depth 10 m</th>
<th>Depth 20 m</th>
<th>Depth 30 m</th>
<th>Depth 35 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>10.8</td>
<td>12.04</td>
<td>13.77</td>
<td>13.50</td>
<td>13.70</td>
</tr>
<tr>
<td>Feb</td>
<td>10.76</td>
<td>11.22</td>
<td>11.43</td>
<td>11.82</td>
<td>12.00</td>
</tr>
<tr>
<td>Mar</td>
<td>11.49</td>
<td>11.49</td>
<td>11.44</td>
<td>11.77</td>
<td>11.95</td>
</tr>
<tr>
<td>Apr</td>
<td>14.06</td>
<td>13.44</td>
<td>12.03</td>
<td>12.79</td>
<td>12.76</td>
</tr>
<tr>
<td>May</td>
<td>17.51</td>
<td>15.40</td>
<td>14.72</td>
<td>14.10</td>
<td>13.84</td>
</tr>
<tr>
<td>June</td>
<td>22.09</td>
<td>19.16</td>
<td>16.58</td>
<td>15.13</td>
<td>14.76</td>
</tr>
<tr>
<td>Aug</td>
<td>24.49</td>
<td>21.97</td>
<td>17.26</td>
<td>15.23</td>
<td>15.01</td>
</tr>
<tr>
<td>Sept</td>
<td>22.41</td>
<td>21.65</td>
<td>20.89</td>
<td>18.33</td>
<td>16.96</td>
</tr>
<tr>
<td>Oct</td>
<td>20.15</td>
<td>20.62</td>
<td>20.75</td>
<td>20.04</td>
<td>19.88</td>
</tr>
<tr>
<td>Nov</td>
<td>17.29</td>
<td>17.76</td>
<td>18.37</td>
<td>18.52</td>
<td>18.55</td>
</tr>
<tr>
<td>Dec</td>
<td>13.19</td>
<td>13.75</td>
<td>14.85</td>
<td>15.20</td>
<td>15.37</td>
</tr>
</tbody>
</table>

**Brač and Split channels**

The Brač Channel spreads between the mainland and the Brač Island. It is bordered by the line between the small town Stobreč and Gomička cape on the southwestern island coast, and by the line St. Rok to Makarska in the southeast. The channel is narrowest between Pučišća (island Brač) and the mainland (5 km) and widest in its southeastern part (13 km). The greatest depth (78 m) is in the most south-eastern part of the Channel.

The Split Channel is a part of the sea between the islands Čiovo, Šolta and Brač. It is bordered by the southern Čiovo coast in the northwest, by a line that over the small islands Fumija, Kraljevac and Zaprinovac cliff stretches to the small islands Klude and Veli Drvenik. A line running from Veli Drvenik across the cape Obinčki rt to Šolta, along the northern Šolta coast and through the Split Strait to the cape Zglav borders it in the southwest and south. Its eastern border is the line connecting the Gomička cape on the Brač Island and Stobreč on the mainland. The greatest depths were recorded in front of the island Veli Drvenik in the western channel part (68 m); eastward the depths are smaller (on the average 50 to 57 m). About 300 m long shoal Mlin stretches between the western Šolta part and Čiovo (0.2 m the shallowest point). There is a large submarine erection between the Gomička Cape and Stobreč with average 15 to 20 m deep sea over it (9 m the shallowest point).

**Water mass circulation and prevailing currents**

Movement of water masses in the Split channel and Brač channel is mainly westward, and forms part of the general current pattern of the Adriatic. Surface currents are under wind influence, especially during the summer season. Therefore, "maestral" the predominant summer wind generated eastward currents in a surface layer, while the "bora" (wind from the north) generates southward currents.

Current field characteristics of the Brač and Split channels were described after analyzing all the available data on currents measured on several occasions since 1972. During the earlier period currents were measured from moored ships over 24 or maximum 48 h. The latest measurements were done in 1990 and 1991 by automatic moorings, so that these series are also longer and results more appropriate for observations of wind effects. Measurements from a moored ship are performed under mainly calm conditions which is not the case with automatic
Current measurement stations are so distributed to cover a rather large part of both channels. In addition, we had available a lot of the data from the close vicinity of the site of planned submarine outfall. This analysis will give special attention to the currents in front of the Split town port and in the area in front of Stobreč where sewage outfall is planned to be built.

It might be expected that the occurrence of westward and northward directions are very probable. These directions are in fact a part of the incoming current of general Adriatic circulation along our coast. Their frequency is followed by the frequency of eastward and southeastward directions which are very likely a compensatory counter current, prevailing in the bottom layer as distinct from the westward directions which mainly occur in the surface layer.

Westward directions are particularly frequent in winter, whereas eastward and westward directions probability is very similar for summer. It is important that the highest current values are mainly related to westward directions coinciding in time with maximum frequencies of these directions. So, for example, the greatest current speed of about 50 cm s\(^{-1}\) was recorded at the station in front of the town port on 22 and 23 November 1972 when westward direction frequency amounted as high as to 49%. On the other hand the lowest observed most probable current speed was recorded from the same station when the eastward direction is highly probable. It may be concluded that from the viewpoint of sea water transport and its characteristics, westward flow, that is the current to the western quadrant is most important in the areas in front of Split harbor and Stobreč.

The resultant currents amount up to 50 cm s\(^{-1}\) with the most frequent values between 10 and 20 cm s\(^{-1}\). The highest value of mean daily resultant of all the data collected by now was 47 cm s\(^{-1}\) and was recorded in front of the Split town port. Mean current speeds are highest in the surface layer, ranging from 8 to 20 cm s\(^{-1}\). Current speed decreases with depth to be 6 to 11 cm s\(^{-1}\) near the bottom. Of all the measurements ever since 1972 resultant surface current of eastward direction was recorded on only one occasion; all other measurements showed surface currents of westward direction suggesting extremely high probability of westward flow. Frequently, surface currents have opposite directions of bottom currents which may be accounted for by compensatory mechanisms. This situation occurs particularly under the conditions of strong "jugo" wind forcing an onshore surface flow in the area of Split and Stobreč which is compensated by an offshore current towards the south in deeper layers.

The highest speeds occur in autumn and winter months as a consequence of stronger wind forcing. So, maximum recorded speeds in the study area vary about 60 cm s\(^{-1}\) occurring in the surface layer what points to the fact that they are due to wind forcing.

Even though wind speed is lower in summer than in winter wind forcing is more obvious. This is due to the fact that momentum of motion is transferred to a considerably shallower sea water layer in summer that is only to the layer down to the thermocline owing to summer stratification. In summer, surface flow completely follows wind forcing as shown by the available data. To conclude, summer wind induces the flow whose direction fully agrees with the wind direction. Under "bora" conditions the flow is of offshore direction and under "jugo" it is of westward direction with an onshore component. The most frequent summer wind (maestral), which locally blows from the southwest, forces surface flow along the northern coast of the Brač island of, generally, eastward direction.

Under summer conditions with poor wind the flow is relatively poor, as well, in front of Stobreč, with a tendency to be modified by bottom topography. As it is well known, a shoal in
this area has depth not exceeding 10 m in its central part. It seems that the current field eddy occurs and that its position is determined by the position and magnitude of the shoal.

On-shore winds generated surface currents are caused by "maestral" wind and the south and south-eastern wind. While the frequencies of the "maestral in the summer season is high, the frequencies of the south and south-eastern winds are low. The south-east wind, has a high frequency in all seasons except the summer and is much stronger than the south or "maestral" winds.

Off-shore winds generated surface currents are induced by northern winds (N, NE, NW) and the mean yearly frequency are 16.1 %, 24.5 %, and 5.1 % respectively. Long-shore currents, which can be regarded as favorable for the outfalls operation, are induced by easterly and westerly winds, and the mean yearly frequencies are 13.7 % and 3.5 % respectively. It can be concluded that on average more than 60 % of the total surface current frequencies are favorable (off-shore or parallel to the shore line) with respect to the outfall design.

Temperature and salinity

Temporal changes of sea water temperature in the Brač and Split Channels may be presented on the basis of data collected from two stations, Split and Stobreč (mouth of Žrnovnica River) between July 1972 and August 1973, and 10 stations in September 1990 (Figure 2.7a) and 14 stations in April 1991 (Figure 2.7b).

A temperature gradient was marked at both stations in July 1972, disappearing gradually in August, September and November due to vertical water mixing. The entire water column was isothermal at the station in front of Split during the late autumn and winter. Temperature inversion, with the surface colder than deeper layers, was recorded from the station in front of Stobreč. Surface layers were again heated in March so that temperature gradient was pronounced in warmer months. There was a thermocline between 10 and 20 m in August 1973.

The research carried out in September 1990 and April 1991 showed temperature stratification with the thermocline between 10 and 20 m in the wider area of Brač and Split channels in September. In April the vertical isothermy was present almost throughout the study area. No horizontal temperature gradient was recorded from the surface layer (0.5 m) of the Split and Brač channels.

Salinity distribution at the surface of the Brač and Split channels shows that the Cetina fresh water effects are limited to the eastern part of the Brač Channel at the end of summer (September 1990) whereas only a narrow belt between Dugi Rat and Stobreč has lower salinity at the beginning of spring (April 1991). The shape of isolines suggests prevailing surface east-westward flow which was more pronounced in April 1991 than in September 1990.

Higher or lower sea water density or ρ depends on temperature and salinity and is affected more by either former or latter parameter. Temporal variations of ρ at stations in front of the town Split and Stobreč in 1972/73 in dictated that the stratification is pronounced at both stations in summer whereas the water column is homogeneous in winter. In August 1972 the occurrence of "upwelling" or rise of bottom water due to the inflow of the open sea water in the bottom layer was pronounced at station in front of Stobreč. This phenomenon is indicated by the very well defined isotherms.
The data collected in September 1990 from the coastal profile of other stations point to the fact that bottom topography affects the sea water density isolines. This means that the shoal between Split and Stobreč affects the rise of more dense water closer to the surface.

The T-S diagram, based on all the available data from a wider area of the Brač and Split channels, shows vertical stratification in this area to be due to the vertical distribution of salinity, which is particularly low at surface of the stations close to Stobreč and Dugi Rat strongly affected by Cetina runoffs and to a lesser extent by those of the Žrnovnica River. However, this fresh water is retained in the narrow coastal belt which becomes narrower affected by the jugo wind. As shown by the data on currents, "jugo" induces an onshore flow component in the surface layer making the belt of fresh water along the coast still narrower. A comparison of T-S diagram for April 1991 to that for September 1990 shows late spring fresh water runoffs to exceed those in the late summer due to greater precipitation quantities.

**Nutrients and oxygen concentration**

Most of the data on nutrient concentrations refer to the sea water close to the coast (Split) directly affected by urban effluents. The data collected in September 1990 and April 1991 refer to the thorough area of the Brač and Split channels so they are better representative of nutrient loads in this area.
Fig. 2.7b. Location of stations during April 1991 cruise

Table 2.6. Summarized concentrations of ammonia (mmol NH$_3$-N/m$^3$) by levels in the Brač and Split channels

<table>
<thead>
<tr>
<th>Time</th>
<th>Depth (m)</th>
<th>Geom. mean</th>
<th>Stand. dev. (ln)</th>
<th>Max</th>
<th>Min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sept. 1990</td>
<td>0</td>
<td>0.44</td>
<td>1.23</td>
<td>5.15</td>
<td>0.06</td>
</tr>
<tr>
<td>April 1991</td>
<td>0</td>
<td>0.92</td>
<td>0.50</td>
<td>2.17</td>
<td>0.42</td>
</tr>
<tr>
<td>Sept. 1990</td>
<td>20</td>
<td>0.24</td>
<td>0.89</td>
<td>0.56</td>
<td>0.03</td>
</tr>
<tr>
<td>April 1991</td>
<td>20</td>
<td>0.74</td>
<td>0.40</td>
<td>1.35</td>
<td>0.36</td>
</tr>
<tr>
<td>Sept. 1990</td>
<td>bottom</td>
<td>0.38</td>
<td>1.67</td>
<td>11.57</td>
<td>0.02</td>
</tr>
<tr>
<td>April 1991</td>
<td>bottom</td>
<td>0.76</td>
<td>0.42</td>
<td>1.48</td>
<td>0.0</td>
</tr>
</tbody>
</table>

Table 2.7. Summarized concentrations of nitrite (mmol NO$_2$-N/m$^3$) by levels

<table>
<thead>
<tr>
<th>Time</th>
<th>Depth (m)</th>
<th>Geom. mean</th>
<th>Stand. dev. (ln)</th>
<th>Max</th>
<th>Min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sept. 1990</td>
<td>0</td>
<td>0.09</td>
<td>0.34</td>
<td>0.127</td>
<td>0.047</td>
</tr>
<tr>
<td>April 1991</td>
<td>0</td>
<td>0.09</td>
<td>0.28</td>
<td>0.144</td>
<td>0.062</td>
</tr>
<tr>
<td>Sept. 1990</td>
<td>20</td>
<td>0.08</td>
<td>0.26</td>
<td>0.127</td>
<td>0.047</td>
</tr>
<tr>
<td>April 1991</td>
<td>20</td>
<td>0.09</td>
<td>0.47</td>
<td>1.206</td>
<td>0.041</td>
</tr>
<tr>
<td>Sept. 1990</td>
<td>bottom</td>
<td>0.25</td>
<td>0.74</td>
<td>0.775</td>
<td>0.064</td>
</tr>
<tr>
<td>April 1991</td>
<td>bottom</td>
<td>0.28</td>
<td>0.84</td>
<td>1.188</td>
<td>0.090</td>
</tr>
</tbody>
</table>
Table 2.8. Summarized concentrations of nitrate (mmol NO₃-N/m³) by levels

<table>
<thead>
<tr>
<th>Time</th>
<th>Depth (m)</th>
<th>Geom. mean</th>
<th>Stand. dev. (ln)</th>
<th>Max</th>
<th>Min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sept. 1990</td>
<td>0</td>
<td>0.62</td>
<td>0.30</td>
<td>7.30</td>
<td>0.17</td>
</tr>
<tr>
<td>April 1991</td>
<td>0</td>
<td>0.52</td>
<td>0.44</td>
<td>1.11</td>
<td>0.23</td>
</tr>
<tr>
<td>Sept. 1990</td>
<td>20</td>
<td>0.37</td>
<td>0.57</td>
<td>0.80</td>
<td>0.14</td>
</tr>
<tr>
<td>April 1991</td>
<td>20</td>
<td>0.45</td>
<td>0.39</td>
<td>0.91</td>
<td>0.23</td>
</tr>
<tr>
<td>Sept. 1990</td>
<td>bottom</td>
<td>0.52</td>
<td>1.15</td>
<td>5.00</td>
<td>0.22</td>
</tr>
<tr>
<td>April 1991</td>
<td>bottom</td>
<td>0.60</td>
<td>0.91</td>
<td>1.74</td>
<td>0.13</td>
</tr>
</tbody>
</table>

Table 2.9. Summarized concentrations of phosphate (mmol PO₄-P/m³) by levels of Brač and Split channels

<table>
<thead>
<tr>
<th>Time</th>
<th>Depth (m)</th>
<th>Geom. mean</th>
<th>Stand. dev. (ln)</th>
<th>Max</th>
<th>Min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sept. 1990</td>
<td>0</td>
<td>0.067</td>
<td>0.467</td>
<td>0.121</td>
<td>0.022</td>
</tr>
<tr>
<td>April 1991</td>
<td>0</td>
<td>0.067</td>
<td>0.191</td>
<td>0.088</td>
<td>0.052</td>
</tr>
<tr>
<td>Sept. 1990</td>
<td>20</td>
<td>0.033</td>
<td>0.881</td>
<td>0.105</td>
<td>0.006</td>
</tr>
<tr>
<td>April 1991</td>
<td>20</td>
<td>0.066</td>
<td>0.234</td>
<td>0.094</td>
<td>0.046</td>
</tr>
<tr>
<td>Sept. 1990</td>
<td>bottom</td>
<td>0.058</td>
<td>1.480</td>
<td>0.193</td>
<td>0.000</td>
</tr>
<tr>
<td>April 1991</td>
<td>bottom</td>
<td>0.073</td>
<td>0.221</td>
<td>0.110</td>
<td>0.058</td>
</tr>
</tbody>
</table>

Ammonia concentrations were equal throughout the water column in April 1991 and significantly exceeded those from September 1990 (Table 2.6). Nitrites by different levels showed no differences between different sampling intervals. However, the nitrite quantities at the bottom of the Brač-Split Channel were significantly different from those in the upper sea water layers (Table 2.7). Differences between mean nitrate concentrations were not great with the exception of the bottom layer means for September 1990. Mean phosphate concentrations showed practically no differences either as to the sampling intervals or to the layers of the Brač-Split Channel.

As shown by the collected data on ammonia concentrations at the coastal profile of stations in September 1990 the station in the vicinity of Split appears to be the source of surface layer ammonia. There are also some indications that ammonia is released by remineralization from the bottom. As to the nitrates at the coastal profile of stations in September 1990 it is evident that they originate from the bottom west of the station in front of Split.

Records of nutrient concentrations characterize this channel area as oligotrophic.

Variations in dissolved oxygen concentrations, that is oxygen saturation, may be observed on data collected from station in front of Split in 1972/73.

During summer (July, August, September) oxygen saturation stratification occurred with the 100% isoline at 25 m depth. From September 1972 a slight oxygen deficiency occurred at the surface, due to nutrient input by precipitations from the land, as well as at the bottom. During winter, the entire water column was well aerated and oxygen saturated owing to the good vertical water mixing and reaeration. With the coming of spring oxygen concentration was increased due to phytoplankton activity.

Vertical structure of oxygen saturation, measured during September 1990 cruise along the profile of coastal stations show that the oxygen saturation structure differs from that on the shoal.
between Split and Stobreč. The sea water is oxygen saturated throughout the water column in the
eastern part (Stobreč-Dugi Rat), whereas bottom layers show deficiency and surface layer
oxygen saturation in the western parts with respect to the station in front of Split. This is a
consequence of vertical distribution of sea water density in September, which prevents mixing of
the surface and bottom layer water, as well as of biological activity of production in the surface
layers and oxygen assimilation in the bottom layers. It is important that oxygen deficiency at the
bottom coincides with the higher nitrate quantities.

Under the conditions of sea water stratification horizontal distribution of oxygen saturation
shows oxygen deficiency in the bottom layer of the Split Channel due to organic matter input by
currents and sedimentation from the area of Split.

During winter months, when vertical stratification disappears the entire water column is well
aerated affecting disappearance of oxygen deficiency. Therefore it may be stated that temporal
and spatial oxygen distribution is prevalently affected by physical conditions in the Brač and
Split channels whereas anthropogenic effects have not yet become obvious.

Granulometry of marine sediments

The September 1990 cruises for studies of geological properties of the sea bottom included the
area of the Brač and Split channels from the line connecting Dugi Rat and Postira to the line
connecting the islands Šolta and Drvenik and the mainland. In 1973 the profiles along the
isobaths of 15, 20, 30 and 40 m along the southern coast of Split peninsula were studied in the
area of Kašuni, Sustipan and Katalinića brig.

Loam was recorded from the southern part of Split peninsula along three parallel profiles
vertical to the coastline. This points to the fact that this fine sediment stretches parallel to the
coastline and that there is a calm sedimentation area with no influences nor signs of bottom sea
water movements adjacent to the southern coast of Split peninsula.

Loamy facies with very small fine sand particles prevails in the northern part of the Brač
Channel, whereas the IV fraction (particles size between 0.1 mm and 2.00 mm) with some
ingredients of the I and II fraction (particles size < 0.01 mm, and between 0.01 and 0.05 mm
respectively) particles is prevalent in the southern part. Therefore it may be stated that the
loamy-clayey facies occurs in this area where, apart from terrigeneous component, due to the
relative vicinity of the northern coast of Brač Island, biogeneous component occurs, as well.

The particles of the I and II fraction, with far lower presence of the IV fraction particles, were
recorded from the area of the Split Channel on the southern coast of Čiovo Island forming the
facies of clayey-sandy loam.

The distribution of particles in the sediment of the Brač and Split channels gives respective
sediment facies, which complies with the principle of basic and regular granulometric selection
with respect to the distance from the coast and depth. This area is prevalently an area of
undisturbed sedimentation with the dominance of the I and II fraction particles.

The structure of size fractions of sediment particles reveals a lot about hydrodynamical
properties of a particular area. Sediment is a deposit for a lot of substances of anthropogenetic
origin. The main processes of remineralization of organic matter also take place there. The Table
2.12 gives the fractions by particle size in the Brač and Split channels. However, to obtain mean
particle diameter, as a common sediment measure which may be compared to some other
properties, cumulative frequency of relative occurrence of individual particle sizes was related to
particle size classes on a probe paper. The size classes were transformed, if necessary, to obtain linear relationship of probability and particle sizes.

Table 2.10. Granulometric structure on three profiles vertical to the coast of the southern part of Split peninsula

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Fraction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I</td>
</tr>
<tr>
<td>Profile Katalimica Brig</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>40</td>
</tr>
<tr>
<td>Profile Susjepan</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>40</td>
</tr>
<tr>
<td>Profile Kasjuni</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>40</td>
</tr>
</tbody>
</table>

Table 2.11. Mechanical (granulometric) sediment structure (fractions in %) in the Brač and Split channels at the stations indicated on Figure 2.8.

<table>
<thead>
<tr>
<th>Station</th>
<th>I &lt;0.01 mm</th>
<th>II 0.01-0.05 mm</th>
<th>III 0.05-0.1 mm</th>
<th>IV 0.1-2 mm</th>
<th>V &gt;2 mm</th>
<th>Texture mark</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>30.43</td>
<td>29.57</td>
<td>18.71</td>
<td>20.97</td>
<td>0.32</td>
<td>Clayey-sandy loam</td>
</tr>
<tr>
<td>2</td>
<td>18.05</td>
<td>34.75</td>
<td>18.67</td>
<td>27.49</td>
<td>1.04</td>
<td>Sandy loam</td>
</tr>
<tr>
<td>3</td>
<td>35.84</td>
<td>33.65</td>
<td>15.24</td>
<td>15.24</td>
<td>0.05</td>
<td>Loam</td>
</tr>
<tr>
<td>4</td>
<td>3.92</td>
<td>7.73</td>
<td>6.08</td>
<td>80.41</td>
<td>1.86</td>
<td>Loamy-clayey sand</td>
</tr>
<tr>
<td>5</td>
<td>18.47</td>
<td>32.11</td>
<td>18.68</td>
<td>28.96</td>
<td>1.78</td>
<td>Sandy loam</td>
</tr>
<tr>
<td>6</td>
<td>6.08</td>
<td>17.32</td>
<td>14.54</td>
<td>61.34</td>
<td>0.72</td>
<td>Loamy-clayey sand</td>
</tr>
<tr>
<td>7</td>
<td>38.38</td>
<td>27.90</td>
<td>16.14</td>
<td>17.53</td>
<td>0.05</td>
<td>Loamy-clayey loam</td>
</tr>
<tr>
<td>8</td>
<td>7.96</td>
<td>27.89</td>
<td>8.26</td>
<td>41.32</td>
<td>14.57</td>
<td>Loamy-clayey sand</td>
</tr>
<tr>
<td>9</td>
<td>28.87</td>
<td>27.18</td>
<td>19.85</td>
<td>23.89</td>
<td>0.21</td>
<td>Clayey-sandy loam</td>
</tr>
<tr>
<td>10</td>
<td>13.56</td>
<td>25.88</td>
<td>19.15</td>
<td>37.79</td>
<td>3.62</td>
<td>Loamy-clayey sand</td>
</tr>
</tbody>
</table>

Table 2.12. Mean sediment particle diameter in the Brač and Split channels at the stations indicated on Figure 2.8.

<table>
<thead>
<tr>
<th>Station</th>
<th>Depth (m)</th>
<th>Mean particle diameter (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>50</td>
<td>25</td>
</tr>
<tr>
<td>2</td>
<td>34</td>
<td>45</td>
</tr>
<tr>
<td>3</td>
<td>52</td>
<td>25</td>
</tr>
<tr>
<td>4</td>
<td>51</td>
<td>400</td>
</tr>
<tr>
<td>5</td>
<td>55</td>
<td>4.5</td>
</tr>
<tr>
<td>6</td>
<td>45</td>
<td>256</td>
</tr>
<tr>
<td>7</td>
<td>53</td>
<td>45</td>
</tr>
<tr>
<td>8</td>
<td>60</td>
<td>135</td>
</tr>
<tr>
<td>9</td>
<td>65</td>
<td>40</td>
</tr>
<tr>
<td>10</td>
<td>28</td>
<td>80</td>
</tr>
</tbody>
</table>
If particle size reflects the dynamics of water masses in a particular area (greater presence of smaller particles is suggestive of poorer bottom flow and vice versa, than it is obvious that the flow is stronger along the Brač Island coast and poorer along the northern coast of the channels. Isolines in the central part of the Brač-Split Channel point to a possible cyclonic flow.

**Transparency**

Transparency measured at station 1 (Figure 2.7) in front of Split between 1976 and 1990 ranged between 5 and 37 m. Extremely high transparency was recorded only once whereas the lowest value of 5 m was recorded several times. Mean value of measured values was 12.23 m and standard deviation 5.74 m. Transparency shows here no definite trend.
2.2. BIOLOGICAL ENVIRONMENT

2.2.1. Terrestrial vegetation

Present vegetation has almost completely been the result of the thousand years of human activities in this area. Coastal plain and slightly steep slopes are mainly used for agriculture. However, agricultural land has been permanently lost as a result of the recent development of towns and residential zones. Steeper slopes and mountain sides have preserved the residues of original vegetation cover, even though secondary vegetation of coppices and underwood extends here and covers completely bare surfaces. The coastal plain may have lost its original vegetation already in Neolithic with first forest clearing, ploughing and firing.

Primary vegetation of this area belongs to two plant-geographical zones: Mediterranean - evergreen one and sub-Mediterranean - deciduous (Figure 2.8).

The Mediterranean - evergreen zone lies prevalently in the lower coastal part dominated by Quercus ilex L.

The sub-Mediterranean - deciduous vegetation with the species Carpinus orientalis Mill, Quercus pubescens L. Traxinus ornus L. and Ostrya carpinifolia Scop., is dominant in higher parts below mountain sheer rocks.

However, long term frequently careless wood exploitation has changed the structure of the Kaštela area vegetation. The primary evergreen vegetation has been strongly degraded or it almost completely disappeared. Therefore different degradational stages of this vegetation cover the most part of this area.

Deserted terraces were planted by pine woods of Pinus halepensis Mill., cypress (Cupressus sempervirens Mill) and arborvitae (Thuja orientalis). Of wild growing plants Pistacia lentiscus, Pistacia terebinthus, Phillyrea media, Juniperus oxycedrus and Spartium junceum are encountered here.

Pine woods spread very quickly invading new areas of deserted anthropogenic terraces.

The largest pine trees was planted on the Marjan Hill. Pine trees also dominate on the east of Solin basin and toward Žrnovnica.

Very degraded surfaces with shallow and skeleton soil are overgrown by rocky pastures and dry grassland characterized by a large number of species.

Strongly degraded surfaces of evergreen vegetative belt (on the west from Kaštel Gomilica to Trogir), where trees and coppice vegetation has almost completely disappeared, are of the form of spacious, deserted rocky land covered of arid rocky grassland and Adriatic coastal rocky land (Brachypodio - Chrysopogonetea).

Low, alluvial plains along the rivers Jadro and Žrnovnica and also Pantan spring were once covered by wetland vegetation of which very little has remained along the Jadro River. Wetlands vegetation still covers some parts of the right bank and estuary of the Žrnovnica River and the Pantan. Of wetland vegetation there may be found Sparagenum erectum, Juncus maritimus, Chlorociperus longus and the reed species Phragmites Communis Trin.
Fig. 2.8. Vegetation cover of the area
2.2.2. Marine biology

Qualitative and quantitative (density) phytoplankton composition was observed at stations in front of Split and Stobrec in 1972 and 1973. Seasonal variation amplitudes of phytoplankton were very small. Phytoplankton quantity ranged between 52000 and 96000 cells/L.

During the September 1990 and April 1991 cruises in the Brač and Split channels phytoplankton chlorophyll biomass (chlorophyll a) was determined apart from its qualitative structure. Values of chlorophyll a biomass ranged from 0.09 to 0.48 mg chl a m\(^{-3}\). Highest chlorophyll a biomass was recorded from stations in vicinity of Trogir and Split. The April cruise was realized during regular spring phytoplankton bloom so that chlorophyll a values varied from 0.35 to 1.47 mg chl a m\(^{-3}\).

Vertical distribution of chlorophyll a on the profile of coastal stations shows high concentrations in the surface layer of stations in front of Split and Stobrec and bottom layer west of Split. The area with high surface concentrations corresponds to the area with high ammonia (NH\(_3\)-N) concentrations and the area with high bottom concentrations to that with high nitrate (NO\(_3\)-N) concentrations.

The same samplings were carried out in the Kaštela Bay and open Adriatic waters (Stončica) during the same time interval. A comparison of obtained data showed Brač and Split channels to be more similar to Stončica than to the Kaštela Bay. Chlorophyll a quantities in the Kaštela Bay were three to four times those recorded from most of the channels stations. Vertical distribution was uniform in April pointing to intensive vertical sea water mixing. During April, production in the area of the channels was more similar to that in the Kaštela Bay than to that in the open sea (Stončica).

Qualitative phytoplankton structure shows great variety throughout the area, pointing to a rich but still "healthy" phytoplankton community. The area of the Brač and Split channels is more strongly affected by precipitation waters than by sewage effluents of the town of Split. Seasonal variations of zooplankton biomass in the coastal zone of the Brač Channel are shown by the data collected during 1972/73 (Table 2.13).

<table>
<thead>
<tr>
<th>Station</th>
<th>Time</th>
<th>10</th>
<th>11</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>September 1972</td>
<td>89</td>
<td>67</td>
</tr>
<tr>
<td></td>
<td>November 1972</td>
<td>47</td>
<td>47</td>
</tr>
<tr>
<td></td>
<td>April 1973</td>
<td>36</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>July 1973</td>
<td>57</td>
<td>42</td>
</tr>
<tr>
<td></td>
<td>August 1973</td>
<td>69</td>
<td>91</td>
</tr>
<tr>
<td></td>
<td>November 1973</td>
<td>105</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>January 1974</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Geometrical mean</td>
<td></td>
<td>38</td>
<td>12</td>
</tr>
</tbody>
</table>

September 1990 and April 1991 cruises showed that zooplankton biomass at stations in front of Split and Stobrec was 107 and 70 mg/haul respectively in September and 61 and 49 mg/haul respectively in April. Spatial distribution of zooplankton biomass in the Brač and Split channels
showed the greatest concentrations in the channels centre in September, and between Postira and Dugi Rat and in the Split Strait in April. This affects small pelagic fish behavior, that is their concentrations were also greatest at these sites which are also the sites of their spawning.

Of planktonic fish stages sardine eggs and larve are dominant both by their numbers and percentages. The analysis of spatial distribution of the total numbers of fish eggs and larvae showed their greatest concentration in the area close to Stobrec in September 1990 and between Postira and Dugi Rat in April 1991. Greater quantity of eggs in the area of the Split Strait in April is indicative of the possible effect of incoming current from the open sea to this area.

The analysis of benthic flora may be used as a good indicator of pollution state of a particular area. This particularly applies to three principal systematic algal groups: RHODOPHYTA (red algae), PHAEOPHYTA (brown algae) and CHLOROPHYTA (green algae). The group CHLOROPHYTA is most tolerant to pollution and eutrophication whereas PHAEOPHYTA are least tolerant.

The phytobenthos of the Split peninsula was studied in 1973/74. Two transects have been chosen, Zvončac and Stobrec. During the 1977/78 research algae were determined from Zvončac and Katalinića brig transects (Table 2.14).

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>RHODOPHYTA</td>
<td>27 47.4</td>
<td>16 40.0</td>
<td>59 62.8</td>
<td>38 53.5</td>
</tr>
<tr>
<td>PHAEOPHYTA</td>
<td>17 29.8</td>
<td>15 37.5</td>
<td>21 22.3</td>
<td>19 26.8</td>
</tr>
<tr>
<td>CHLOROPHYTA</td>
<td>13 22.8</td>
<td>9 22.5</td>
<td>14 14.9</td>
<td>14 19.7</td>
</tr>
<tr>
<td>TOTAL</td>
<td>57</td>
<td>40</td>
<td>94</td>
<td>71</td>
</tr>
<tr>
<td>R/P</td>
<td>1.6</td>
<td>1.1</td>
<td>2.8</td>
<td>2.0</td>
</tr>
</tbody>
</table>

Phytobenthic research was carried out in a wider area of Brač and Split channels in 1990 (Table 2.15).

<table>
<thead>
<tr>
<th>Taxonomic groups</th>
<th>Split</th>
<th>Stobrec</th>
<th>Čiovo</th>
<th>Brač</th>
<th>Entire area</th>
</tr>
</thead>
<tbody>
<tr>
<td>RHODOPHYTA</td>
<td>59 68.6</td>
<td>87 64.0</td>
<td>97 68.8</td>
<td>107 63.3</td>
<td>140 61.4</td>
</tr>
<tr>
<td>PHAEOPHYTA</td>
<td>10 11.6</td>
<td>27 19.9</td>
<td>26 18.4</td>
<td>39 23.1</td>
<td>50 21.9</td>
</tr>
<tr>
<td>CHLOROPHYTA</td>
<td>17 19.8</td>
<td>22 16.2</td>
<td>18 12.8</td>
<td>23 13.6</td>
<td>38 16.7</td>
</tr>
<tr>
<td>TOTAL</td>
<td>86</td>
<td>136</td>
<td>141</td>
<td>169</td>
<td>228</td>
</tr>
<tr>
<td>CYANOPHYTA</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>ANGIOSPERMAE</td>
<td>2</td>
<td>1</td>
<td>-</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>TOTAL</td>
<td>89</td>
<td>138</td>
<td>142</td>
<td>173</td>
<td>233</td>
</tr>
<tr>
<td>R/P</td>
<td>5.9</td>
<td>3.2</td>
<td>3.7</td>
<td>2.7</td>
<td>2.8</td>
</tr>
</tbody>
</table>
The greatest changes in the structure of phytobenthic settlements of the coastal channel part were found at the Zvončac transect (Split) where the number of species was considerably smaller than on other transects. Recorded species mainly prefer eutrophized water most frequently polluted by chemicals. The changes at Stobreč transect were not of that intensity. A considerably greater number of species was recorded from the transects of the southern Ćiovo coast and western Brač coast. It is also important that no nytrophilous species were found which is indicative of the fact that the area of Brač and Ćiovo have not yet been under the man-made impact.

Faunal material was also collected during the research of the Brač and Split channels. It is qualitatively presented by systematic categories.

Table 2.16. Numerical and percentage presence of macrozoobenthic species by systematic categories at the transects Zvončac, Katalinića brig and Stobreč during earlier studies

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No</td>
<td>%</td>
<td>No</td>
<td>%</td>
</tr>
<tr>
<td>PORTIFERA</td>
<td>5</td>
<td>6.2</td>
<td>4</td>
<td>7.3</td>
</tr>
<tr>
<td>CNIDARIA</td>
<td>4</td>
<td>5.0</td>
<td>3</td>
<td>5.4</td>
</tr>
<tr>
<td>ANNELIDA</td>
<td>3</td>
<td>3.7</td>
<td>1</td>
<td>1.8</td>
</tr>
<tr>
<td>ARTHROPODA</td>
<td>14</td>
<td>17.5</td>
<td>14</td>
<td>25.4</td>
</tr>
<tr>
<td>MOLLUSCA</td>
<td>31</td>
<td>38.7</td>
<td>23</td>
<td>41.8</td>
</tr>
<tr>
<td>TENTACULATA</td>
<td>4</td>
<td>5.0</td>
<td>1</td>
<td>1.8</td>
</tr>
<tr>
<td>ECHINODERMATA</td>
<td>17</td>
<td>21.2</td>
<td>7</td>
<td>12.7</td>
</tr>
<tr>
<td>TUNICATA</td>
<td>2</td>
<td>2.5</td>
<td>2</td>
<td>3.6</td>
</tr>
<tr>
<td>TOTAL</td>
<td>80</td>
<td>55</td>
<td>105</td>
<td>93</td>
</tr>
</tbody>
</table>

Studies of qualitative structure of zoological component of bionomic steps of supralittoral, medilittoral and infralittoral down to 30 m depth at the transects Split (Zvončac), Stobreč (southern side), Ćiovo (southern side) and Brač (northern side) were carried out as a part of the complex research in September 1990.

The transect on the southern side of Ćiovo is marked by the number and diversity of species present there (112), followed by the transect along the northern side of the Brač Island (96) whereas the data for the transects in Split (Zvončac) (76) and Stobreč (75) were very similar and slightly poorer (Table 2.17).

Table 2.17. Numbers and percentage presence of macrozoobenthic species by systematic categories at individual transects studied in September 1990

<table>
<thead>
<tr>
<th>Systematic Category</th>
<th>Split No</th>
<th>%</th>
<th>Stobreč No</th>
<th>%</th>
<th>Ćiovo No</th>
<th>%</th>
<th>Brač No</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>PORTIFERA</td>
<td>8</td>
<td>10.5</td>
<td>7</td>
<td>9.3</td>
<td>22</td>
<td>19.6</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>CNIDARIA</td>
<td>5</td>
<td>6.6</td>
<td>3</td>
<td>4.0</td>
<td>6</td>
<td>5.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ANNELIDA</td>
<td>5</td>
<td>6.6</td>
<td>5</td>
<td>6.7</td>
<td>5</td>
<td>4.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ARTHROPODA</td>
<td>9</td>
<td>11.8</td>
<td>8</td>
<td>10.7</td>
<td>13</td>
<td>11.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MOLLUSCA</td>
<td>37</td>
<td>48.7</td>
<td>44</td>
<td>58.7</td>
<td>49</td>
<td>43.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TENTACULATA</td>
<td>1</td>
<td>1.3</td>
<td>1</td>
<td>1.3</td>
<td>1</td>
<td>0.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ECHINODERMATA</td>
<td>7</td>
<td>9.2</td>
<td>6</td>
<td>8.0</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TUNICATA</td>
<td>4</td>
<td>5.3</td>
<td>1</td>
<td>1.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The transect along the southern side of Ciovo is far from any pollution source and is exposed to a permanent inflow of the sea water carried by current and to waves resulting in the richness and diversity of zoological element. Similar applies to the transect near Brač. However, the areas of Split and Stobreč are affected by municipal effluents. The adverse effects are manifested as poor zoological element of mediolittoral and upper infralittoral in the area of Split and Stobreč, where the changes in floral and faunal structure have already been recorded.

2.2.3. Fisheries, places of special interest for spawning and nursery grounds of commercial important species

The most important commercial pelagic species in the area are sardina (*Sardina pilchardus* Walb), anchovy (*Engraulis encrasicolus* L.), while demersal species are silver hake (*Merluccius merluccius*), striped mullet (*Mullus barbatus*), boops (*Boops boops*) and *Maena smaris*.

The usual positions for traditional fishing under lamplight of sardinas and anchovies are shown on Figure 2.9. The average yearly yield of these species for the past period was estimated at 500 t for the Kaštela Bay and at 2000 t for Brač-Split channels, while at present time was estimated at 50 and 1500 t respectively.

The trawl fishing is forbidden over the entire area of Kaštela Bay, while in Brač-Split channels is forbidden in the 1 Nm wide coastal strip and in the area between Stobreč and Supetar (Figure 2.10). According to the recently adopted regulation (NN 46/1996) trawling is allowed in the period from 1 October until 31 March from 5.00 a.m. to 10.00 p.m in Wednesday and Thursday only. There are no information on yearly yield.

The Kaštela Bay is the spawning area for sardina and anchovy, but not Brač and Split. Recently was discovered that species *Lithognathus mormyrus*, L. was spawned during June and July at northeastern coast of Ciovo island (Kraljević et al., 1992).

Estuaries of Jadro river and Pantana spring are the most important nursery grounds for sardines and anchovies, and very probably for other marine species. A similar situation should be at the estuary of Žrnovica river, but there are not adequate information.

2.2.4. Rare or endangered species and sensitive habitats

So far, no rare or endangered species and sensitive habitats are identified in the area.

2.2.5. Quality of receiving waters

Quality of receiving marine waters could be expressed in terms of the levels of pollutants concentrations in different components of marine ecosystems, as well as a health of the marine ecosystems. Both way, in describing the present and past trends in quality of marine waters, are used in this report.

**Kaštela Bay**

The Kaštela Bay has been used as a recipient of the total amount of untreated urban waste waters of Trogir, Kaštela, Solin, and about 40 % of the total amount of the town of Split, as well as total, partially treated, industrial waste waters of the whole industry in the region. This kind of pollution, together with airborne pollution and drainage from the urban and agricultural areas affect the marine ecosystems.
Fig. 2.9. Usual station for traditional fishing under lamplight
Fig. 2.10. Zone for trawl fishing
An eutrophication phenomenon in the Bay is very well developed. Results of the analyses of long-term data series of dissolved oxygen, nutrients, transparency and phytoplankton have shown a continuous increase of the eutrophication in the Bay. While the concentration of oxygen in the euphotic layer increases due to a higher phytoplankton productivity, in the bottom layer it decreases as a result of the activity of heterotrophic bacteria (Figure 2.11). The nitrogen/phosphorus ratio in sea water has decreased, and today is much lower than in the open sea. From the Secchi-disc data it is clear that transparency has also decreased for the last three decade (Figure 2.12). Primary production as well phytoplankton biomass has also increased (Figure 2.13). The structure of phytoplankton community has been changed and dinoflagellate species have become dominant rather than diatoms.

The direct consequence of the eutrophication is the occurrence of mass mortality of marine organisms which normally happened by the end of summer in the eastern, the most polluted, part of the Bay.

Microbial pollution of the Bay is very high. Dispersion of the pollution depends on winds conditions, but almost entire area of the Bay is not suitable for bathing (Figure 2.13).

Concentration of mercury in the marine sediment is very high (1.95 - 8.79 mg Hg/kg of dry sediment), due to more than 40 years of discharge of waste from a chlor-alkali plant which was operating in Kaštela Sučurac.

The Bay could be considered as sensitive area because it can be found highly eutrophicated area as a result of poor water exchange and a discharge of large quantities of urban waste water.

---

**Fig. 2.11. Average annual values of dissolved oxygen in the surface and bottom layer at the central sampling station in Kaštela Bay**
Fig. 2.12. Average annual values of transparency (Secchi disc) at the central sampling station in Kaštel Bay.

Fig. 2.13. Increase of the primary production and chlorophyll a in the Kaštel Bay.
**Trogir Bay**

Comparing to the Kaštela Bay, the Trogir Bay is much less polluted. A study of sanitary quality of marine waters in the Bay, performed in the summer 1993, shows that the Bay is moderately polluted by urban waste waters, particularly in the eastern and north-eastern part. This part, obviously, is under the influence of urban waste waters of the town of Trogir and village of Seget. The distribution of indicators of faecal pollution throughout the Bay depends on wind conditions.

There are no other available information which could be used for the characterization of quality of marine waters in the Bay.

**Brač and Split channels**

The most northeastern part of the Split channel and the northwestern part of the Brač channel are under strong influence of high polluted city harbors (it receives a large amounts of untreated urban waste water). In this part of the channels the greatest changes in benthic communities have been recorded as a result of waste water pollution. A number of species was considerably smaller than on the western part of Split channel and at the northwestern coast of Brač island. In this part (Zvončac profile) the group of Phaeophyta (brown algae), the least tolerant to eutrophication, is represented by 11.6 %, while the group of Chlorophyta, the most tolerant to pollution and eutrophication, is represented by 19.8 %. In the same time at the profile at Ćiovo island the percentage of Phaeophyta and Chlorophyta are 18.4 % and 12. % respectively. The changes at the Stobrec are less pronounced than at the Zvončac profile (Figure 2.14). A similar changes were found in number of zoobenthic species (Figure 2.15).

The concentrations of heavy metal (Cd, Pb, Cu, and Zn) in surface sediment sampled in 1990 are given in Table 2.18.

**Table 2.18.** Mean concentration of Cd, Pb, Cu, and Zn in surface sediment (mg/kg of dry sediment)

<table>
<thead>
<tr>
<th>Station</th>
<th>Cd</th>
<th>Pb</th>
<th>Cu</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.796</td>
<td>38.48</td>
<td>26.45</td>
<td>167.47</td>
</tr>
<tr>
<td>2</td>
<td>0.831</td>
<td>28.71</td>
<td>20.01</td>
<td>115.57</td>
</tr>
<tr>
<td>3</td>
<td>1.006</td>
<td>37.99</td>
<td>24.93</td>
<td>149.75</td>
</tr>
<tr>
<td>4</td>
<td>0.674</td>
<td>17.24</td>
<td>11.92</td>
<td>63.86</td>
</tr>
<tr>
<td>5</td>
<td>0.832</td>
<td>35.89</td>
<td>19.55</td>
<td>117.11</td>
</tr>
<tr>
<td>6</td>
<td>0.503</td>
<td>20.19</td>
<td>12.82</td>
<td>73.84</td>
</tr>
<tr>
<td>7</td>
<td>0.650</td>
<td>38.08</td>
<td>24.04</td>
<td>162.02</td>
</tr>
<tr>
<td>8</td>
<td>0.487</td>
<td>24.42</td>
<td>14.36</td>
<td>72.47</td>
</tr>
<tr>
<td>9</td>
<td>0.730</td>
<td>34.50</td>
<td>22.28</td>
<td>160.28</td>
</tr>
<tr>
<td>10</td>
<td>0.674</td>
<td>32.59</td>
<td>15.63</td>
<td>88.09</td>
</tr>
</tbody>
</table>
Fig. 2.14. Presence of species of benthic algae on studied localities in Brač-Split channels.
Fig. 2.15. Presence of macrozoobenthic species by systematic categories on studied localities in the Brač-Split channels.
The reported values are within the range of natural concentration for marine sediments from the open Mediterranean sea, only zinc was present at a level which was twice of natural values. The increased zinc concentration was explained by the discharge of urban waste water into the channels.

The Brač and Split channels, in general, could be considered as less sensitive area because of relatively good water exchange with open sea, they are not subject to eutrophication or oxygen depletion, and could be considered unlikely to become eutrophic or to develop oxygen depletion due to the discharge of urban waste water.

2.2.6. Sanitary quality of marine coastal waters and die-off rate of faecal bacteria

Split town port and Vranjic basin are principal faecal pollution sources, besides a numerous outlets dispersed along the entire coastline of the studied area, since they receive untreated municipal sewage effluents. The speed and direction of waste water spreading in this area and its effects on the adjacent coastal sea is highly dependent on wind direction and speed. Split recreational zones only partly meet the requirements for their use (Figure 2.16). The poorest sea water quality was regularly recorded from Zvončac and Bačvice, which may be attributed to town port impact. Stations Bene, Kašjuni, Hotel "Split" and Hotel "Lav" almost always met the requirements for their use. No essential oscillations in the number of faecal pollution indicators were recorded during the period of investigations with the exception of 1986 when these values were extremely high throughout the Split area. This was probably due to uncontrolled discharges of material from septic tanks into the collectors in the close vicinity to the sea, which overloaded the coastal area with faecal wastes.

Die-off rate of faecal bacteria (T_{90}) were measured at different depths at the station in front of Split in September 1990 and April 1991. The former measurement was carried out during poor insulation (very cloudy) and the latter during a sunny day. Both measurements showed that T_{90} significantly increase with depth (Table 2.19).

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>T_{90} (hour)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>September 1990</td>
</tr>
<tr>
<td>0</td>
<td>5.48</td>
</tr>
<tr>
<td>5</td>
<td>7.84</td>
</tr>
<tr>
<td>10</td>
<td>9.32</td>
</tr>
<tr>
<td>20</td>
<td>13.80</td>
</tr>
<tr>
<td>30</td>
<td>20.29</td>
</tr>
<tr>
<td>40</td>
<td>28.75</td>
</tr>
<tr>
<td>45 (bottom)</td>
<td>62.73</td>
</tr>
</tbody>
</table>
Fig. 2.16. Sanitary quality of the coastal water in the area
2.3. ASSIMILATIVE CAPACITY OF RECEIVING WATERS

The assimilative capacity of a body of water was defined by Goldberg (1979) as "amount of material that could be contained within a body of seawater without producing unacceptable biological impact". The word assimilation is not quite proper, therefore GESAMP (1986) replaced it by a word "environmental". The environmental capacity is defined as a ability of the environment to accommodate a particular activity or rate of activity without unacceptable impact.

The determination of environmental capacity of the study areas to accommodate urban waste waters requires rather more scientific information than is currently available. The capacity of Split-Brač channels to accommodate the waste waters was determined using a numerical model (see Appendix 2). The model was used to assess impacts of organic substances contained in the urban waste waters on the oxygen concentration. The model was made for the "steady state" conditions, without the time component. It was tested using the existing data, which is not sufficient, specially because there are no data for the summer critical season. It is, also, very important to point out that the model doesn't deal with the changes in biological components of the marine ecosystems which would happened as consequences of the urban waste waters discharge.

Results of the model indicated that this area has the ability to accumulate the planned quantities of the urban waste waters without unaccepted oxygen concentration decrease. Despite the mentioned disadvantages the results were used as good indications in the decision taking on the suitability of the Split-Brač channels to accommodate of the urban waste waters. In order to confirm the conclusion that the Split-Brač channels are the best solution for the accommodation of the urban waste waters, for the purpose of this report, the Kaštel Bay, Split and Brač channels and Trogir Bay are discussed in terms of their volume, sea current velocities and predominant directions and general physical characteristics.

The Kaštel Bay is a semienclosed oval shape bay. Its longest axis is 14.8 km long, while the shorter axis is 6.6 km long. The total volume of the Bay is 1.4 km$^3$, and average depth is about 23 m. The shallowest parts of the Bay are the eastern and western corners. The residual current field variations and the water exchange with the Split channel is mainly wind-driven. The average flushing time is about a month. The narrow coastal strip of the Bay is a highly developed area with various uses (housing, industry, harbor, tourism, recreation, etc).

The Trogir Bay, a semi-enclosed bay, as well, is much smaller than the Kaštel Bay. It is 5 km long, only, and 2.5 km wide. The depth at the planned location of the submarine outfall is 25 m, while the average depth is about, which gives the total volume of about 0.25 km$^3$. The residual currents (during the summer period in 1993) were very weak, particularly during a calm weather. The average current speed in the surface layer was 9 cm/s and at the bottom layer was 6 cm/s, while the predominant directions were N and ENE. The water exchange with the adjacent basin, would be, therefore, very weak. The coastal strip of the Bay is rather developed for tourism and recreation. Only, the north-eastern part is developed for housing (Trogir and Seget).

The Split-Brač channels represent a much larger water body than the Kaštel bay. The average depth of the Split channel is 60 m, its length is 20 km, and wide is about 10 km. The total volume of the channel is about 12 km$^3$. The average depth of the Brač channel is about 50 m and its volume is about 16 km$^3$. The main directions of sea currents in the channels are westward and northward (measured in September 1990 and April 1991). These directions are in fact a part of the incoming current of general Adriatic circulation along the Croatian coast. The
highest speeds occur in autumn and winter months as a consequence of stronger wind forcing. The maximum recorded speeds in the surface layer are up to 60 cm/s.

In the summer, surface flow completely follows winds directions. Under "Bura" conditions the flow is of offshore direction and under "jugo" it is of westward direction with an onshore component. The most frequent summer wind "maestral", which locally blows from the southwest, forces surface flow in eastward direction. Mean speed in the bottom layer measured in September 1990 in the Split channel at a station in the vicinity of the planned submarine outfall was 4.2 cm/s (minimum 1.5 cm/s and maximum 11.3 cm/s). The onshore current direction (N) frequency at the bottom level was zero, while at the surface level was 32%. The sea currents measurements at the station located in vicinity of Stobrec submarine outfall showed the following: in September 1990 the average speed in the upper layer was 4.8 cm/min (minimum 1.1 cm/s, maximum 12.6 cm/s) and in the bottom layer was 6.2 cm/s (minimum 1.1 cm/s, maximum 14.2 cm/s); the onshore current component (N) frequency in the bottom layer was 12% (average speed 6.3 m/s) and in the bottom layer was 20% (average speed 8.1 m/s); in April 1991 the average speed in the upper layer was 16.5 cm/s (minimum 1.5 cm/s, maximum 45.6 cm/s); the onshore current direction (N) frequency 10% (average speed 13.9 cm/s).

The coastal strip of the channel in its western part is mainly undeveloped.

The ratio of the volumes of the Split-Brač channels, Kaštel and Trogir bays is 112:5.6:1. This makes the Split Channel the most suitable to accommodate of waste water, while the Trogir Bay is the least suitable.

Sea currents, directions and velocities also favor discharge to the Split-Brač channels. The predominant directions are along the shores, which will result in the waste water not being transported towards the shores but removed from the area of discharge to a wider area. The secondary dilution of the discharged waste will be much higher. In case of the Kaštel and Trogir bays onshore direction of sea currents are significant, which could bring the waste to the shore. Some amount of the waste could be trapped in the bay. The accumulation of waste in the bays would impact the marine ecosystems. In the case of Trogir Bay, due to its small dimension it is impossible to discharge the waste waters far enough offshore, in order to preserve the coastal water for bathing and recreation.

The depth of the planned submarine outfall plays the significant role in the selection of the most suitable location. In the Split-Brač channels, the depth of the outfall is 55 m and 32 m respectively, while in the Kaštel Bay and in the Trogir Bay are 30 and 25 m, respectively. In the of case the Split channel the discharge of waste water would occur well enough below the thermocline during a summer season. The probability that the waste water would enrich the sea surface is very low as the plume would be trapped below the thermocline and generally dispersed in the water column. A similar situation will apply in the Brač channel and Kaštel Bay. In Trogir Bay however it is more likely that the will plume reaches the surface and the waste water transported towards the shore by relative fast onshore winter-induced currents.

The present ecological conditions of the Split-Brač channels also indicate that this is the most suitable environment for the accommodation of urban waste waters.

On the basis of previously said, it can be concluded that the Split-Brač channels represent ecologically the most acceptable solution for the disposal of Split, Solin, Kaštel and Trogir waste waters. The advantages are:
- they have the largest volume;
- they are the deepest, what is very convenient for thermocline and for primary dispersion;
- they are not closed, so the outfalls could be as long as necessary;
- main current is longitudinal, and so it will transport the waste waters of the channels into the open sea (waste water will not stay in the channels);
- the influence of the urban areas of towns Omiš, Split and Trogir is the least in Split channel.
2.4. SOCIOCULTURAL ENVIRONMENT

2.4.1. Present and projected population

The number of inhabitants in the Kastela Bay area varied in different intercensuses periods, but the population growth rate has always been rather high (Table 2.20).

Population expansion reached its highest point in the intercensus period of 1961-1971-1981. This significant rise in population proves that the Kastela Bay is an attractive urbanized area with the city of Split, i.e. its coastal agglomeration, having absorbed a large part of the migration. These processes took place in the period of intensive changes in the population economic structure (decline of agrarian complex and loss of rural population) and consequent changes in spatial distribution of the population in wider gravitational zone. In the decade between 1971 and 1981 the population growth continued, however at a lower rate. The population growth rate decreased from 2.3 per cent in the period between 1971 and 1981 to 1.2 per cent in the period between 1981 and 1991. This is very important because such a trend leads towards a gradual restraining of excessive growth which has already resulted in overpopulation in the area.

Table 2.20. Population according to censuses in the period between 1857 and 1991.

<table>
<thead>
<tr>
<th>Year</th>
<th>Kaštela</th>
<th>Split</th>
<th>Trogir</th>
<th>Kastela Bay</th>
<th>% in Croatia</th>
</tr>
</thead>
<tbody>
<tr>
<td>1857</td>
<td>9,540</td>
<td>13,407</td>
<td>14,545</td>
<td>46,174</td>
<td>2.12</td>
</tr>
<tr>
<td>1900</td>
<td>13,124</td>
<td>18,486</td>
<td>26,208</td>
<td>70,665</td>
<td>2.24</td>
</tr>
<tr>
<td>1948</td>
<td>15,806</td>
<td>24,318</td>
<td>57,022</td>
<td>114,657</td>
<td>3.03</td>
</tr>
<tr>
<td>1953</td>
<td>17,038</td>
<td>23,955</td>
<td>67,822</td>
<td>127,369</td>
<td>3.24</td>
</tr>
<tr>
<td>1961</td>
<td>20,125</td>
<td>25,445</td>
<td>87,303</td>
<td>151,984</td>
<td>3.65</td>
</tr>
<tr>
<td>1971</td>
<td>24,626</td>
<td>27,797</td>
<td>133,048</td>
<td>203,951</td>
<td>4.60</td>
</tr>
<tr>
<td>1981</td>
<td>28,550</td>
<td>27,105</td>
<td>180,571</td>
<td>256,082</td>
<td>5.56</td>
</tr>
<tr>
<td>1991</td>
<td>32,286</td>
<td>27,402</td>
<td>207,147</td>
<td>289,003</td>
<td>6.04</td>
</tr>
</tbody>
</table>

Some studies, done before aggression in 1991 and significant socioeconomic changes, are predicting a further increase of population in the area to reach 376,000 in the year 2011, and 415,000 in the year 2025. After the transition changes happened in the last five years it is very difficult to predict the future development in the area. It would need some time to settle down present difficulties in the economy and related consequences in the society.

2.4.2. Present and planned land use

Figure 2.17 shows the planned land use of the wider area of the Kastela Bay. The largest part of the coastal strip is devoted for the settlements and recreation. Area for Touristic development is also very significant. Comparing the planned land use with present land use it comes out that tourism and recreation are receiving much more importance than in the past. New touristic zones are planned in Kastela between K. Lukšić and K. Kambelovac, on the southwestern part of Ćiovo island and westward of Stobreč.

The planned submarine outfall in Stobreč is located in between the existing and planned touristic zone, while the Mavarštica outfall is located in the vicinity of the planned touristic zone on the western part of Ćiovo island. Both treatment plants are located in the vicinity of existing or planned settlement area of low density.

The planned main sewer collectors in the Kastela, Solin and Trogir will be placed in a settlement area of low density, while in Split will be placed mostly in an industry and services area.
Fig. 2.17. Planned land use in the area
3. LEGISLATIVE AND REGULATORY CONSIDERATIONS

3.1. NATIONAL LEGISLATIVE

An umbrella law in the field of environment is "Law on the Environment" which passed in the Parliament in 1995. Different sectorial laws deal with specific subjects relevant to the environment. The Law on Waters, among other subjects, deals with pollution protection of the sea from land based sources of pollution. In accordance with the law provisions a criteria for the classification of coastal marine waters, as well as regulations on maximum permissible concentrations of dangerous and other substances in industrial and urban wastewaters before discharge into a natural recipient should be developed. Until the new regulations will be adopted, old regulations are still in the force. According to the Regulations on Water Classification (NN 15, 1981) coastal marine water could be classified in four categories (I category for shellfish culture, II category for bathing, recreation and water sports, III category for fisheries, and IV category for harbor).

The classification of coastal marine water could be done in the compliance with 11 parameters (Table 3.1).

Table 3.1. Parameters used in the classification of coastal marine waters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>I category</th>
<th>II category</th>
<th>III category</th>
<th>IV category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suspended matter (mg/l), no more than</td>
<td>10</td>
<td>20</td>
<td>60</td>
<td>-</td>
</tr>
<tr>
<td>NVB coliforms/l, no more than</td>
<td>100</td>
<td>5,000</td>
<td>200,000</td>
<td>-</td>
</tr>
<tr>
<td>Dissolved oxygen (% of sat.)</td>
<td>70</td>
<td>60</td>
<td>40</td>
<td>20</td>
</tr>
<tr>
<td>pH</td>
<td>8.1 ± 0.2</td>
<td>± 0.3</td>
<td>± 0.3</td>
<td>± 0.4</td>
</tr>
<tr>
<td>Degree of biological product</td>
<td>oligotroph.</td>
<td>oligotroph.</td>
<td>oligotroph.</td>
<td>eutrophic</td>
</tr>
<tr>
<td>Visible waste</td>
<td>without</td>
<td>without</td>
<td>without</td>
<td>without</td>
</tr>
<tr>
<td>Temperature increase (°C)</td>
<td>0</td>
<td>2</td>
<td>3</td>
<td>12</td>
</tr>
<tr>
<td>Oil, crude oil, refined petroleum products - on a surface (mg/l)</td>
<td>0.05</td>
<td>1</td>
<td>10</td>
<td>100</td>
</tr>
<tr>
<td>Surface active substance (miliequivalents T-X-100/l)</td>
<td>0.05</td>
<td>1</td>
<td>10</td>
<td>100</td>
</tr>
<tr>
<td>Radioactivity (Bq/l)</td>
<td>Total radionuclides should not exceed the maximal allowed concentration of alpha=0.1, beta=1.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dangerous substances</td>
<td>Should be not present at concentration higher than prescribed for each category</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

By the Regulations of Maximum Permissible Concentrations of Dangerous Substances in Freshwater and Coastal Marine Waters (NN 2, 1984) the maximum permissible concentrations (mg/dm³) of dangerous substances for each of the water category are prescribed. According to the same Regulations the concentrations of dangerous substances in waste waters at marine outlets could be 200 times greater than values prescribed for coastal marine waters.
At the regional levels still is in force the Action Plan for Water Protection from Pollution of the Split Region which prescribes the maximum permissible concentration of dangerous substances which may contain waste waters to be discharged into a public sewer system (Table 3.2). Waste waters entering a public sewer system should not contain: flammable and explosive substances; noxious gases (H₂S, SO₂); nitrogen oxides, HCN, chlorine, etc.; waste waters from hospitals, slaughterhouse, veterinary stations and similar which were not disinfected before discharge; solid and viscose such as: ash, sludge, metal scrap, plastics, wood, glass, feather, hair, meat, chemicals, etc.; acid, alkaline and aggressive substances; other noxious substances. pH of industrial waste water should be not less than 5.5 and more than 9.5. The discharge of industrial waste waters into public sewer system or coastal waters is allowed only after the pretreatment in accordance with an authorization for discharge.

<table>
<thead>
<tr>
<th>Substance</th>
<th>Concentration mg/l</th>
</tr>
</thead>
<tbody>
<tr>
<td>settled material</td>
<td>20</td>
</tr>
<tr>
<td>suspended matter</td>
<td>200</td>
</tr>
<tr>
<td>BOD₅</td>
<td>300</td>
</tr>
<tr>
<td>COD</td>
<td>500</td>
</tr>
<tr>
<td>total oils</td>
<td>40</td>
</tr>
<tr>
<td>mineral oils</td>
<td>20</td>
</tr>
<tr>
<td>phenols</td>
<td>0.5</td>
</tr>
<tr>
<td>Cr_total</td>
<td>2</td>
</tr>
<tr>
<td>Cu</td>
<td>2</td>
</tr>
<tr>
<td>Zn</td>
<td>2</td>
</tr>
<tr>
<td>Ni</td>
<td>2</td>
</tr>
<tr>
<td>Fe</td>
<td>5</td>
</tr>
<tr>
<td>Pb</td>
<td>0.5</td>
</tr>
<tr>
<td>Cd</td>
<td>0.5</td>
</tr>
<tr>
<td>cyanides</td>
<td>0.5</td>
</tr>
<tr>
<td>anionic detergents</td>
<td>10</td>
</tr>
<tr>
<td>nonionic detergents</td>
<td>10</td>
</tr>
<tr>
<td>cationic detergents</td>
<td>-5</td>
</tr>
<tr>
<td>radioactive substances</td>
<td>4x10⁻¹² Ci/l</td>
</tr>
</tbody>
</table>

The quality requirements for bathing is prescribed by the regulations on quality standards for sea water at marine beaches (NN 33/1996). The quality requirements are given in Table 3.3.
### Table 3.3. Quality requirements for bathing water

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Limited values</th>
<th>Method of determination</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Colour</td>
<td>natural</td>
<td>visual inspection</td>
</tr>
<tr>
<td>2. Transparency (m)</td>
<td>minimum 2 (depending on depth)</td>
<td>Secchi's disc</td>
</tr>
<tr>
<td>3. Visible floating materials</td>
<td>without</td>
<td>visual inspection</td>
</tr>
<tr>
<td>4. Visible mineral oils</td>
<td>no film visible on the surface</td>
<td>visual inspection</td>
</tr>
<tr>
<td>5. Suspended matter</td>
<td>without</td>
<td>visual inspection</td>
</tr>
<tr>
<td>6. Turbidity (degrees of the silicate scale)</td>
<td>20</td>
<td>comparison with the standards, and turbidimeters</td>
</tr>
<tr>
<td>7. pH(^1)</td>
<td>8.1±0.3</td>
<td>pH meter, colorimeter</td>
</tr>
<tr>
<td>8. Dissolved oxygen (% of saturation)</td>
<td>70-120</td>
<td>Winkler's method, electrochemical method</td>
</tr>
<tr>
<td>9. Ammonia (mg/l N)</td>
<td>0.1</td>
<td>phenolate method</td>
</tr>
<tr>
<td>10. Total coliforms / 100 ml</td>
<td>500 (80 % of samples)</td>
<td>a) NBB(^1) 35-37°C</td>
</tr>
<tr>
<td>11. Faecal coliforms / 100 ml</td>
<td>1000 (20 % of samples)</td>
<td>b) MF(^4) selective agar 35-37°C</td>
</tr>
<tr>
<td>12. Faecal streptococci / 100 ml</td>
<td>100 (80 % of samples)</td>
<td>a) NBB(^1) 44.5°C</td>
</tr>
<tr>
<td>13. Enteroviruses(^4)</td>
<td>0</td>
<td>b) MF(^4) selective agar 44.5°C</td>
</tr>
<tr>
<td>14. Salmonella(^5)</td>
<td>0</td>
<td>concentration by membrane filtration and incubation on selective medium</td>
</tr>
</tbody>
</table>

1) lower pH values can be tolerated in case of lower salinity due to freshwater discharge.
2) performed only in the case of existing pollution or epidemiology on special request of responsible health authority.
3) NBB - most probable number
4) MF - membrane filtration
5) PFU - ineffective unit

The sludge could be used in agriculture, but in accordance with the Regulations on the protection of agricultural land from pollution by noxious substances (NN 15/1992), but the sludge must be stabilized before the application, and the content of noxious substances should be below prescribed values (Table 3.4).
Table 3.4. Maximum permissible concentrations of heavy metal and selected organic substances in sludge (mg/kg dry weight)

<table>
<thead>
<tr>
<th>Substance</th>
<th>Concentration mg/kg dry weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cd</td>
<td>10</td>
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<tr>
<td>Hg</td>
<td>10</td>
</tr>
<tr>
<td>Pb</td>
<td>500</td>
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<tr>
<td>Mo</td>
<td>20</td>
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<td>As</td>
<td>20</td>
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<tr>
<td>Co</td>
<td>100</td>
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<tr>
<td>Ni</td>
<td>100</td>
</tr>
<tr>
<td>Cu</td>
<td>500</td>
</tr>
<tr>
<td>Cr</td>
<td>500</td>
</tr>
<tr>
<td>Zn</td>
<td>2000</td>
</tr>
<tr>
<td>2,3,7,8 - TCDD</td>
<td>0.002</td>
</tr>
<tr>
<td>3,4,3',4'- TCAB</td>
<td>0.01</td>
</tr>
<tr>
<td>PCB, PCP, HCH (total without lindane), triazin herbicide (total) HCB, heptachlor, endrin, aldrin, and dieldrin</td>
<td>0.05</td>
</tr>
<tr>
<td>Lindan</td>
<td>0.1</td>
</tr>
<tr>
<td>Total isomers DDT+DDD+DDE</td>
<td>0.5</td>
</tr>
</tbody>
</table>
3.2. INTERNATIONAL AGREEMENTS

Croatia had ratified the Barcelona Convention for the Protection of the Mediterranean Sea against Pollution and Protocol for the Protection of the Mediterranean Sea against Pollution from Land-Based Sources (LBS Protocol). In the accordance with provisions of the Protocol Croatia is obliged to undertake measures to eliminate pollution of the sea from land-based sources by substances listed in annex I to the LBS Protocol (Appendix 3). Croatia is also strictly obliged to limit pollution from land-based sources into the marine environment by substances or sources listed in annex II to the LBS Protocol (Appendix 3). Discharges of the waste into the sea shall be strictly subject to the issue, by the competent national authorities, of an authorization taking due account of provisions of annex III to the LBS Protocol (Appendix 3).
3.3. EU DIRECTIVES

Council Directive of 21 May 1991 (91/271/EEC) concerns the collection, treatment and discharge of urban waste water and the treatment and discharge of waste water from certain industrial sectors. According to the Directive all Member States shall ensure that all agglomerations with a population equivalent (p.e.) of more than 15,000 are provided with collecting systems for urban waste water at the latest by 31 December 2000. For urban waste water discharging into receiving waters which are considered "sensitive areas" Member States shall ensure that collection systems are provided at the latest by 31 December 1998 for agglomeration of more than 10,000 p.e.

Urban waste water entering collecting system shall before discharge be subject to secondary treatment or an equivalent treatment at the latest by 31 December 2000 for all discharges from agglomeration of more than 15,000 p.e. Urban waste water discharging into sensitive areas shall be subject of treatment by 31 December 1998 at latest for all discharges from agglomerations of more than 10,000 p.e.

Urban waste water discharges from agglomerations of between 10,000 and 150,000 p.e. to coastal waters, identified as less sensitive areas, may be subject to treatment less than secondary level providing that such discharges receive at least primary treatment and comprehensive studies indicate that such discharges will not adversely affect the environment. In exceptional circumstances, when it can be demonstrated that more advanced treatment will not produce any environmental benefits, discharges into less sensitive areas of waste from agglomerations of more than 150,000 p.e. may be subject (which need to be approved by the Commission) of the same way of treatment. Only technical problems can be accepted for a longer period for complying with the above mentioned deadline, but the longer period may not extend beyond 31 December 2005.

In accordance with the Criteria for identification of sensitive and less sensitive areas, sensitive areas are, inter alia, coastal waters which are found to be eutrophic or which in the near future may become eutrophic if protective action is not taken, and areas where further treatment than secondary is necessary to fulfill Council Directives. A marine water body or area can be identified as a less sensitive area if the discharge of waste water does not adversely affect the environment as a result of morphology, hydrology or specific hydraulic conditions which exist in that area. The following elements shall be taken into consideration when identifying less sensitive areas: open bays, estuaries and other coastal waters with a good water exchange and not subject to eutrophication or oxygen depletion or which are considered unlikely to become eutrophic or to develop oxygen depletion due to the discharge of urban waste water.

Urban waste water treatment plants should be designed, constructed and operated and maintained in order to comply with the requirements of the directive and to ensure sufficient performance under all normal local climatic conditions. When designing the plants, seasonal variations of the load shall be taken into account.

The discharge of industrial waste water into collecting systems and urban waste treatment plants should be subject to prior regulations and/or specific authorizations by the competent authority or appropriate body. Industrial waste water entering collecting systems and urban waste treatment plants shall be subject to pre-treatment in order to: protect the health of staff working in collecting systems and treatment plants; ensure that collecting systems, waste water treatment plants and associated equipment are not damaged; ensure that the operation of the waste water treatment plant and the treatment of sludge are not impeded; ensure that discharges from the
treatment plants do not adversely affect the environment, or prevent receiving water from complying with other Community Directives; ensure that sludge can be disposed of safely in an environmentally acceptable manner.

Sludge arising from waste water treatment shall be re-used whenever appropriate. Disposal routes shall minimize the adverse effects on the environment. Competent authorities or appropriate bodies shall ensure that before 31 December 1998 the disposal of sludge from urban waste water treatment plants is subject to general rules or registration or authorization. The disposal of sludge to surface waters by dumping from ships, by discharge from pipelines or by other means should be phased out before 31 December 1998.

Competent authorities or appropriate bodies shall monitor discharges from urban waste water treatment to verify compliance with the requirements of the Directive accordance with the control procedures.
4. DETERMINATION OF THE POTENTIAL IMPACT OF THE PROPOSED PROJECT COMPONENTS

The main positive impact of the planned sewer system and submarine outfalls will be elimination of pollution by urban waste water from the Kaštel Bay and Trogir Bay. The Bays are semienclosed and in the accordance with Criteria for identification of sensitive and less sensitive areas of the Council Directive (91/271/EEC) concerning urban waste water treatment their could be consider as a sensitive areas. Recovery of the Kaštel Bay will take some time, which is impossible to assess because of lack of data. For sure, the Bay will become very important resource for further development, specially tourism. The elimination of pollution from the bays will improve the environmental quality in the whole area.

The planned sewer systems in the first phase (pretreatment of the urban waste water only) will transfer into Brač and Split channels practically all the waste discharging at present into Kaštel Bay (Figures 4.1., 4.2 and Table 4.1).

The performed assessments and numerical model show that the two wastewater outfalls will have no significantly negative effects on the marine ecosystems in Brač and Split channels, nor on the present and planned use of the coastal sea and land strip in the areas neighboring the outfalls. Some local changes are expected in the immediate vicinity of the outfalls.

Since the wastewater treatment plant is planned to be built in several phases, it is necessary to implement a comprehensive monitoring program of effects on the marine ecosystems with regard to the present and planned use of the coastal sea and land strip, in order to enable a timely decision on a higher degree of treatment, as required.

In order to make proper decisions regarding necessary treatment and improvement of collecting system Computerized Decision Support Systems in Coastal Water Resources Management have to be implemented. This system will aid decision makers in the process of transforming data into necessary information to solve unstructured problems of coastal water quality management.
Contributions to the pollution of Kaštelan Bay in 1995.

Contributions to the pollution of Kaštelan Bay in 2005.

Figure 4.1. Present and planned domestic pollution load by BODs into Kaštelanbay

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Figure 4.2. Present and planned domestic pollution load by BOD5 into Bral and Split channels
Table 4.1. Present and planned population and domestic wastewater pollution load by BOD5 from Split, Solin, Kaštela and Trogir into Kaštela Bay, Trogir Bay, Brač and Split channels

<table>
<thead>
<tr>
<th>Town</th>
<th>Population</th>
<th>Winter</th>
<th>Summer</th>
<th>Year</th>
<th>Winter</th>
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4.1. IMPACTS DURING CONSTRUCTION

4.1.1. Collecting system, treatment plants and tunnels

**Collecting system**

The pipes of the sewer system will be mostly buried and partly placed in the tunnels (two main tunnels with total length of ca. 3400 m). During the trenching to bury the pipes, machinery and vehicles will produce substantial noise and dust, which will disturb neighboring population. The noise will be much more intensive on Čiovo island due to rocky ground, and much more important since this area is very quiet with residential or summer houses, without any economic activity. The impacts on local population and tourists will be more significant during summer season when numerous summer houses located in this part of the island are occupied by numerous tourists.

Trench along roads will disturb local traffic and in some cases will block access to some houses. This type of impact will be significant in the older parts of the towns (especially in Trogir old city and Kaštela) where roads are traditionally very narrow. In this area construction of the pipelines will be very complicated because excavation can endanger stability of houses. This will have influence on the preparation of the work and increase of cost of the work. It will, also, at most places be required to replace existing underground installations (water pipelines, telephone wires, etc.). In this case a certain number of households will be temporarily without services of running water, electricity or telephone.

In same time the earth works will impact public services and local shops activities along the place of work. This impact will be common without any specific characteristics.

Connections of existing sewer pipes with the new constructed may lead to the leakage of urban waste which could create health hazard for workers and local population.

Earth works will not significantly affect neither flora and fauna of the area because sewer are located in the urbanized areas. Construction will not impact the flow and characteristics of ground waters, but the flow of surface waters (drainage waters and sporadic water flows) will be disturbed in the area of Kaštela.

The construction of transmission mains will not endanger known historic monuments but in the area of Solin it could happened that on the route of pipelines some so far unknown archeological monuments could be found. In accordance with transmission mains projects the pipes will be not laid down in the ecological sensitive areas.

The rising mains of pump stations Divulje-Pantana and Lokvice are designed to cross the Kaštela bay and will be buried and concreted. The trenching through Kaštela Bay will produce turbidity, caused by clay and sand particles. This, however, will not last a long time, no more than one week after accomplishment of the work, and will cause no significant changes in plant and animal communities of the Bay. The communities on the place of the rising mains will be completely destroyed, but in several year time they will be recovered. The trenching through the Bay would have negative impact on juvenile organisms of commercial important species, if any retain in this part of the bay. During the construction traffic in this part of the bay may be temporary disturbed.

Impacts of the construction of pump stations and storm water overflows will be similar to the impacts of transmission mains. The locations of pump stations and overflows have been chosen taking in consideration local characteristics which could create difficulties in the construction.
**Treatment plants**

The construction of both treatment plants will create noise and dust by earthworks and intensified road transport. Civil engineering works at the treatment plant will have impacts as any other typical construction work. The most significant impact will have traffic to and out of construction site. The impact of intensified road transport will be much more important on Ciovo island because this area is very quiet area without heavy traffic and noise. A special problem will be Mavašćica area. At the Stupe area there will not be significant impacts because in this area heavy traffic is common.

At the Stupe location construction of the plant will require replacement of existing small creeks. In the rain period of construction it is very probable that rain runoff over the construction site will wash out materials and caused increased turbidity of Stobreč bay and Mavašćica bay. This impact can be temporary significant on aesthetic and ecological characteristics of the sea water in the bays. It will impact bottom communities.

Surplus excavation materials could be used for sanitation of existing left quarries in the area or for earth work in the area when appropriate. The quality of excavated materials can be of good quality for civil works and beneficial uses.

At the location Stupe there are electric overhead lines which have to be relocated. On the site in the southern corner there are several houses which have been illegally constructed. These houses will not impact preliminary work but can impact extension of the treatment plant in the future.

The location Ciovo do not have such problems because it is natural green area.

**Tunnels**

The size of the tunnels (Stupe 2436 m, Ciovo 1851 m) and complexity of the work as well as possible impacts require the preparation of specific environmental impact assessment study. This study is prerequisite to obtaining a Location Permit in accordance with Croatian legislative.

The construction of the tunnels will have a significant impacts on local and wider areas with respect to noise, dust, traffic, vibration, visual impact and disposal of excavation materials. The amount of excavated materials will be very significant (Stupe 38500, Ciovo 20500 m3). This material can be used locally for fill platform at treatment plant site (Ciovo), filling of quarries or for beneficial uses.

Impacts of construction Ciovo tunnel will be significant on both portals but much more important at south portal in Mavašćica area especially regarding traffic impact. These impacts will be less significant at the Stupe tunnel.

4.1.2 Submarine outfalls

The outfalls are not located in ecological sensitive areas or ground of endanger and protect species.

Since the part of Stobreč submarine outfall is designed to be buried and concreted, trenching through Stobreč Bay will produce turbidity, caused by clay and sand particles. This, however, will not last a long time, no more than one week after accomplishment of the work, and will cause no significant changes in plant and animal communities of the entire Bay. The communities on the place of the submarine outfall will be completely destroyed, but in several year time they will be recovered. The trenching through the Bay would have negative impact on juvenile organisms of commercial important species, if any retain in this area.
The construction works at the inner Stobrec bay will be significant (big size of the pipe 1000 mm and big excavation work) and will create temporary local problems in use of the sea in this area. Dragged material (ca 1500 m³) have to be disposed at the appropriate disposal site.

The construction of the submarine outfall at Ciovo island (⌀ 500 mm in first phase) will not create turbidy as the Stobrec outfall, but it will create much more noise because of rocky ground.

The lay down operation of the both outfalls will affect the navigation of pleasure boats in the area of activity in a short time period.

The submarine outfall on Ciovo island will hamper trawl fishing in the area of submarine outfall, while sardines and anchovies fishing will be not affected. Stobrec submarine outfall is already in the trawl fishing forbidden zone.

Assembling of the pipe and preparation work for laydown (pressure testing, attaching of concrete loads, etc.) will have local impacts. It is not known where this work will take place and there for it not possible to asses impacts. It seems that Mavašica Bay because of the size and coast line configuration is not suitable for such activities, while Stobrec bay is suitable.
4.2. IMPACTS DURING THE USE

4.2.1. Impacts of the sewerage system and the wastewater treatment plants

The treatment plant Čiovo have a size of 110 x 200m and its location is about 250 m far from neighboring house, but if necessary it could be relocated to be more than 300m. Location is on the level of 15 to 20 m over sea level.

The treatment plant Stupe have a size of 190 x 380 m and it is located ca 100 m from the closes houses. At the southern corner of site location there are several illegally constructed house. Location is on the level of 13 to 10 m over sea level.

Impacts on the air quality

Easily volatile gases of very intensive smell occur in wastewaters. These odours occur particularly at anaerobic state of the effluent.

Due to emission of unpleasant scented substances at the waste discharge facilities, undesirable changes of air quality are possible:

- in the operating environment of the waste waters treatment plant in particular the preliminary works, where potentially septic waste water is first broth to the site. This include Reception Chamber, Inlet Channels, Screens, Aerated Grit/Grease Channels, Cess Tanker reception screenings.

- in the facilities surrounding but much less.

The distribution of unpleasant odours in the facilities surroundings is affected not only by the type and intensity of the scented substance but also by wind direction and intensity.

At the entrance to treatment plants the unpleasant odours are possible due to the processes of anaerobic degradation in the sewerage system, that is under the conditions of oxygen depletion in the effluent. In our cases this is possible owing to the increase of soil and shallow trenches temperature in summer. This means that the water temperature increase may accelerate the process of organic matter degradation and consequently the rate of oxygen depletion in the water. This problem is particularly pronounced in this case since the water is conveyed over a long distance.

Odour is a highly individual perception and its measurements requires a panel of test persons an a rather laborious test procedure. Therefore, it is very difficult the assess odour impact from the waste water treatment plants on neighboring population. But, considering the locations of both treatment plants in relation with the neighboring population, it comes out that the locations are not suitable regarding the predominant nightly winds in the warm period of year.

Unpleasant odour problems can be created at the pump stations and impacting neighboring population.

Noise and Vibration

There will be limited equipment at the treatment plants that will emit significant noise, like: aeration blowers and power generation plant using biogas.

Vibration may occur in the rising mains and partly not in the treatment plants, such as the air blowers and power plant. Vibrations in the outfalls are due to air penetration in the pipes during emptying and filling of the sewer. This is of particular importance for the safety of the
polyethylene pipes, since vibrations may cause concrete blocks to unfasten and let the submarine part to lift up to the surface.

**Leakage**
There are a possibilities of smaller breaks and leakage of joints elements of the pipes and channels which would cause the pollution to the ground. Such leakage would produce harmful sanitary and ecological effects.

The extent of these effects would mainly depend on the quantity of leaked water. In the case of smaller quantities the effects will be insignificant. At this stage of the planning process it is impossible to assess the importance of this impact but it should be avoided.

This impact can be very important for Kaštela area because of usage of ground water for irrigation. In coastal belt the leakage will pollute coastal marine water and endanger usage of this water.

Leakage from the treatment plant Stupe and incoming and outgoing pipes can significantly impact river Žrnovnica which is classified as I category of water quality.

**Impacts caused by insects**
Sewage effluents and the waste substances they contain are very suitable habitat for insects (flies, mosquitoes, etc.). Exposed surfaces are particularly suitable. Since sewage effluents contain also pathogenic microorganisms the insects are particularly dangerous as disease carriers. Because of the regularity in anti insects actions this kind of impact could be considered as negligible.

**Impacts due to the generation of combustible gases**
Gases may occur at any point in the system under anaerobic conditions which are feasible in our case because of long transport of wastewater. This particularly applies to the spaces closed to prevent unfavorable odours to disperse. If these spaces are not properly aerated they present potential hazard for explosion. This kind of impact could be avoided by appropriate design, construction and maintenance of the sewer system and treatment plants.

Fire hazard on treatment plants are only relevant to sludge digestion process and related handling and use of digestor gas.

**Traffic movements at the treatment plants**
There will be significant number vehicle movements during the normal working day. This will include cess tankers delivering waste to the site. This will be very significant during the initial phases of the development of the sewer system, but in the latter development of the treatment plants there will be significant sludge tracks taking sludge cake of site.

At the treatment plant Stupe the main access route to the plant will be via the proposed industrial/warehousing development area and traffic will not cause problems. At the treatment plant Čiovo the existing road to the location coming through Mavaščica village which is not appropriate for this type of transport, and another access road should be found.

**Aesthetic impacts**
The significant aesthetic impacts will have The treatment plant will have the significant aesthetic impacts while major pump stations will have only minor impacts. Other elements of the system won't have any impact.
The proposed plants structures consist mainly of low buildings and tanks many of which will be located below ground level. The tallest structures will be vent stacks from odour control, biogas flaring and power generation exhaust chimney. This stack will be about 10 m above ground level. As the Čiovo treatment plant is located deep in valley it will not be visible from the village Mavašćica or any local road. Treatment plant Stupe will be visible but as it is located in industrial/warehouse area. There for this structures will not have any significant aesthetic impacts.

Health hazard

Health hazard to the local population from any of the component of the sewerage system (transmission mains, pump station, treatment plants) is negligible (distance from the houses more than 200 m). The only one how can be impacted are the workers especially at the treatment plants.

Problem erase when workers are in contact with raw wastewater. Another problems are entry to confined spaces in the system (transmission mains and pump stations) and at the treatment plant.

Solids disposal

Solid waste associated with treatment works will consist of screenings, grit and sand, grease and oil, and biosolid sludge cake. These solid waste will have impacts on environment depending on the way of treatment and disposal.

For the first phase of treatment plant development it is proposed to instole a small incineration plant for the incineration both screenings and grease and oil. If a modern incineration technology would be used then the exhouse gases will not represent an environmental nuisance. Other option is to damp waste of the first phase to the municipal landfill site.

Grit and sand after removal organic materials within them will not have any significant impact on environment and can be used for landscaping.

In the second and further stages of treatment plants development a significant amount of sludge will be produced. The sludge will be digested at the treatment plants and will have long term stability. If the sludge has a good quality than will not have negative impact on environment and can be of beneficial uses in agriculture or silviculture. Such sludge can be also dumped on landfill site if necessary.

Quality of the sludge is directly related to quality of the wastewater inflow to the treatment plant. The problems are created mainly by industrial wastewater discharged into sewer system containing toxic and hazard substances. Any heavy metal present in wastewater will concentrate in the sludge produced on the works and jeopardize the beneficial use of the sludge. The use of polluted sludge in karstic area, as it is Kaštelan Bay area, is very dangerous for the pollution of fresh and marine environment.

Because of restructuration of local industry it is in this time very difficult to predict impact of the industry on the sludge quality.

Adequate agricultural areas in this region exist for beneficial uses of sludge. Since the local population and farmers are not familiarize with beneficial uses of the sludge at the beginning the will be resist to the sludge application.
**Confirmation to existing and planned land use**

Characteristics of location area of the treatment plants are described in Chapter I of this report. As it was presented the location of Stupi treatment plant is already planned for the construction of the plant and because of that is not in contradiction with land use plan (master plan). The treatment plant Čiovo is planned on natural green area but it is not in conflict with other uses of land. This area (deep in valley) is not suitable for any beneficial use of land (narrow and steep area). Some problems might arise because of vicinity of neighboring Mavštica village. Distance from the first houses is 250 m.

**4.2.2. Impacts of the submarine outfalls**

The main direct environmental consequence of a sewerage outfall is the contamination of the recipient waters with raw faecal material (in case of untreated or inadequately treated sewage), intestinal microorganisms (including pathogens), nutrients and other oxygen consuming substances. This consequences of waste disposal may be:

- reduced quality of recreational coastal waters;
- oxygen depletion and eutrophication of recipient waters, including excessive algal blooms and fish kills under extreme conditions;
- alternations of marine ecosystems in the vicinity of disposal point;
- spreading of pathogens by wind.

Phase I installation at the treatment plant anticipated preliminary treatment only. The key requirement for this phase is that there should be "no visible slick" on the sea surface. Phase II includes the installation of a primary treatment process. This will substantially reduce suspended solids together with associated organic matter. In Phase III the quantity the waste water treatment by the plant increased and the quality of marine environment could be decreased. Therefor, it may become desirable to treat the wastewater to an improve standard. This may be carried out in several appropriate steps:

- organic reduction,
- disinfection of effluent,
- ammonia reduction, total nitrogen reduction and phosphorus reduction.

The HARO-3 three dimensional stationary model developed by USA-EPA was used to predict impact of the submarine outfalls on the oxygen concentration in the marine environment (Appendix 2).

**Sea water temperature**

Sewage effluent disposal in the wider area of Brač and Split Channels will not cause any changes of the sea water temperature.

**Microbial pollution of coastal marine waters**

The distance of the outfalls disposal point from the coast were calculated for the first phase of water treatment development (pretreatment of urban waste water only), using some basic characteristics of the sea water, such as physical properties, prevailing currents and die-off rate of bacteria. On this basis it may be predicted with relative high probability that microbial pollution will not be increased in the coastal strip intended for recreational pursuits (Appendix 1). If a secondary treatment including the UV desinfector of the effluent is applied the probability level will be much higher.
The transfer of urban waste water from Kaštel Bay into Split-Brač channels and elimination of all existing small outlet and septic tanks (by development of sewerage system) will improve sanitary quality over the entire area. The expected sanitary quality of coastal waters in the area is shown on Figure 4.3.

**Oxygen and nutrient concentrations**

The pretreatment of only the urban wastewaters is envisaged during the first stage of construction of waste water collection system. These waters which will be conveyed through the outfall will contain large quantities of suspended matter (180 mg/l), the degradation of which will require high oxygen amount (BOD$_5$=180 mg/l): A considerable part of suspended matter will sediment in the vicinity of the disposal point, whereas the rest will be spread to a wider area by currents.

In the first phase of treatment plant development significant oxygen depletion will occur on the bottom close to the disposal points especially in summer and early autumn due to the organic degradation. However, anoxia is very unlikely to occur owing to relatively favorable currents in the bottom layer. Oxygen content reduction will not be significant in the wider area of the Brač and Split channels. In winter, oxygen concentration reduction will be very poor. During the third phase the organic matter will be removed from effluent and oxygen depletion will be much lower.

In the second and third phases of waste treatment plants the organic effect of the waste water will be reduced and any solids deposition in the vicinity of the outfalls diffuser minimized.

Long-term discharge of municipal effluents, regardless on treatment level, will very likely cause increase of nutrient concentrations which will later affect moderate changes in phytoplankton and zooplankton populations and consequently the changes in primary production. The impact of this impact impacts is impossible to predict therefore a comprehensive monitoring program was proposed.

All above mentioned impacts of effluent discharges will be much more less intensive at the vicinity of Ćiovo outfall due to smaller amount of wastewater discharged (equivalent population Kaštel-Trogir system at final stage ca 150,000, while Stobreč ca 500,000), higher depth of discharged (Ćiovo outfall 52 m, Stobreč outfall 36 m) and assimilative capacity of Split channel.

**Sea water color and turbidity**

Waste waters will increase turbidity in the vicinity of the outfalls discharge which will limit the light penetration. Whereas these changes will mainly occur in deeper layers in summer, they will occur through the water column in winter even though of far smaller extent.

Waste water discharge will also cause the sea water colour change to a green yellowish. However, this discoloration will not be visible in the surface layer in summer due to stratification. This impacts will much more pronounced during the first phase due to high suspended particles and associated organic matter content in the effluent, while during the third phase will be practically eliminated. This impact will be of less intensive at Mavalačica submarine outfall.

A gradual transparency reduction and change of the sea water colour will presumably occur as a secondary effect of nutrient content and primary production increase in the wider area.
Figure 4.3. The expected sanitary quality of the coastal waters in the area
Flora and fauna

Disposal of municipal waste waters will affect flora and fauna of the wider area of the outfall. In the first place, the number of plant species will be reduced and followed by the species diversity reduction with a considerable increase in the number of nitrophilus algal species.

As to the fauna of the wider outfall area, the number of species will also be reduced with an increase in the number of specimens and biomass of individual species.

Dramatic reduction of both the number of plant and animal species and their total biomass will occur in the close vicinity of the point of disposal due to the sedimentation of suspended particles from the effluent.

The construction of the submarine outfalls and elimination of waste water discharge by numerous outlets located will have positive impact on benthic communities along the coast in the area between Stobreč and Rt Marjan. The discharged waste will not reach the coast line and the communities will be recovered. The recovery time to the previous conditions will between 5 to 10 years.

The commercial fish species will not be subject of significant impact of discharged waste water.

Impacts on other present and potential uses of the coastal and marine environment

Discharge of pretreated municipal waste waters will not impair the present quality of coastal sea water. So, its presents and planned uses for recreation and bathing will not be endangered. Construction of the sewerage system in the wider area of the present one, to which the waste waters, now disposed uncontrolled into the sea, will be collected for treatment at central treatment plant, will contribute to the improvement of the present state.

The Mavašćica outfall is located in the area of commercial fishing (trawling) so that the decision to ban this activity in these areas will produce some small impact on this activity. The Stobreč outfall is located in the area where trawl fishing is forbidden.

No data are available on the infective diseases so that there is no basis for any estimate of the outfalls impact on their eventual reduction or extension.

Since trenching to bury and concrete the submarine part of the Stobreč outfall is proposed at approximate length of 900 m, to the point at which the sea water depth reaches 12 m, recreational pursuits will not be limited in this area. Anchorage, fishing an any other activity that may damage the pipes will be limited but only at greater distances offshore.

4.2.3. Overflows

Part of the existing sewerage system in Dujmovica catchment area is of a combined type. It means that during the rainy period of the year storm water will be discharged by storm water overflows. Only three overflows have been planned. All of them will discharge water in the north port sea which is classified as IV category in accordance with the Croatian law. Discharged water will have impact on sea water quality in this area.

Study of the analyses of possible impact of overflow water was made as part of the project of sewerage system Split-Solin /1/. Based on that study it was concluded that overflow waters can be discharged in the north port sea after the ratio of dilution of wastewaters with storm waters of 1:3 was accomplished. It was concluded that discharge of these waters won't have negative impact on the usage of sea water of the north port and therefore this solution is in accordance with the Croatian standards.
This approach is not in accordance with the EU standards that require the determination of the outfall frequency and total volume of overflow waters during one year period. Therefore it is necessary to develop simulation model of the sewerage system which will be done in next phases of the design of the sewerage system.

4.2.4. Tunnels

The most important impact of the tunnel will be on the health of workers. It is possible that within the tunnel, that is a closed area, gases that evaporate from sewers (methan) that are toxic and explosive can be accumulated. There is a danger for workers lives and danger of destruction due to explosion unless respective measures concerning the accumulation of gases within the tunnel and measures and procedures that should be done before entering the tunnel were undertaken.

During the operational period tunnels won’t have significant environmental impact. The Environmental Impact Assessment will be undertaken for this object and therefore this problem won’t be further discussed.
5. ANALYSIS OF THE ALTERNATIVES OF THE PROPOSED PROJECT

Before the selection of the optimal alternative for the sewer system in the wider area of the Kaštel Bay, several alternatives were analyzed considering the total concept and the specific elements of the sewer system. Accordingly, extensive investigations and studies of the characteristics of the coastal sea and waste water have been carried out as well as the urban-planning analyses, climatological characteristics, techno-economical analyses and environmental impact studies. This process of the selection of the optimal alternative lasted more than four years. All these analyses started from the present state, local, national and international requirements, local characteristics, short-term and long-term needs, requirements and financial, technical and technological possibilities as well as the available personnel.

The adopted solution, and its realization in phases is considered to be optimal for this region and for the present situation.

5.1. ANALYSES AND ALTERNATIVES SOLUTIONS OF THE MAIN CONCEPT

Several alternatives were analyzed at the level of a concept. The first analysis referred to the sewer system, i.e. either combined or separate. Considering the fact that the greatest part of the existing sewer system is of a combined type it was necessary to decide whether to keep the same kind of system or to build a separate system. Consequently, a separate system was selected and the existing system will also be transformed into this new type. The separate system was selected considering the ecological factors (better control of the disposal of waste water and reduction of the storm water overflow), economic reasons (decrease in the costs of pre-pumping and treatment), maintenance and reclamation of the existing system (problems with significant infiltration, insufficient capacity of the present sewer system, etc.) In addition, there is no sewer system in a large area covered by the cities (more than 60%), so that the separate system is more efficient for the construction in phases, where the sewer system for fecal (domestic) water is built first and later the storm run-off system.

As the result separate system was proposed for sewerage systems of Split, Solin, Kaštel and Trogir.

The second analysis referred to the configuration of the sewer system as a whole.

Three basic possibilities were considered: (a) unique system for all cities Split, Solin, Kaštel and one part of Trogir (one treatment plans and one submarine outfall), Figure 5.1.; (b) a great number of small sewer systems (a treatment plant and an outfall for each large catchment area, Figure 5.2.; (c) optimum number of sewer systems (most efficient collection, treatment and disposal systems).

Each of the alternatives was analyzed considering several criteria, such as the most important ones:
- environmental impacts,
- technological efficiency of the system,
- functional efficiency of the system,
- exploitation of the system
- reliability of the system and
- economical efficiency of the system.
Figure 5.1. Concept of a unique sewer system - one treatment plant

Figure 5.2. Concept with several small sewer system - several treatment plant
Appropriate study was produced /1/, /5/ and results of the study were discussed between groups of experts and interested institutions and organizations. The discussions were held according to the present state and past experience, obtained data, requirements in accordance with Croatian regulations, and international requirements (Mediterranean protocols and declarations, EU directives). The following conclusions were reached:

Single treatment plant

Central treatment plant was planned at location of Split community because Split is the far the biggest community in the area and collecting waste water at one location in this area have been economically and technically the most acceptable solution.

A unique system is the optimal solution regarding environmental impacts because all waste water will be controlled at one location, one treatment work and one submarine outfall. The treated waste water will be discharged in the Brač channel. There will not be discharges in Kaštel Bay from municipalities and industries and full protection of the Kaštel Bay from point sources of pollution will be achieved.

The treatment plant construction, operation and maintenance costs will be minimum (cost per m3 of treated waste water).

This alternative taking in account whole sewerage system has been the most expensive one especially in the initial phase of the construction because it will require significant reconstruction of existing sewerage system, construction of numerous pump station and high operation costs of the sewerage system (waste water should be prepumped several times). There are a number of technical objections to the alternative of single treatment plant: The general fall in the Kaštel and Trogir area is from east to west and significant pumping would be required (Fig. 1.15.), there is no simple and obvious route for main pipelines from east to west (from Trogir to Split), travel time of waste water will be too long which will result in septicity and odour problems (length of main pipeline more than 25 km), connection of the settlements in Ciovo would be difficult to achieve (Fig. 1.16.).

Regarding operation, sewerage system will be sensitive to the malfunctioning which could results in occasional pollution of the coastal waters.

This alternative has been difficult for the phasing of the system development and construction because it requires, in the beginning period, significant construction, time of construction and costs in order to start functioning.

This is also the least favorable solution considering the existing state and the possibilities for bringing into accordance the interest of the four cities.

Several treatment plants

For areas of Split and Solin, based on existing sewerage system and topography (the possibility of collection by gravity), the possible sewerage systems are /1/:

- the sewerage system of the catchment areas of Dujmovača and Solin with the waste water treatment plant situated in commercial port area and the belonging submarine outfall for discharge into the Kaštel Bay,
- the sewerage system of the southern part of Split peninsula (old city center) with the waste water treatment plant on Katalinić Brig and the belonging submarine outfall for discharge into the Brač Channel,
the sewerage system of the catchment area of Stobreč with the waste water treatment plant situated at Supa and the belonging submarine outfall for discharge into the Brac Channel, and

the sewerage system of the area of Podstrana with the waste water treatment plant situated in the center of that area and the belonging submarine outfall for discharge into the Brac Channel.

For the area of Kaštela, as a realistic solution, there has always been assumed only one sewerage system with the waste water treatment plant situated in that area and a submarine outfall for discharge into the Kaštela Bay /5/.

Also for the area of Trogir there has always been assumed only one unique sewerage system with the treatment plant situated on Ćiovo Island and a submarine outfall for discharge in the Split Channel /14/.

The solution which includes several small sewer systems is optimal considering the economic factors of transmission mains construction (savings in size of pipelines, capacity of pump station and pumping costs) and the present state (no big changes in the existing system).

It is the least acceptable solution considering the environmental impacts (disposal in the bays). Discharge of effluent in the bays would require full tertiary UV treatment to achieve the necessary water quality in the closed bays. Kaštela bay and Trogir bay have been classified as a sensitive sea waters /3/. As it was presented in Chapter 2 the eastern part of Kaštela bay was found to be eutrophic. Impacts of the treatment plant on land environment has been significant and it was difficult to find so many appropriate locations for treatment plants.

Construction, operation and maintenance costs of the treatment work will be significantly higher because several treatment works would be built resulting in higher unit costs per m³ of waste water and higher costs because treatment level if effluent is discharged in the bays.

This alternative has been favorable regarding phasing of the sewerage system construction and development because systems can be developed separately in shorter time period with immediate results and improvements in coastal water protection.

Management and operation of the system will be more expensive and less reliable (several operation units-depots, more staff, lack of experts and operational experience to operate such type of work at the required consistent standards).

Optimal solution

Consequently, it was concluded to find an optimal solution regarding the economic, environmental and other criteria, so that after an analysis the alternative for the construction of two sewer systems: Split-Solin and Kaštela-Trogir was proposed and accepted (two plants and two outfalls).

Regarding ecological impacts, this solution makes it possible to satisfy long-term environmental criteria and the control of the waste waters and, hence, the long-term protection of the Kaštela and Trogir Bays. With such solution there will no be municipality and industry waste waters discharges in to the bays (point sources of pollution). The disposal of the waste water outside the bays makes it possible to use the assimilative capacity of the sea in the bays for all diffuse and uncontrolled pollutants in this area which are and will be significant /3/ (storm runoff, agricultural drainage waters, fresh waters from rivers, air deposit and others). This ensures long-term protection of the bays with relatively low cost of the systems and plants operation.
Treatment and discharge of the effluent by long submarine outfalls into the Brač and Split channels will not jeopardize water quality in the channels although waste water will be treated only mechanically /13/. Study and simulation of the long term effects of discharges of waste water into the channels show that there will be no reduction in oxygen concentration except small reduction in the vacancy of the diffuser and all Croatian, international and EU standards can be achieve. The channels have good water exchange and are not subjected to eutrophication and can be classified as less sensitive areas. Results of simulation are given in the Appendix 2.

In order to protect sea water and performance of treatment works treatment of industrial wastewaters at production site has to be instituted and trade effluent policy has to be established except for biologically degradable effluents. It is necessary to pay special attention to heavy metals and other toxic materials that can eventually be found in industrial waste water. Therefore it is necessary to analyze the necessary pretreatment of industrial wastewater and to strictly define the requirements for the connection to the sewerage system. These activities must be completed before the construction and commissioning of the sewerage system has finished.

Solution with two treatment plants and two sewerage system was the most economical solution regarding construction, operation and maintenance costs of treatment plant and sewerage system (pipelines, pump stations, tunnels, and others) /10, 14/.

Split as the far biggest city and producer of waste water was the logical priority in the problem solving process. Based on previous studies and projects /1/ it was concluded that Split should have the unique sewerage system and the waste water treatment plant with the belonging submarine outfall for discharge into the Brač Channel. It was logical that Solin, as the settlement closest to Split, should be included in the solution for Split and therefore the unique Split-Solin sewerage system was formed.

For all settlements in the Trogir area as well as parts of the town of Trogir situated on Ćiovo Island the most acceptable solution was the collecting of waste waters at the unique treatment plant situated on the southern side of the island with the belonging outfall for discharge into the Split Channel. Also logical and the most acceptable was to connect the rest of the town of Trogir situated on the land with that solution in the unique sewerage system. One more reason to do that are the small quantities of waste water. Since the town of Trogir together with adjacent settlements must have the treatment plant and the belonging outfall situated on the southern side of Ćiovo Island, there was a question of justification of construction of the separate treatment plant and outfall for discharge into the Kaštel Bay for the area of Kaštel. Conducted analyses /14/ confirmed that the most acceptable solution was to connect the area of Kaštel with Trogir in the unique Kaštel-Trogir sewerage system with the unique waste water treatment plant and the outfall for discharge into the Split Channel. This solution is economically, technically and environmentally the most acceptable with small impacts on land and sea environment, and also reliable and suitable under local conditions.
5.2. ANALYSES AND ALTERNATIVE SOLUTIONS FOR THE PLANT LOCATION

Since the adopted solution includes two sewer systems, i.e. Split-Solin and Kaštel-Rogir it was necessary to select the location for the treatment plants.

**Split-Solin collecting system**

In the Split-Solin sewer system all previous solutions included a treatment plant on the Katalinić Brig /18/. This traditional location was considered with several other locations. After an initial analysis /1/ of the locations and requirements to be satisfied, four locations were selected as the best ones: Katalinić Brig, Gizdaruša, Stobrec quarry and Stupe, Figure 5.3.

Each of the potential locations was analyzed at the level of conceptual design including the necessary urban-planning solution. The analysis of each of the potential alternatives impacts and characteristics included:

- urban characteristics of the locations (land use, conditions satisfying the surrounding area, cultural monuments, etc.),
- environmental characteristics (sanitary conditions, noise, smell, flora and fauna, water resources, etc.),
- position with regard to the urban and required infrastructure (electricity, water-supply, telephone, roads, etc.),
- positions with regard to the recipient (disposal/outfall),
- position with regard to the present and future sewer system as well as other micro and macro location characteristics of the area,
- costs (land, construction cost, operation cost),
- flexibility and reliability.

The alternative locations were analyzed employing the multicriterional analysis and the Promethee method with 15 criteria. This analysis showed that the best alternative for the treatment plant was the Stupe location, than Katalinić brig, Gizdaruša and Stobrec quarry /1/.

Sensitive analyze of the multicriterial procedure was performed and in all combinations the best solution was location Stupe.

The biggest disadvantage of Katalinić brig location is the shortage of available area for the higher level of treatment and very high cost of the construction in city center and the most attractive part of the city. This location is favorable in regard to disposition and collecting of the waste water. Significant and expensive steps should be taken at this location to reduce negative impacts on the surrounding area. Gizdaruša location situated on the coast should be completely constructed below ground level in order to reduce negative impacts on surrounding area and therefore it is very expensive one. Besides, an outfall at this location will be very unacceptable because of shallow sea and submarine reefs in front of the location. A treatment plant situated on the coast would have negative impact on the development of the rest of the coastal strip. Stobrec quarry location is situated in the center of intensive urban development, and it is far away from the sea and the possible position for effluent discharge. This location is very unfavorable in regard to existing sewerage system and their collection in the treatment plant as well as for local population. Therefore it is necessary to conduct complex and expensive measures in order to reduce negative impact on the surrounding area.

Results with regard to several groups of criteria were the following: The most inexpensive installation (construction only) is for Stupe location and then Gizdaruša; Operational costs of the system and treatment plant are the most favorable for Stupe location and then Katalinić brig;
In regard to necessary resources the most favorable is Stupe and then Stobreč quarry; in regard to flexibility and environmental impact situation is the same; in regard to the disposition the best location is Katalinić Brig and then Stupe.

In accordance with the Study, the Stupe location has been chosen as the best. This location has the smallest environmental impact on the area around the treatment plant and in regard to lend section of the submarine outfall. Besides, this location will fit into the present state of construction and planned development of the area. In all public presentations of the project, local population considered this location as the most favorable and the most acceptable. For this location sewerage system was designed on the level of preliminary design, including treatment plant and submarine outfall. Solution of the sewerage system has been included in the land use plan and master plan of the city.

Kastela-Trogir collecting system

The sewer system Kastela-Trogir included the analysis of several locations for the treatment plants and two of these were selected as the best ones, i.e. the valley near Zedno and the Rastići area, Figure 5.4. After a detailed analysis the valley near Zedno was selected, i.e. near Mavasćica /14/.

This location is on an abandoned terrain. Unlike this place the Rastićand location is well visible and situated near the area intended for tourism of high category, partly in this very location /19/. In addition the Mavašćica location is more favorable considering the economic and ecological factors.

In order to unite all waste waters at the Rastić location it would be necessary to prepump waste water several times to a height of 50 m (Figure 1.16). Therefore the operational costs are far bigger than the ones for Mavašćica location. Besides, the construction of trunk sewer through the Saldun bay, mostly under the sea, would be far more expensive than the construction of "Čiovo" tunnel. Therefore in regard to the construction of the sewerage network, Mavašćica location is more favorable. This location is situated next to the existing housing and in the area of future development and therefore it is extremely unacceptable for the local population. In order to eliminate negative impacts on the surrounding area it would be necessary to place the biggest part of treatment plant installations inside stable object to make them invisible but it is a very expensive solution.

Mavašćica location is closed deep inside the bay (Photography 2), it is invisible and it won’t have impact on the development of the surrounding area, that can not be said for Rastićand location. It won’t be necessary to conduct any special measures in order to reduce negative impacts on the surrounding area. Mavašćica location, even though far better located in regard to present and planned construction in this area, is not very well accepted from the local population that always has negative attitude in regard to the treatment plant. Therefore the phased construction of the treatment plant and lots of effort will be necessary in order to explain to the local population the importance of the treatment plant for preservation of the environment and development of tourism.
Figure 5.3. Analyzed locations of the central plant for the Split-Solin sewer system

Figure 5.4. Analyzed locations of the central plant for the Kašte-Trogir sewer system
5.3. ANALYSES AND ALTERNATIVE SOLUTIONS FOR THE WASTE WATER DISPOSAL

The protection of the coastal sea water bay as a combination of treatment and self-purification of the sea, is the most common method used in Mediterranean area as well as in Croatian coastal urban areas. It is "treatment-submarine discharge" system. This system is analyzed and applied as unique technical-technological unit with all its general and specific characteristics. It is possible because Croatian standards are recipient standard type which allow dilution of waste water in the sea water.

The treatment plant effects a partial or complete purification of the waste water, but the location of outfall, and its relation to the coastal area and its depth, while the sea, i.e. submerged outfall is used for further purification, so that the required standards of the open and coastal sea can be satisfied. This means that the required sea water quality is obtained by combination and location of the outfall and degree of preliminary purification in the plant. The combination to be applied depends on the local conditions and on the results of the selection performed to obtain an optimal combination.

If effluent is discharged in sensitive waters it is necessary to apply the higher treatment level, but if effluent will be discharged in less sensitive water then only mechanical treatment is sufficient, similarly to the EU directive concerning urban waste water treatment (91/27/EEC).

Considering the possible effects of the common configuration of treatment plants, only certain combination are possible and analyzed. Three basic alternatives of the installation of the "plant-submarine discharge" system have been used. They are:

1. Treatment plant- total biological purification (or similar); outfall-minimum length (more than 300 m)
2. Treatment plant- total mechanical purification (or similar); outfall - necessary length according to computation
3. Treatment plant - partial mechanical purification; outfall - necessary length according to computations

Alternative 1 represents an extreme case in regard to the treatment level, and minimum level in regard to the depth of the submarine outfall. This system is applied when assimilative capacity of the sea water is small, like closed bays and sea water with low water exchange rate and sensitive waters. The minimum length of submarine outfall must be 300 m in accordance with Croatian standards. Effluent from treatment plant must be disinfected. It is important to know that first 300 m of outfall are the most expensive part of the outfall because that is area under stronger influence of waves and coastal activities.

Alternative 2 includes full mechanical or partial biological treatment which includes removal from waste water of settling suspensions, floating materials, oils and grease and partly BOD. Remaining waste in water is left to the autopurification processes of the sea water. This system is applied when assimilative capacity of the sea water is good, like open bays and sea water with moderate water exchange rate and less sensitive waters. In order to speed up autopurification processes and make substances in effluent less harmful, the waste water is released using diffusers, thus obtained high initial dilution. The computation of submarine outfall length is primarily based on satisfying the bacteriological standard as it is the most critical one. By a combination of dilution and the process of autopurification, the required bacteriological standard can be satisfied with the length of the outfall being ca 1000 m.
Alternative 3 includes the minimum possible degree of preliminary purification and maximum possible length of outfall for the analyzed case. In order to satisfy the standard of the open and coastal sea considering the aesthetic criterion, and to protect the outfall from getting clogged, it is necessary to use minimum mechanical purification to remove the floating matter, grease and sand. Thus the standard should be satisfied by dilution and sea-water activities. The computation of submarine outfall length is primarily based on satisfying the bacteriological standard as it is the most critical one. This system is applied in case when assimilative capacity of the sea water is high, like channels and sea water with good water exchange rate and nonsensitive waters.

Each alternative has some specific characteristics, advantages and drawbacks when compared according to the ranking criteria. But, each alternative must satisfy the sea water standard in regard to short and long term effects on the sea water. In accordance with long term practice the alternative 3 can be safely applied in case of small quantity of waste water or in case when waste water is released in the open and deep sea (channels), i.e. when sea water has a high assimilative capacity. If the sea water assimilative capacity can not accommodate waste quantities released by outfall (if long term negative impacts are possible) higher treatment level must be used.

When solving the problems of the waste water disposal for Split, Solin, Kaštela, Trogir, all three alternatives were considered; i.e. It has been proposed that system "Treatment plant-submarine outfalls" develops gradually in stages. Alternative 3 to be applied in the initial phase when the waste water quantity is small; alternative 2, i.e. alternative 1 to be applied when the quantities increase and when negative impacts upon the recipient are possible according to the monitoring of the sea water quality (when it is necessary in accordance with results of monitoring and simulation data or other requirements). According to the previous investigations it is not planned to have a long-term disposal of either untreated or treated waste water into the Kaštela and Trogir Bays as they considered as sensitive waters which will be continuously and increasingly influenced by air deposit and other diffuse sources of pollution.

In order to make proper decisions Computerized Decision Support Systems in Coastal Water Resources Management have been proposed and partly implemented. Computerized Decision Support Systems differ from traditional record-keeping and transaction-processing use of computers primarily because they require a symbiosis between the users and the system in order to be effective. DSS have a three main components: data subsystem (static and dynamic data base), model subsystem (planning models, management models and operation/control models) and dialog subsystem. This system will aid decision makers in the process of transforming data into necessary information to solve unstructured problems of coastal water quality management.

Results of calculations (Appendix 1 and Appendix 2) show that in accordance with the present knowledge such results can satisfy not only present standards but even the new Croatian standards (still in preparation) that are similar to EU standards, International protocols and EU standards (91/27/EEC; 76/160/EEC).

The main advantage of such approach is in rational and reliable solving of the problem of waste water disposal because during the initial period of the operation of the system the shortage of qualified staff and resources for the system operation won't have negative impact on the required level of sea preservation. In the initial period the problem of sludge handling and disposal is also eliminated. During the initial period the operational costs are minimal. After the beginning of the system operation better informations about waste water quality can be collected because waste waters will be united at the unique treatment plant, as well as about recipient condition. Therefore it will be possible to better plan a necessary increase of the treatment level.
This approach is also more acceptable for the local population that is gradually getting used to the existence of the treatment plant. Local population will notice advantages of the beneficaility of the solution and will accept bigger financial liabilities and the development of treatment works.

With this approach, during the initial period, the impacts on eco-system of the sea are bigger and impacts on terrestrial eco-system and the area in the vicinity of the treatment plant are smaller. Increase of the treatment level will reduce the impact on eco-system of the sea and increase the impact on terrestrial eco-system and the surrounding area because of treatment plant development, treatment products and solids disposal, Figure 5.6.

In order to protect sea water, treatment of industrial wastewaters at production site has to be instituted at the beginning of system operation and trade effluent policy has to be established except for biologically degradable effluents. Process of greening of industry has to start as soon as possible.
5.4. ALTERNATIVE SOLUTIONS FOR THE TREATMENT PLANTS TECHNOLOGY

The selection of technology for the waste water treatment for the Split-Solin sewer system included two main alternatives: AB process and a traditional activated sludge process /10/. The phased installation program was designed depending on the development of collecting system, the final effluent quality requirements and the treatability of the wastewater. Each alternative included a preliminary design solution and a comparison after which the AB process was selected as a more efficient one. Both processes are similar in the costs and environmental impacts, but the AB process was selected since it ensures better construction in phases and makes possible partial biological treatment, which is considered to be long-term efficient considering the assimilative capacity of the Brač-Split Channel, less sensitive waters /10/.

No matter that all conducted researchs imply that there is no need for a higher level of treatment, all installations were designed for tertiary treatnent level with UV desinfection in order to determine long-term required area and other resources.

All alternatives require the sludge treatment to the level that enables its use for agricultural purposes in accordance with Croatian and EU standards. The basic requirement is adequate treatment of industrial waste water.

In regard to large excavation in the surrounding area for purposes of cement manufachring, there is enough space for sludge disposal if it wouldn't be used for agriculture. Sludge can be composted and together with municipal waste used to cover solid landfill site. This option was discussed in the municipal waste treatment analyses.

The two processes are identical considering the first phase of the construction with the partial mechanical treatment. Since there is no unique sewer system and, hence, there are no reliable samples of the waste water (combined system), it is considered that the final technology of higher treatment level should be selected according to the results obtained after the operation of a pilot plant. It should start after the collection of the waste water at the plant after the first phase of construction.

The present characteristics of the waste water in Split, due to great dilution, are of the same quality as the effluent from the secondary treatment plant during the greatest part of the year (BOD5 25-50 mg/l).

The same study was not developed for the sewer system Kaštela-Trogir so that the results of the Split-Solin were used instead. The same procedure to be used for the solution of this problem was proposed for this system as well.
5.5. ANALYSES AND ALTERNATIVE SOLUTIONS FOR SUBMARINE OUTFALLS

The studies included the analyses of alternative solutions for submarine outfalls, such as the alternatives for the locations of diffuser disposition, route for the land section and submarine section of the outfall and various types of construction for the diffusers and construction in phases.

These analyses were developed according to previous oceanographic investigations, modeling and computations (Appendix 1), taking into account the position of the treatment plant and its construction in phases (treatment level of the plant). These analyses also included the requirements related to the use and function of the sea in the area under consideration.

For the Split-Solin sewer system the requirements for the submarine outfall and diffuser placement are not the same for the entire area of Brač Channel in the south of Split peninsula from Stobreč to city harbor, Fig. 1.9. In the central part of that area of Brač Channel there is shallow sea with submarine reefs (depth 8-18m) that disable the construction of submarine outfalls. Therefore the possible location for the outfall are further east toward Stobreč or further west toward city harbor. Considering the waste water treatment plant location in the area of Stobreč, the most acceptable location for the outfall was the area of Brač Channel in front of Stobreč.

Environmental requirements for the diffuser location (place of discharge) for Stupe treatment plant are relatively similar in the Brač Channel for the entire area of Stobreč (depth from 30 to 50 m) because depths and velocities are similar in the entire area. Depth is generally increasing with the distance from the shore and therefore the disposal is environmentally more favorable with the greater distance from the shore., Fig.1.9. Mixing and exchange rate of water are more favorable toward the middle of Brač Channel. Outfall route is favorable in this area because use of fishing boats with the net is prohibited. Therefore there are no restrictions for the construction of the outfall and the diffuser in this area. Environmental and construction characteristics of the sea bottom in this part of Brač Channel are the same and thus don’t have the significant impact on the selection of the diffuser location.

Construction costs of the land section of the outfall have the biggest impact on the selection of the location. The existing documentation includes the solutions which were selected according to multicriterional analysis. Within the Split-Solin system two routes for the outfall were analyzed, Figure 5.7. The analysis were performed according to preliminary solutions for each alternative /1/. Both routes are in the Stobreč area. The main difference between these two routes is the cost of implementation which is significant and partly the ecological characteristics which are similar at both outfall locations. Both routes are very expensive. The route through the Stobreč Bay was selected as a more efficient one.

Waste water disposal requirements for the Kaštela-Trogir sewerage system on the south side of the Čiovo Island and this part of Split Channel are pretty much the same because configuration of the sea bottom is similar, Fig. 1.14. Conditions are favorable because of significant depth of the sea (50 - 70 m) that increases with the distance from the shore toward the middle of the bay and very good exchange rate of sea water. Environmental and construction characteristics of the sea bottom in this part of Split Channel are the same and don’t have the significant impact on the selection of the diffuser location.

On the Čiovo peninsula two positions for the submarine outfall of the Kaštela -Trogir system were analyzed. /14, 14/. Distance between them is about 1.5 km. Conditions are more favorable
toward the west because the sea is deeper and therefore conditions for dilution. Construction conditions, costs and environmental impacts for each of them are very similar. The selected location is more distant from the small islands (St. Fumija) and other downstream islands in this aquatorium, i.e. it is the location near the Mavašćica bay, Figure 5.8. The diffuser is situated within the area where use of fishing boats with the net is prohibited. Outfall route through the smaller bay Mavašćica is more favorable because of the good protection of the pipeline on the bottom and smaller impact of the waves and therefore greater reliability of the disposal system and smaller construction costs.
Figure 5.6. Alternative routes and positions for the submarine outfalls for the Split-Solin sewer system

Figure 5.7. Alternative routes and positions for the submarine outfalls for the Kaštel-Trogir sewer system
6. PROPOSED MEASURES TO PREVENT, REDUCE OR MITIGATE THE ADVERSE EFFECTS OF THE PLANNED WASTEWATER DISCHARGE SYSTEM

6.1. STRATEGIC PREREQUISITES FOR THE PROTECTION OF KAŠTELA AND TROGIR BAY AND BRAČ AND SPLIT CHANNEL AGAINST POLLUTION FROM LAND BASED SOURCES AND ACTIVITIES

Protection of Kaštel and Trogir Bay

In order to ensure long-term protection of Kaštel and Trogir Bay, considered as sensitive areas, it is necessary to:
- eliminate all outfalls that discharge municipal wastewater into the bays
- eliminate all outfalls that discharge industrial wastewater into the bays
- reduce diffuse sources of pollution (storm runoff, air deposit, etc.), and
- establish permanent control of pollution sources and monitoring of coastal water.

Protection of Brač and Split channel

The permanent protection of Brač and Split Channel, considered as less sensitive areas, in the wider area of Split, Solin, Kaštel and Trogir should be ensured by the fullfined the following:

a) General condition

1. Disposal of the wastewater via long submarine outfalls, and achieving appropriate initial and secondary dilution.
2. Purification of the wastewater prior to discharge into the sea by long submarine outfalls.
3. Pretreatment, prior to discharge into the municipal sewerage network, of industrial wastewater that can be detrimental to:
   - the operation of the biological treatment plant
   - usage of the sludge produced at the treatment plant
   - marine ecosystems.
4. Elimination of all existing uncontrolled coastal outfalls.
5. Appropriate purification of storm runoff and overflow water.
6. Control of all other diffuse sources of pollution.

b) Construction of sewerage system

Construction of appropriate sewerage system (collecting system, treatment plant and submarine outfall) would create conditions for the fulfilled of the mostly above listed general condition. But its construction all urban and industrial waste waters generated in Split, Solin, Kaštel and Trogir area will be collected at two treatment plants (Stupe and Čiovo), treated at appropriate level and discharged into Brač and Split channels via long submarine outfalls.

c) Design and quality of construction of collecting system, treatment plants and submarine outfalls

In order to ensure efficient collection of all wastwaters into the collecting system, it is necessary to design and construct using best available knowledge and available materials and technology, and local characteristics, to ensure high-quality construction.
d) Efficient management and maintenance of sewerage system

Efficient management and maintenance of sewerage system is the key element for efficient protection of environment and sea water because the efficient organization, experienced, well trained and adequately paid staff are necessary to ensure permanent efficient operation of the sewerage system (collecting system, treatment plant, submarine outfall).

e) Public participation

The public (local communities, NGOs, representative of scientific community, etc.) should be the main promoter of protection measures as well as a proofreader of measures that are already undertaken. Therefore it is necessary to include the public in the development of entire project.

f) Monitoring and information

In order to collect necessary data for coastal water resources management and to inform the public and all interested sides about the level of sea water pollution, discharges and activities it is necessary to establish monitoring of sea water quality, discharges and all other elements associated with the sewerage system and treatment plant (solids disposal, sludge use, costs, etc.). An appropriate information system to inform general public and all interested party about all activities that were or will be undertaken as well as about achieved results should be developed.

g) Computer-based Decision Support System for Coastal Water Resources Management

Monitoring data together with other relevant data by computer-based Decision Support System (DSS) have to be transformed into necessary information’s to aid decision makers to take environmental sound decision in coastal water resources management: DSS will aid to scientifically anticipate the measures for: determination of the level of pollution of sea water in the entire area (simulation models), determination of necessary measures for the sea water protection (the treatment plant development, increasing the treatment level, correction of system operation), determination of measures for expansion of the existing sewerage system, determination of other structural and nonstructural measures for the protection of the environment, etc.

By applying above listed it could be concluded that the sea water of Brač and Split Channels will be protected from:

a) Bacterial pollution

During the initial phase (preliminary treatment only) the installation of long submarine outfalls will be in accordance with the calculation of dilution and time of bacterial decay in order to ensure required standards for the open sea (III category) at the outfall location and standards for bathing and recreational water (II category) on the boundary 300 m from the shore. To meet these requirements the outfalls length should be 2600 m, length of diffuser 400 for Stobreć, and 2050 m and diffuser length of 400 m for Čiovo.

During other phases (secondary treatment) the protection will be ensured with UV disinfection of the effluent and submarine outfall of such length that the distance of the diffuser beginning from the shore is always greater then 300 m.

b) Aesthetic pollution

During the initial phase (preliminary treatment only) installation of screens, aerated grease/grit channels will ensure that there is no visible slick on the sea surface.
During the second and other phases of construction of the wastewater treatment plant (Primary treatment, Secondary treatment) the protection will improve by installation of settling tanks.

In order to reduce negative aesthetic impact it is necessary to install screens (6 mm opening) at overflows, and grit/grease channels where necessary (at the location of significant sources of pollution).

c) Organic pollution

During the initial phase almost entire organic pollution will be discharged into the sea and according to the calculation output and the results of simulation model it will be accommodated without significant detrimental effects.

During other phases of construction of the treatment plant (primary, secondary and tertiary), if necessary, the organic pollution will be significantly reduced (from 20 to 99%).

d) Heavy metals and toxic materials

During the initial and all other phases of the system development, the protection of sea water will be achieved by control and purification of industrial wastewater at the place of origin.

e) Nutrient content

The reduction of nutrient content of wastewater and therefore the protection of the sea water will be achieved by installation of higher levels of purification and especially tertiary treatment plant, if necessary.
6.2. SPECIFIC MEASURES PROPOSED TO PREVENT, REDUCED OR MITIGATED THE NEGATIVE EFFECTS OF THE PLANED SEWERAGE SYSTEM

The adverse effects of collecting system, treatment plants and submarine outfalls may be reduced by respective measures and procedures during their construction, use and maintenance.

6.2.1. Legal and administrative measures during the construction

The construction of the sewerage system installations must be in accordance with legislation and especially with the Building Law (NN 77/1992, N.N. 33/1995) and other laws relevant for this objects (Water Law, N.N. 107/1995).

The construction must also be in accordance with requirements issued by different authorities such as: sanitary requirements, water authorities requirements and requirement of local sewerage system organisation, requirements of harbour authorities and roadbuilding authorities, electrical supply requirements, requirements of other infrastructure organisations, location permit etc. Construction methods and procedures are presented in Building permit.

In order to construct as fast as possible and without negative environmental impacts it is necessary to define the Implementation Schedule taking in account local requirements and characteristics. It is also necessary to co-ordinate the construction with all activities in the area or activities that will be influenced during the construction.

It is always recommended to contact the local population and discuss the most favourable construction method.

6.2.2. The collecting system

6.2.2.1. Measures during design and construction

General

To eliminate the dangers associated with the system the need for safety should be considered in the design of such system. They should be properly sized, closed, watertight and hard enough to sustain all possible loads that may occur during normal operation or at damages. Sections which cross the water supply mains are separately made so to avoid any contact of sewage effluent with supply water mains or at a sufficient distance apart.

Use of the most impervious concrete possible and construction of pipes and canals with elastic joints, leakage will be almost completely prevented.

Continuity of the operation of pumping stations must be ensured with the following: reserve pumps and reserve power sources - diesel power generator sets at all major pumping stations (Dujmovača, Duje, Lokvice, Pantana-Divulje), mobile diesel-power generator sets or double power sources at other smaller pumping stations.

The sewerage system should be planned as to avoid threatening historic monuments and passing through ecologically sensitive areas. The same will be achieved with consulting and observing the requirements of the services for the preservation of historic monuments in each town: Split, Solin, Kaštela and Trogir.

Design of the sewerage network and its objects should consider the planned urbanistic characteristics of the sewer routes as well as planned municipal infrastructure (electricity, water supply etc.)
In order to avoid negative impacts created by construction activities in tourist areas, especially in Trogir and Čiovo island, construction should be organize out of tourist seasons.

Special plan of measure for utilities supply should be prepared and implement during the collecting system construction in order to eliminated the negative impacts on local population, public and other institutions.

For the protection of unknown historic monuments especially in Solin and Trogir area earth works should be implemented after consultation with institutions responsible for protection of historic monuments.

During design and construction period it is necessary consult Water authorities in Split in order to avoid negative impacts on surface water streams, especially in Kaštel area.

Responsible authorities must establish legal act that prohibits any activity in the crossing areas of raising mains of pum station Lokvice and Pnatana-Divulje that could damage the pipes (fishing boats with nets, anchoring etc.). The pipes position must be marked on both coast and nautical maps and corrections made on already existing maps.

The collecting system should be equip with flow meters and pump station with control system.

**Odour and noise**

The problem of odour is solved by ventilators and filters for air cleaning. The problem of noise is solved by burying the structures under ground and sufficiently apart from residential areas.

Noise associated with the operation of pumping stations can be reduced if diesel power generator set is housed inside an appropriate building or noiseless power generator sets were used. This should especially be considered for pumping stations Lokvice and Divulja-Pantana. Pumping station odour control consists of ventilation and air purification prior to discharge into the atmosphere. It should be especially considered for pumping stations located within 20 m from the residential areas, if possible.

**Measures for prevention of health hazard**

The sewerage system is built to safeguard the health of the population. However, some parts of the sewerage system may be dangerous for human health if required measures are not undertaken.

To prevent the production of aerosols, which may adversely affect the health of the surrounding population, there should be no open areas in the entire waste water collection system.

Maintenance staff must be well training in the procedure for entry to confined space and control other hazard.

Unauthorized access to the elements of sewerage system (pump stations, overflows, etc.) is prevented by the fencing or guard rail, locking up of the objects and posting the warning signs.

**Fire extinguishing measures**

These works are not source of any special danger of fire and no special measures are required.

Prevention of accumulation of methane and other inflammable gases in sewers and pumping stations will be achieved with efficient ventilation system.
**Other measures**

Existing collection system in Split is combined type sewerage system. In order to prevent pollution caused by overflow water it is necessary to install screens (6 mm opening) at the overflows, and oil and grease separators if necessary.

In order to determine the real impact of these waters on the coastal sea water it is necessary to develop the mathematical model of collecting system and determine frequency of overflows and total annual pollution loads. Based on obtained results it is necessary to dimension overflows and belonging outfalls for overflow water.

It is also necessary to determine long term pollution of storm runoff and its impact on marine environment in order to anticipate measures of protection.

**6.2.2.2. Measures during operation**

Negative impacts during operation of the system must be avoided by proper maintenance. Prerequisite for proper maintenance is the development of maintenance plan and its application, as well as appropriate storage of spare parts.

Maintenance of the system must be regularly and during the maintenance all necessary measures against hazard health impacts to workers must be applied. Appropriate training of stuff is necessary.

The system must be regularly wash out, control and repair if necessary. Special attention should be paid to maintenance of raising main crossing the Kaštel bay, overflows and pump station.

Deposit and crust in pump station should be regularly cleaned. Illegal connection of storm water to foul system should be eliminated.

Regularly control of flow in the system must be taken in order to control infiltration waters.

Screens on stormwater overflows must be regularly clean especially during and after rainfall season.

The pumps must be regularly controlled and maintenance. From time to time stand by system for energy supply must be controlled.

**6.2.3. Treatment plants**

**Measures for prevention of air quality impairment**

Two kinds of preventive measures against unpleasant odors and aerosols may be distinguished: designing and operational. The former measures mean closing of all the structures which should be aesthetically and functionally adapted to the environment in the best way possible or buried.

One of the operational measures is the forced ventilation of the entire indoor space. Ventilated air will be released into the atmosphere upon appropriate treatment (using biofilters). It should include all elements of preliminary works: Reception Chamber, Inlet Channels, Screens, Aerated Grit/Grease Channels, Cess Tanker reception and screens. In addition the row sludge processing units must be covered and provided with ventilation/odor control: primary sludge thickening, secondary sludge thickening/dewatering, sludge blending and digested sludge dewatering.
Measures for reduction of vibrations

All the works that may produce vibrations such as: air blowers and power plant have to be appropriately mounted on vibration dampers to prevent transmission of vibration to the surrounding terrain.

The problem of vibration of the outfalls as the result of air penetration into the pipes will be eliminated by the construction of an appropriate ventilation shaft.

Fire extinguishing measures

These works are not source of any special danger of fire and no special measures are required. Hazard related to handling and use of digester gas are well recognized and current practice have to be used so that this hazard is minimized. Usual fire hazards measures is necessary to apply in accordance with low for all elements of the treatment plants.

Measures for prevention of health hazard

The sewerage system is built to safeguard the health of the population. However, some parts of the sewerage system may be dangerous for human health if required measures are not undertaken. In general there are no hazard to the health of neighboring people from treatment plants.

Hazard relation to the operation of treatment plants must be recognized and strictly controlled.

The control of entry to confined space must be strict. Works operation and maintenance staff must be fully trained in the procedures for entry to confined spaces and control of the other hazards associated with operation of treatment.

Measures to minimized emission of bacterial aerosol spary have to be applied, such as tree screens, raised sides to aeration tanks, and selection equipment that minimizes the generation of spray.

In order to prevent accidents and possible detrimental effects on the population, the area of the wastewater treatment plant must be fenced and permanent security guard service established.

Measures for prevention of noise

All equipment that will emit significant noise (like: power generation, aeration blowers, etc.) must be housed in sound attenuating buildings.

Solids disposal

Solid wastes associated with the operation of the treatment works have to be properly treated and disposed: screenings must be washed, dewatered and dispose at sealed landfill site or incineration on-site; grease and oils must be incineration on-site or collect and dispose with urban oil and grease waste; grit and sand must be wash and clean from organic material so that it can be used for landscaping; stabilized biosolids must have long term stability and to be suitable for agricultural or horticultural purposes.

Aesthetic impacts

Appropriate solutions like tree planing have to be implemented in order to minimizing the visual impacts and wind effect on the operation of works and improve aesthetic conditions.

Work buildings have to be finish in accordance with local building traditions and other buildings in the area.
Traffic

Traffic to and out of plant must be properly regulated. New road out of village Mavašćica should be considered in order to avoid all problems related traffic through existing inappropriate road through village.

Insect nuisance

Although problem related insect (filter flies and mosquitoes) is not problem for the proposed type of plant usual control must be considered.

Measures for prevention of pollution fresh and sea water against pollution by surface runoff

In order to prevent pollution of fresh waters (river Žrnovnica) and coastal sea (Stobreć and Mavašćica bays) it is necessary to take appropriate measures against storm water runoff (construction of channels and settling basins).

6.2.4. The submarine outfalls

6.2.4.1. General

To protect the submarine part of the outfalls from wave and anchorage impacts as well as from impacts resulting from various other activities in the narrow coastal strip, it is planned to bury and concrete the pipes to the point of 8 m of sea water depth (have to be determined by design). The rest of the pipe will be protected by forbidding all the activities in the sewer surrounding that may damage it.

To avoid either vertical or horizontal shifting of pipes (as affected by currents or air penetration into the system) pipes should be fixed by appropriate weights.

Since the submarine outfall for discharge into the Stobreć Bay is passing through the possible location of the future ferry port, pipeline must be laid deep enough into the bottom to protect it from effects of possible anchoring of ships.

Instructions for the outfall construction will be provided by Port authorities in Split.

To provide normal diffuser operation it will be placed on the supports and elevated a 1 m above the sea bottom. A flange is fitted at the diffuser end to permits cleansing from time to time.

6.2.4.2. Measures that should be undertaken during the construction of submarine outfalls

As it was mentioned before, the construction of submarine outfalls won't have significant impact on the marine environment. In order to avoid and reduce assumed negative impacts during the construction of submarine outfalls it is necessary to undertake the following measures:

- in the coastal area, the outfall pipes should be buried and protected with concrete in such way to cause minimum turbulence within the area.
- during the installation of submarine pipeline it is necessary to effectively and on time secure the aquatorium (especially in the Split Channel). It must be marked and made public in order to avoid accidents and to secure lives of the stuff on ships and workers that will perform the installation.
6.2.4.3. Measures that should be undertaken during the operation of submarine outfalls

In order to secure the planned operation of assumed submarine outfalls and therefore prevent negative impacts of the discharge of urban waste waters on marine eco-systems and to make possible the usage of sea for planned purposes it is necessary to undertake the following measures that can be classified as legal, technical and organisational ones.

i) legal measures
- responsible authorities must establish legal act that prohibits any activity in the area of the submarine outfall that could damage the outfall (fishing boats with nets, anchoring etc.)
- fishing in area around the diffuser location (500 m) must be ban.

ii) technical measures
- the submarine outfall position must be properly marked on the land and on the sea;
- the outfall position must be marked both on the coast and on nautical maps and corrections made on already existing maps. Changes must be announced for the public especially before the summer season starts;
- the control of accuracy of outfall operation and its maintenance must be done at least once a year (in the beginning of spring) by autonomous divers or submarine robot TV cameras;

iii) technical measures
- the system of regular control of outfall operation and maintenance must be established and carried out in accordance with technical and technological requirements of the construction;
- establish and organise technical team that will immediately intervene to fix any damage that could prevent the planned operation of the outfall.

6.2.5. Tunnel

Since the construction of the tunnels will have significant impacts on local and wider areas with respect, noise, dust, traffic, vibration, visual impacts and disposal of excavation materials it be necessary to prepare a separate environmental impact assessment for both tunnels.

6.2.6. Organization and management

It is recommended to operation company that core team of operation staff recruited before the works development so that installation can be used for training.

It is necessary to organize smaller team of chemist and laboratory staff for waste water monitoring and establishing good trade effluent monitoring.

It is recommended to operation company to carry over necessary recruitment, training and built up of the drainage system management and control team.

A study have to be carried out covering current organization and proposed organization (staffing levels and training requirements) in accordance with system development (new treatment plants, submarine outfalls and transmission mains).

Operational company have to buy necessary equipment and tools for appropriate control and maintenance of the system.
6.2.7. Other measures and studies

1. In order to make proper decisions regarding necessary treatment and improvement of collecting system Computerized Decision Support Systems in Coastal Water Resources Management have to be implemented. This system will aid decision makers in the process of transforming data into necessary information to solve unstructured problems of coastal water quality management.

2. Monitoring and collection of wastewater characteristics data (flows and concentrations) including and storm water data should be established.

3. Monitoring and collection of meteorological and climatological data at location of treatment plants should be established.

4. It is necessary set up wastewater and effluent monitoring system at the treatment plants (flows and concentrations).

5. It is necessary to organize monitoring of agricultural and others land and crops receiving sludge from treatment plant.

6. After installation of the first phase preliminary work, pilot studies should be carried out to characterize the treatability of the waste water and provide design information for future process selection.

7. It is necessary set up study of sludge disposal outlets in accordance with local conditions and needs including sludge management and disposal policy study.

8. Trade effluent policy should be established and strict trade effluent monitoring controls instituted.

9. Study have to be carried out to determine necessary treatment of industrial wastewaters at the production site and necessary steps for greening of industry.

10. Strict controls must be applied to setting and monitoring of standards for trade effluent.

11. Prior to commissioning of the wastewater treatment plant, the sanitary landfill site for disposal of sludge and solids from treatment plants must be determined.
7. PROPOSED RESEARCH AND MONITORING PROGRAMME

7.1. JUSTIFICATION FOR THE PROGRAMME

The nature and size of the investment, as well as its potential environmental impacts, requires the good knowledge and understanding the marine ecosystems in the area, in order to avoid undesirable negative impacts of discharged waste waters.

Numerous studies of the Kaštela bay have showed that the Kaštela bay is threatened by urban and industrial waste and for its recovery would be necessary to stop the discharge the wastes. The study of the Split and Brač channels performed in September 1990 and April 1991 has showed that the Brač and Split channels, even degraded in restricted coastal areas, due their relative large volume and the circulation of water masses were found to be the best available solution for the receiving the waste waters.

The research of the Split and Brač channels was performed in September 1990 and April 1991, missing the summer the most critical season from the ecological point of view.

In order to confirm the conclusions based on the available results and used for the design of the sewerage project, and gather further information necessary to evaluate the present state, it would be necessary to undertake further investigations of the marine environment of the area. The results of investigation are very important, also, for the decision on the final waste water treatment level, which will be made later taking into consideration impacts of pretreated waste water on the marine environment.
7.2. AIMS OF THE PROGRAMME

The main aims of the programme are:

- to collect information on the dynamic of water masses in the areas of the submarine outfalls and in the entire channels area during summer season, the most critical period from the ecological point of view and use of the coastal zone for bathing and recreation;

- to evaluate the present level of the degradation of marine ecosystems of Brač and Split channels and Kaštela bay, using different physical (transparency, TSS) chemical (oxygen concentration and saturation, nutrients concentration) and biological (structure and composition of phytoplankton, zooplankton, bacterioplankton and benthic communities, and primary and secondary production) parameters;

- to assess the present level of pollution by selected pollutants contained in urban and industrial waste waters.
7.3. OUTLINE OF THE RESEARCH PROGRAMME

1. Current measurements (by current meters)
   Period: January-February (period of homogenous water), and July-August (period of intensive stratification)
   Duration: 25-30 days
   Locations: 13 stations (I-XIII) indicated on the Figure 7.1
   Levels: 2 levels; surface (3 m) and bottom (3 m above the bottom)

2. Physical parameters (by CTD probe)
   Parameters: salinity, temperature, sigma T, Secchi disk
   Period: 6 times (at a beginning and end of the current measurements, and in May and October)
   Locations: 26 stations (1-26) and 13 current measurement stations (I-XIII) indicated on the map
   Levels: profile from the surface to the bottom

3. Surface waves
   Parameters of wind generated surface waves are proposed to be measured in the period October-April by anchoring waverider station in front of Split port (Figure 7.1)

4. Meteorological data
   Wind speed and direction will be measured at 3 stations: main meteorological station Split-Marjan, Rt Luka and at island Drvenik Veli (Figure 7.1)
   Air pressure and temperature will be measured at the main meteorological station Split-Marjan.

5. Chemical parameters
   Parameters: dissolved oxygen, nitrate, nitrite, ammonia, N$_{org}$, ortho-phosphate, P$_{org}$, orthosilicate
   Locations: 30 stations (3, 4, 5, 6, 7, 8, 9, 10, 15, 16, 18, 20, 21, 22, 23, 24, 25, 28 and II-XIII) indicated on the Figure 5.1
   Levels: 4-7 levels (surface, 5, 10, 20, 30, 50 m, and bottom
   Period: same as for the physical parameters

6. Biological parameters
   Parameters: composition of the phytoplankton community, chlorophyll a, primary productivity, density of heterotrophic bacteria, heterotrophic nanoplanckton, bacterial production, structure and composition of microzooplankton, structure and composition of benthic communities
   Locations:
   i) plankton on 30 stations (same as chemical parameters), except the primary productivity which will be measured at stations IV, VII and 23
   Levels: 3 levels (surface, 20 m, bottom) except for primary productivity 5 levels (0, 5, 10, 20, and 30 m)
   Period: same as the physical parameters
   ii) benthic communities on 10 profiles, up to 30 m depth as indicated on the Figure 7.2
   Period: once

7. Spawning areas and Nursery grounds
   Parameters: temperature, salinity, oxygen, pH, nutrients, ichtioplankton, juvenile fish organisms
Locations: estuaries of Cetina, Žrnovnica, Jadro, Pantan, and shallow bay (Bene, Supetar, Kaštela Sućurac, Nečujam, Lestimerova, Livka, Stiniva, Zastup, Lovrećina, Luka-Povlja)
Period: monthly

8. Indicators of faecal pollution
Parameters: faecal and total coliforms, faecal streptococci
Locations: 17 stations as indicated on the Figure 7.3
Levels: surface layer
Period: monthly (V, VI, IX) and weakly (VII, VIII)

9. Concentration of heavy metals
Parameters: i) surface sediments: concentration of Cd, Zn, Hg, Pb, Cu, Cr, granulometric composition, and organic matter content
  ii) shell fish Mytilus galloprovincialis: concentration of Cd, Zn, Hg, Pb, Cu, Cr
Locations: i) 15 stations (4,10,15,22,23,24,26, and II-IX) indicated on Figure 7.1
  ii) 15 stations distributed all over the coastal region
Period: i) once
  ii) seasonally

10. Concentration of chlorinated hydrocarbons
Parameters: i) surface sediments: concentration of chlorinated hydrocarbons (Aldrin, Chlordane, DDT, Dieldrin, Dioxins and Furanes, Endrin, Heptachlor, Hexachlorobenzene, Mirex, PCBx and Toxaphene)
   ii) shell fish Mytilus galloprovincialis: concentration of chlorinated hydrocarbons (Aldrin, Chlordane, DDT, Dieldrin, Dioxins and Furanes, Endrin, Heptachlor, Hexachlorobenzene, Mirex, PCBx and Toxaphene)
Locations: i) 15 stations, same as heavy metals
   ii) 15 stations, same as heavy metals
Period: i) once
   ii) seasonally

11. Consumption of dissolved oxygen by sediments
Consumption of dissolved oxygen by sediments from 5 stations located in the Kaštela bay and Split and Brač channels should be measured seasonally by "on board" method.

The cost of the proposed research programme is estimated at the level of 700,000-900,000 US $.
7.4. OUTLINE OF THE MONITORING PROGRAMME

Sewage effluent control as well as the observation of the changes occurring in the marine environment due to the disposal of sewage effluents should be permanently carried out to:

- collect information on the marine environment in order to prepare the proper decision on the required level of waste waters treatment;
- evaluate the impacts of the outfalls on the surrounding marine environment;
- implement necessary measures for protection of the environment and health of the surrounding population;
- to assess the recovery rate of the Kaštela bay;
- to complain the state of marine environment with the prescribed values.

Parameters to be monitored and frequency of measurements

A) EFFLUENTS:

- flow rate;
- nutrients (total phosphorus, total nitrogen, nitrites, nitrates, ammonia);
- BOD;
- total suspended matter;
- heavy metals (Cd, Zn, Hg, Pb, Cu, Cr);
- chlorinated hydrocarbons (Aldrin, Chlordane, DDT, Dieldrin, Dioxines and Furanes, Endrin, Heptachlor, Hexachlorobenzene, Mirex, PCBx and Toxaphene);

Sampling should be performed on a seasonal basis at the manhole at the end of land sewer part, so as to permit the calculations of daily mean values.

B) MARINE ENVIRONMENT:

1. Physical parameters

- parameters: some as under the research programme
- locations: same as under the research programme
- period: 6 times in a year (I-II, V, VII, VIII, IX, X)
- levels: same as under the research programme

2. Chemical parameters

Same as under the research programme, except period of measurements which should be the same as for the physical parameters.

3. Biological parameters

Same as under the research programme, except period of measurements which should be the same as for the physical parameters.

4. Indicators of faecal pollution

In the Split and Brač channels same as under the research programme. In the Kaštela Bay at 10 stations.

5. Concentration of heavy metals

Same as under the research programme.

6. Concentration of chlorinated hydrocarbons

Same as under the research programme.
7. Consumption of dissolved oxygen by sediments

Same as under the research programme.

Yearly cost of the proposed monitoring programme is estimated at the level of 300,000 US $.
Figure 7.1. Location of the oceanographic and meteorological stations
Figure 7.2. Location of profiles for the benthic communities study
Figure 7.3. Location of stations for the control of sanitary quality of coastal waters
7.5. COMPUTER-BASED DECISION SUPPORT SYSTEM FOR COASTAL WATER RESOURCES MANAGEMENT

Computerized decision support systems are interactive computer-based systems that aid decision makers in the process of transforming data into necessary information to solve unstructured problems of pollution and protection of the coastal sea waters in the Split, Solin, Kaštel and Trogir region.

The main components of the DSS are: data subsystem, model subsystem, and dialog subsystem, as illustrated on next figure.

![Diagram of a Decision Support System]

The data subsystem is directed to the acquisition, storage, management, retrieval and processing of data and it will be subdivided into static and dynamic database. The static data base will include the physical, economic, demographic, environmental, land use, as well as other pertinent features of the system. The dynamic data base on the other hand, includes time series information such as hydrology, wastewater flow, wastewater quality, sea water quality and climatologic data sensing.

The model subsystem is used for analysis, predicting and decision guidance. This subsystem will include a variety of models ranging from simulation (collecting system, treatment plant, submarine outfall, sea water quality, etc.) to optimization models, which may have various levels of sophistication.

The dialog subsystem, is the component of DSS which provides the essential human-machine interface. Dramatic advances in software and hardware technology have provided the means for
the development of user friendly interfaces, including high resolution color graphic, animation and multimedia presentation.

Experience showed that decision support systems have been used in many areas of water resources management to the point that they have become an indispensable part of decision making process.

Taking into consideration series of still unsolved problems connected to: the recovery of Kaštel and Trogir Bay; long-term effects of the discharge of wastewater into Brač and Split Channel; the required treatment level; the impact of overflow waters; the impact of industrial wastewaters, system operation, etc. it is considered that the implementation of such DSS is essential. Implementation of DSS would make the long-term co-ordination of work and system construction with all four municipalities much easier, the public will be better informed and necessary decisions concerning progress of the protection of this region will be made much easier.

By the implementation of DSS the proposed monitoring system could be efficiently and completely used, as well as all data that should be collected during the project preparation phase. This system will unite in one place all existing data and knowledge that are necessary for the efficient management of coastal water resources.

It is necessary to mention that at the Faculty of Civil Engineering University of Split such system is in the development phase.

The costs for establishment of DSS for areas of Kaštel and Trogir Bay, and Brač and Split Channel, as well as for towns of Split, Solin, Kaštel and Trogir were estimated at 395,000 US$. 
8. ESTIMATION COST FOR CONSTRUCTION, RESEARCH, MONITORING, TRAINING AND MAINTENANCE EQUIPMENT

INITIAL PHASE

Initial costs of the construction of structures for the protection of Kaštel and Trogir Bay, and Brač and Split Channel were estimated as:

- collecting system Split/Solin 24,700,000 $  
- preliminary treatment plant "Stupe" 7,600,000 $  
- submarine outfall "Stobreč" 6,350,000 $  
- collecting system Kaštel/Trogir 28,500,000 $  
- preliminary treatment plant "Ciovo" 6,600,000 $  
- submarine outfall "Mavašica" 3,100,000 $  

SUB-TOTAL 76,850,000 $

Monitoring 300,000 $/year  
Research 700,000 - 900,000 $  
Computer-based Decision Support System for Coastal Water Resources Management 395,000 $  
Training of staff 125,000 $  
Equipment and tools for maintenance and control 850,000 $  

FIRST PHASE TOTAL 79,220,000 $

SECOND PHASE

For the second phase of the construction of collecting system and treatment plant the costs will be approximately:

- expenditure of collecting system Split/Solin 16,000,000 $  
- primary and secondary treatment plant "Stupe" 42,800,000 $  
- additional submarine outfall "Stobreč" 3,100,000 $  
- expenditure of collecting system Kaštel/Trogir 14,000,000 $  
- primary and secondary treatment plant "Ciovo" 23,000,000 $  
- additional submarine outfall "Mavašica" 0 $  

TOTAL 98,900,000 $
9. PUBLIC HEARING

On October 24th 1996, JVP Hrvatska Vodoprivreda informed the newspapers to inform the public that public hearing of EIA for sewerage project will be done on October 29th 1996; for Trogir-Kaštel sewerage system it will be done at noon in Kaštel city hall and for Split-Solin sewerage system at 6 p.m. at the premises of Engineer and Technician Association in Split.

The newspaper Slobodna Dalmacija in its issue dated Saturday, October 26. announced the public hearing.

At the public hearing in Kaštel Sucurac that began at 12,05 and finished at 15,20 were present the representatives of NG organisation “Lijepa naša”, representatives of towns of Trogir and Solin, the president of the Business Chamber of the Split county, the representatives of Mavrištica settlement and citizens.

The study was presented by its authors, and representatives of Hrvatska Vodoprivreda presented general informations about the project.

Mr Pejaković, the General Manager of Hrvatska Vodoprivreda OJ Split, began the public hearing, greeted the present representatives and citizens and explained the purpose and way of presentation. The purpose of the public hearing was to inform the population about the study and to let them express their opinion about the planned project and the study.

Mr Bratićević greeted the present in the name of the Government of the town of Kašela and emphasised that that the planned project has great significance for the town of Kašela and expressed his hopes that WB and EBRD by the end of November will decide to finance the project.

Mr Petković presented the subproject of the water supply of this area. Mr Ivancić gave brief information about the development of the subproject of the disposal of wastewaters of this area.

Mr Margeta co-author of the study presented the subproject of the Trogir-Kaštel sewerage system, wastewater treatment plant planned on Ciovo Island and submarine outfall for discharge into the Split Channel.

Mr Barić co-author of the study presented the chapters concerning the environment and national legislation, international contracts and EU Directive that concerns collection, treatment and disposal of wastewater and sludge. He also presented expected negative and positive impacts that the planned sewerage system and its installations could have on the environment.

Mr Margeta then presented the alternatives that were analysed during the project development and measures that were planned or should be undertaken in order to prevent or reduce the negative impacts on the environment.

In the end Mr Barić presented the proposed program of the research and monitoring of the sea.

Participants of public hearing asked the following questions and stated their opinion:

**Kaštel Sucurac**

Ivna Bučan, NGO “Lijepa naša” asked the following questions: 1. Existing industry in the area of Kaštel Bay is presently not operating and therefore it is not a polluter. What will the impact of industry on the planned collecting system be if it is put in operation again, and will it have impact on the quality of sea water? 2. What will happen to the coast in the area of Mavrištica after the construction of the planned outfall? 3. Is the planned level of purification sufficient to
protect the sea water in which the wastewater will be discharged? 4. Will the wastewater of the city of Split be purified in the same way? Will construction start in the same time on both systems?

Miro Matijaca. His objection was that the project has the same approach for the entire area of the Kaštela Bay, when it shouldn’t. In his opinion, the main problem is the eastern part of the Kaštela Bay. Therefore the problem of pollution of eastern part of the bay has to be solved in order to solve the problem of the entire bay. Financial resources intended for the western part of Kaštela Bay should be used to solve other problems in this area.

Boris Škara. He asked why the wastewater treatment plant (Čiovo) wasn’t located 1000 m to the east? After the wastewater treatment plant is constructed where will the screenings be disposed until the sanitary depot for municipal solid wastes is built?

Igor Novak, environmental inspector, Trogir. He is worried that discharged wastewater will pollute the coastal sea water because only mechanical treatment is planned.

Tomislav Čiček, President of County Business Chamber, Split. Has the estimate of operational and maintenance costs for the entire system been done and who will finance it? He is worried because the construction of the sewerage system in the northern part of Čiovo Island wasn’t planned. In his opinion the secondary sewerage network has to be constructed as soon as possible in order to eliminate cess tanks in the entire area.

Ivo Rokov, NGO “Lijepa naša”. Were any measures planned in order to eliminate methylmercury from Kaštela Bay? The level of bacterial contamination is only one out of 12 parameters for determination of the quality of bathing water. The problem of propagation of radioactive slag that was deposited on the grounds of ex “Jugovinil” factory is also present in the area of Kaštela Bay.

Veselko Andromak. The higher level of wastewater treatment gives opportunity for profit and therefore the highest level of wastewater treatment should be installed at once. According to Urbanistic Plan for Kaštela the construction of the new road between Kaštela Road (Kaštelanska cesta) and Adriatic Highway (Jadranska magistrala) is planned. Could this planned road be used to tie the main sewer instead the old Kaštela road (Kaštelanska cesta)?

Marin Bedalov. NGO “Lijepa naša”. The collecting system is the foundation for the further development of the Kaštela Bay but it won’t solve all problems present in the bay (mercury, radioactive slag). There is a worry that this system won’t be constructed in planned construction period because the decision about its realisation has already been postponed several times. Construction of the collecting system will save local wells that are jeopardised by numerous cess tanks which are permeable. He also point out that the citizens of Kaštela are giving full support for the Project.

Ivica Milvonić, journalist. He is familiar with the project and he is supporting it. He asked will the Mavarsčica Bay be occasionally polluted after the construction of collecting system? Were the institutions for the preservation of historic monuments consulted during the planning period because a pre-romanic church of St. Mavro is located in the area of Mavarsčica.

Tonči Buble. He doubts that the location for the wastewater treatment plant is a suitable one. He suggested that location should be discussed at the meeting of the City Council of Trogir and its displacement further to the east considered. He also suggested to increase the level of purification of wastewater. He asked what would happen if there was a pump breakdown or power failure during the operation? How is it possible that quantity of wastewater for Kaštela is
5 times greater than the quantity for Trogir? Is there a possibility for treatment of wastewater of Kaštela in the area of Kaštela and can it be discharged into the sea from Ćiovo? Is the old part of Trogir included in the first phase of construction of the collecting system? Where will the headquarters of the Agency that will manage the system be located?

Stipe Gujinošić protests against the construction of the wastewater treatment plant and outfall in the Mavaršćica Bay where the untreated wastewater of Kaštela will be discharged. He asked why can’t the wastewater be treated at the place of its origin.

Ante Beljan. Will the construction of the collecting system endanger the area planned for tourism west and east from Mavaršćica Bay? Why weren’t all local communities included in the Project and Agency for solution of the problem of wastewater disposal?

After all the participants asked questions and expressed their opinion, the authors of the Study commented and reviewed the discussion and answered the questions.

They haven’t answered particular questions. Instead, comments and answers were made in regard to particular themes.

Comments:

The wastewater treatment plant and outfall location in the area of Mavaršćica

The proposed location for the wastewater treatment plant and submarine outfall in Mavaršćica Bay and problem of possible pollution of sea water in the Mavaršćica area drew the greatest attention and raised a great number of questions.

The concern about the location was only expressed from inhabitants (permanent and owners of weekend houses) of the Mavaršćica Bay.

Regardless of all comments and worries, the location of the wastewater treatment plant situated in the bay behind Mavaršćica village and 250 m (and possibly more than 300 m) from the nearest housing and 400 m from the sea is the most favourable location in accordance with the information given in Report Chapter 1.

The fear expressed by inhabitants is understandable because they don’t have the real conception of the wastewater treatment plant and the outfall neither they had an opportunity to see how the plant operates in practice. They believe that such treatment plant will be odorous and noisy and it will endanger the quality of living in the surrounding area.

In order to eliminate their concerns it is necessary to inform them (organise additional meetings on the spot) about the characteristics of the plant, its operation and measures that will be undertaken in order to eliminate negative impacts.

It is proposed, if necessary, to inform the representatives of local population in practice about similar treatment plants in the country and abroad.

It is necessary to undertake all measures proposed in the Report because they are sufficient to eliminate all negative impacts.

The danger of the pollution of the sea water in the area of Mavaršćica is very small because the sea currents are parallel to the shore and there is a small possibility that discharged wastewater will be brought to the shore.
Treatment level

Proposed conceptual design of treatment and disposal of wastewater guarantees, with high probability, that there won't be unwanted detrimental effects on the marine ecosystem if all proposed measures are undertaken (similar solutions in the area of Croatian Adriatic coast also prove it). Even if there were unwanted negative impacts, the planned monitoring program would detect them on time and measures for a higher level of treatment could be undertaken immediately.

Problems of the common solution for Kaštela and Trogir

It is understandable that local population isn't in favour of purification of the wastewater brought from other areas. Meanwhile, ecological and economical reasons justify the construction of unique system with one treatment plant and one outfall.

Industrial wastewater

Industry has to be treated in accordance with proposed measures which means that industrial wastewater has to be treated at the place of its origin in accordance with proposed criteria.

Other questions

Other questions (problem of mercury, radioactive slag etc.) haven't referred to Studies, but appropriate comments were made.

Split

Public hearing organised at Society of Engineers and Technicians lasted from 18.10 to 21.05. Split/Solin sewerage system and belonging wastewater treatment plant located in Stupe and submarine outfall located in Stobrec were discussed.

Public hearing started the same way as public hearing organised in Kaštel Sucurac. Participants asked questions and expressed their opinion.

Ognjen Bonacci, university professor. The hydrology of the bay hasn't been taken in consideration during the Study preparation and nobody talks about it which is inadmissible. Pollution is brought into the bay by surface and underground water and nobody knows its quantity.

Marko Šparac. Mavaršćica Bay is polluted with oil and grease after the sewerage ring of Split city harbour was built because grit/grease removal wasn't installed as part of the treatment plant. He is also concerned for the future of Mavaršćica Bay after the planned collecting system is built. Where are locations where nothing will be constructed so he can move there? He will use all available measures in order to stop the planned construction in Mavaršćica Bay.

Ljubo Jurić. Proposed solution is perfect and he supports it completely. Grit/grease removal channels are missing at the location of existing treatment plant on Katalinića Brig.

Arsen Ivanišević. He praised the authors for such detailed information and presentation of the Study. He suggests that all available measures must be undertaken in order to protect Mavaršćica Bay. He proposed to change location of the treatment plant Mavaršćica.

Marin Maravić. What are the dimensions of Mavaršćica treatment plant and how big is the open water area?
Drago Matošić. The urban wastewater treatment plant has to be located out of the settlements. Is it possible to treat wastewater of Kaštel in the area of Kaštel and to transport purified wastewater to Čiovo?

Ina Šparac. Why can’t Kaštel Bay become as clean as it used to be?

Comments:

Questions and remarks that referred to the location of wastewater treatment plant and outfall in the area of Mavarštica were similar to those asked at the public hearing in Kaštel and therefore the answers and comments from authors were similar and won’t be repeated.

There were no negative remarks that referred to Split/Solin sewerage system. Participants expressed their praise of such good solution.

The remark that referred to hydrology is correct if total pollution of Kaštel Bay were discussed. It is not correct for the solution of the urban wastewater problem which is the subject of this Study. It should be solved in accordance with the proposed measures for the protection of Kaštel Bay (diffuse sources of pollution).
LITERATURE


10. Marjeta J. and others; Preliminary design of sewerage system Split-Solin, Projects: Analyze of data, Tunnel Stupe, main trunk of north catchment area, Submarine outfall Stobrec, Treatment plant Stupe, Study of long term effects of waste water discharge in Brac and Split channel, Faculty of Civil Engineering Split, SFC-Salzburg, 1990.


19. URBS; Land use plan of community Trogir, Split 1978.

20. Margeta J, and others; Environmental impact assessment study for the sewerage system Kastela-Trogir, Faculty of Civil Engineering, Split 1995.


APPENDIX 1

CALCULATION OF THE SUBMARINE OUTFALL LENGTH
Ecological dimensioning of submarine outfalls
“Stobreč” and “Čiovo”

Contents:
Methodology of calculation
  Methodology of calculation of initial dilution
    Linear sources of pollution
    Point sources of pollution
  Methodology of calculation of secondary dilution
    Brooks Model
    CDR-2D Model
Calculation of submarine outfall “Stobreč”
  Input data and analyzed alternatives
  Results
Calculation of submarine outfall “Čiovo”
  Input data and analyzed alternatives
  Results

Bibliography

Appendices
Methodology of Calculation

After a discharge from submarine outfall orifice, wastewater is mixed with the recipient water forming a polluted plume that is gradually spreading through the recipient. Since the concentrations of some pollutions from the wastewater are several times smaller in the recipient, mixing of wastewater and recipient water causes the dilution of these pollutions.

Basically there are two phases of the wastewater dilution in the recipient water.

First phase is the initial dilution that follows immediately after the discharge of wastewater from submarine outfall orifices. Movement of plume consisted of wastewater and recipient water is under dominant influence of kinetic energy that wastewater had after the discharge from the submarine outfall orifice because of exit velocity and the difference between density of wastewater and recipient water. There are two causes of dilution. The first is velocity gradient that exists plume jet and recipient as well as turbulence in that area; the second is direct lateral flow of recipient water into the plume by means of horizontal recipient stream.

Second phase or secondary dilution follows after the plume density becomes equal to the recipient density so the movement is caused by movement of water masses (stream) of recipient itself. Dilution generated during this phase is the result of turbulences within the recipient stream.

Methodology of Calculation of Initial Dilution

There are two basic methods that are used to determine the initial dilution. They are:

- parametric models
- models derived from basic conservation laws

In this study parametric models were used.

Parametric models are used to determine characteristics of initial dilution process by dimensional analyses of formulas that are approved by experience as functions of one or several number of constants or parameters. Values of constants are dependent on hydrodynamic characteristics of plume consisted of wastewater and recipient water and they are determined experimentally on physical models.

Parameters can be classified into three groups:

- parameters that characterize the submarine outfall,
- parameters that characterize the recipient,
- parameters that are combination of the previous two.

When wastewater is discharged from point sources of pollution (outfall without diffuser or with diffuser with great distance between orifices), the following parameters can be classified into the first group:

- wastewater velocity at the diffuser orifice \( v_0 \),
- wastewater density \( \rho_0 \),
- vertical angle of discharge \( \varphi_0 \),
- volume flow \( Q_0 = v_0 A_0 \),
- flow of mass quantity \( M_0 = v_0 Q_0 \).

For linear sources of pollution (discharge of wastewater through the diffuser with small distance between orifices) the following parameters can be classified into the first group of parameters that characterize submarine outfall:

- wastewater density \( \rho_0 \).
vertical angle of discharge $\varphi$, 
diffuser length $L$, 
distance between diffuser orifices $l$, 
volume flow $q_o = \frac{Q_o}{L}$, 
flow of mass quantity $m_o = v_o q_o$
The following parameters are classified into second group of parameters that characterize the recipient:
density of the recipient water at the outfall $\rho_a$, 
average velocity of sea currents $v_a$, 
horizontal direction of sea currents (in regard to the diffuser axis) $\theta$, 
vertical stratification of the recipient characterized with $\varepsilon = \frac{- d \rho_a}{d z}$ or with Brunt-Vaisal-frequency $N = \sqrt{\frac{g}{\rho_a} \frac{d \rho_a}{d z}}$
Uplift flows $J_0$ and $\dot{J}_0$ are classified into the third group of parameters:
\[ J_0 = \varepsilon_0 Q_0 \quad \dot{J}_0 = \frac{\rho_a - \rho_e}{\rho_0} g \]
as well as several others undimensional parameters. For e.g. for linear sources of pollution they are:
\[ l_e = \frac{q_0^2}{m_0}, \quad l_b = \frac{J_0^{2/3}}{N}, \quad l_1 = \frac{m_0}{J_0^{2/3}}, \quad F = \frac{v_0^2}{J_0} \]
while for point sources of pollution, parameters are the following:
\[ l_e = \frac{J_0^{1/4}}{N^{3/4}}, \quad l_m = \frac{M_0^{1/4}}{J_0^{1/2}}, \quad l_s = \frac{J_0}{v_0^{1/2}}, \quad l_r = \frac{v_0}{N} \]
Basically, any characteristic of the initial dilution process can be expressed as function of previous parameters.
The following parameters of the initial dilution process are the most important for the engineering practice (Figure 1):
minimum level of initial dilution $S_m$ defined using the concentration of the observed parameter as:
\[ S_m = \frac{c_0 - c_e}{c_e - c_a} \]
maximum concentration level $c_m$, 
maximum upwelling of polluted plume $z_m$, 
thickness of polluted plume $h_m$, 
length of the area of initial dilution $x_m$, 
width of wastefield in the end of initial dilution $w_m$, 
depth of discharge $H$
Brooks model of the initial dilution: $S_m = 0.38 g_0^{1/3} q_0^{-2/3} H$ [1] is the most commonly used in present engineering practice. It is used only for linear source of pollution in calm, unstratified recipient. Since streams in the sea are permanent, and uniform vertical profile of density only an exceptional phenomenon, this model doesn’t give a real picture of initial dilution in stratified recipients and recipients with pronounced horizontal streams.

The recent research conducted by Roberts [1], [2], [3] and [4] will be used in this study. The result of these researches are several parametric models for linear sources of pollution in unstratified and linearly stratified media that can be used in practice.

For point sources of pollution results of researches conducted by Lee [5] will be used. He critically analyzed previous models and offered few of his models that can be used in practice.

**Linear sources of pollution**

For linear source of pollution and unstratified media with horizontal streams, and for values $F<0.1$ (stagnant recipient) the initial dilution is not significantly influenced by velocity field. Therefore the solution will be the same for any diffuser position (solution doesn’t depend on $\theta$):

$$S_m = 0.27 g_0^{1/3} q_0^{-2/3} H$$

Previous expression is similar to the one made by Brooks. The only difference is the value of constant that is smaller in this expression since it includes decrease in dilution due to generation of the surface layer of polluted plume. It is hard to expect the generation of such surface layer in the sea since streams are permanent phenomenon. That is the reason why it is more appropriate to use Brooks expression, that gives some greater initial dilution, where horizontal stream velocity is small ($F<0.28$).

For values $F>0.1$ (in this study for $F>0.28$) the initial dilution depends on angle $\theta$, and for streams that are perpendicular to diffusor ($\theta=90^\circ$) there is an asymptotic solution:

$$\frac{S_m q_0}{v_c H} = 0.58$$

In unstratified media, that was previously observed, polluted plume is always upwelling to the surface of the recipient.

If the media is linearly stratified, pollution plume is retained within the recipient and the initial dilution depends on density gradient, that is maximum level of equilibrium of jet. For the outfall with diffusor in linear stratified media with horizontal streams that are vertically uniform, assumption that the source of pollution is linear can be accepted if
In the case where $\frac{L}{b} < 0.2$ and $\frac{b}{b_h} < 0.31$. Under these conditions for values $F < 0.1$, the influence of streams on initial dilution isn't significant, and therefore:

$$\frac{S \cdot g \cdot N}{f_0^{2/3}} = 0.97$$

For values $F > 0.1$ solution depends on $F$ and $\theta$. For e.g. for $0.1 < F < 100$ and for velocity field that is perpendicular to diffuser ($\theta = 90^\circ$), solution is given in following expression:

$$\frac{S \cdot g \cdot N}{f_0^{2/3}} = 2.19 F^{1/6} - 0.52$$

For angles $\theta \neq 90^\circ$, for engineering purposes, in previous expressions projection of velocity vector to the axis of diffuser normal can be used.

Beside the level of initial dilution, in linear stratified media significant are also: the height of minimum level of dilution within the polluted plume $z_m$, that is maximum upwelling of polluted plume $z_e$ and its thickness $h_e$, as well as the length of the area of initial dilution $x_i$ and the width of the wastefield in the end of the process of initial dilution $w$. For $F = 0$ values of parameters $z_e$, $z_m$ and $h_e$ can be determined from following ratios:

$$\frac{z_e}{L} = 2.6 ; \quad \frac{h_e}{L} = 1.8 ; \quad \frac{z_m}{L} = 1.7$$

Between $F = 0$ and $F = 0.1$ values $z_e$, $z_m$ and $h_e$ are slowly increasing, to become approximately constant till $F = 1$. For angles $45^\circ \leq \theta < 90^\circ$ and Froude number values of $1 < F < 100$, maximum upwelling of polluted plume, maximal concentration height, length of the area of initial dilution $x_i$, and width of the wastefield during the initial dilution process $w$ can be determined from following ratios:

$$\frac{z_e}{L} = 2.5 F^{-1/6} ; \quad \frac{z_m}{L} = 1.5 F^{-1/6} ; \quad \frac{x_i}{L} = 8.5 F^{1/3} ; \quad \frac{w}{L} = 1 + 0.17 \left( \frac{x}{L} \right)^{11/2}$$

If value is $F >> 1$, bottom of polluted plume is situated approximately at the level of outfall orifice and it can be assumed that $h_e$ is approximately equal to $z_e$. If maximum upwelling of polluted plume is greater than depth $z > H$, it is more appropriate to use formula for unstratified media.

Previous results for linear stratified media are the result of research on hydraulic models using the assumption of linear source of pollution, and for values of parameters that are used for common submarine outfalls. Using this fact it can be concluded that results can be used for all kinds of diffusers where distance between orifices or discharge velocity are not too big.

Increasing the distance between outfall orifices ($\frac{U_b}{L} > 0.32$) and increasing the wastewater discharge velocity (increasing the initial flow of mass quantity or ratio $\frac{u}{b} > 0.2$), influence of the direction of discharge of wastewater jet is also increasing and therefore the assumption of linear source of pollution can not be used.

For calm recipient, boundary value for orifice distance where there is still some mixing between adjacent plumes can be determined from ratio $\frac{U_b}{L}$. For values $\frac{U_b}{L} > 1.92$ it is more appropriate to use results determined on model for diffuser with only one orifice. These results can not be used for recipient with horizontal streams since there is mixing between adjacent plumes even when the distance between the diffuser orifices is significant. 
**Point sources of pollution**

The following outfalls should be treated as point sources of pollution: submarine outfalls where diffuser is situated on relatively small depths and the distance between the orifices is big enough so there is no mixing between adjacent polluted plumes, as well as smaller outfalls where diffuser is not required since satisfying dilution is achieved by discharge from only one orifice.

If the recipient is unstratified, polluted plume is upwelling all the way to the recipient surface. For such recipient and the condition that polluted plume is under dominant influence of uplift \( l_u/l_u < 1 \), minimum level of dilution for horizontal direction of discharge of wastewater can be determined from following ratios:

\[
S_m = 0.31 \frac{J_{1/3} H^{2/3}}{Q_o} \quad ; \quad H < 5 \frac{J_0}{v_o} \\
S_m = 0.32 \frac{v_o H^2}{Q_o} \quad ; \quad H \geq 5 \frac{J_0}{v_o}
\]

For linear stratified recipient without streams and for horizontal discharge of polluted plume that is under dominant influence of uplift, that is if \( h_s/l_u < 0.6 \), minimum level of dilution \( S_m \), plume thickness \( h_s \) and maximum upwelling \( z_s \), can be determined following expressions:

\[
S_m = \frac{Q_o H^{1/4}}{J_{1/4}} = 0.80 \quad ; \quad \frac{z_s}{l_s} = 4.0 \quad ; \quad \frac{h_s}{l_s} = 1.6
\]

If horizontal streams exist in stratified recipient, for vertical upwelling of polluted plume from point source of pollution that is under dominant influence of uplift force, values of \( S_m \), \( h_s \) and \( z_s \) can be determined from ratios:

\[
S_m = \frac{Q_o}{v_o l_s} = 2.2 \left( \frac{l_s}{l_u} \right)^{1/3} \quad ; \quad \frac{z_s}{l_s} = 2.3 \left( \frac{l_s}{l_u} \right)^{2/3} \quad ; \quad \frac{h_s}{l_u} = 1.8 \left( \frac{l_s}{l_u} \right)^{2/3}
\]

**Methodology of calculation of secondary dilution**

Method that is most commonly used in engineering practice to calculate secondary dilution of wastewater is modeling of hydrodynamics of sea masses using hydrodynamic models. The flow field, generated in this way, is used as input data for model of dispersion and transformation of observed pollution indicator. Results of initial dilution model (concentration of observed indicator) are also used as input data for secondary dilution model.

Hydrodynamics of sea masses is in this study determined assuming the most negative forms of velocity field that are acceptable from the standpoint of bacteriological pollution. For modeling of dispersion and transformation of pollution two models were used: Brooks Model and CDR-2D Model that was produced at Civil Engineering Faculty in Split. Former was used for modeling of bacteriological pollution, BOD–5 and suspended solids, while the letter was used for modeling of bacteriological pollution only since it was proved to be effective.

**Brooks Model**

Brooks Model is based on the assumption of uniform and constant discharge of wastewater from linear source of pollution of length \( L \), installed perpendicular to the direction of sea currents \( v_o \) (Figure 2.3-1). Streams are timespace constant, and have the direction of \( x \).
axis. Vertical diffusion $D_z$ and diffusion in direction of sea streams $D_x$ are disregarded. Results of initial dilution model are used as input data for Brooks Model through maximum concentration of observed parameter within polluted plume $c$:

$$\frac{\partial}{\partial \tau} \left(D_x \frac{\partial c}{\partial \tau} \right) - v_x \frac{\partial c}{\partial \tau} - Kc = 0$$

where:
- $c$ - concentration of analyzed parameter,
- $K$ - coefficient of reaction,
- $v_x$ - velocity of recipient stream,

Horizontal diffusion $D_y$ depends on the width of wastefield $L$:

$$D_y = \alpha L^{1/3}$$

where values of coefficient $\alpha$ are between 0.0015 and 0.0449 cm$^{2/3}$/s. The value of 0.01 is most commonly used in practice.

According to Brooks, the value of maximum concentration of observed parameter at the $x$ distance from a diffuser is given by following expression:

$$c_{max} = c_0 e^{-\frac{x^2}{\beta}} \text{erf} \left( \frac{2x}{\beta} \right)$$

$$\beta = \frac{12D_y}{v_x L}$$

where:

$$\text{erf}(a) = \frac{2}{\sqrt{\pi}} \int_0^a e^{-t^2} dt$$

The width of wastefield $L_x$ at the distance $x$ can be determined from ratios:

$$\frac{L_x}{L} = \left(1 + \frac{2vx}{3L} \right)^{3/2}$$

**CDR-2D Model**

CDR 2D Model is used to calculate secondary dilution for unstratified recipient, when polluted plume is discharged all the way to the surface of a recipient. Minimum level of dilution under these conditions will be found at recipient surface. Polluted plume is then spreading through recipient under the influence of surface streams. Only the surface layer of the recipient will be modeled (assuming that vertical diffusion can be disregarded because calculation is on safe side), and therefore 2-D model will be used. Since the nature of phenomenon allows it (analyzed area is relatively small and pollution is traveling only few hours before it reaches the shore), this problem can be regarded as stationary.

The following equation forms mathematical base of the model:

$$v_x \frac{\partial c}{\partial x} + v_y \frac{\partial c}{\partial y} = \frac{\partial}{\partial x} \left(D_x \frac{\partial c}{\partial x} \right) + \frac{\partial}{\partial y} \left(D_y \frac{\partial c}{\partial y} \right) - Kc$$

where:
- $v_x$ and $v_y$ - components of velocity vector of velocity field in $x$ and $y$ direction,
- $c$ - concentration of observed indicator,
- $D_x$ and $D_y$ - turbulent diffusion in $x$ and $y$ direction,
$K$ - coefficient of reaction of indicator.

The solution of equation is usually searched for over observed area $\Omega$ for natural boundary conditions on an open boundary $\Gamma_1$ formed as:

$$
\left( D_x \frac{\partial c}{\partial x} + v_x \right) n_x + \left( D_y \frac{\partial c}{\partial y} + v_y \right) n_y = q(x,y) ; \ (x,y) \in \Gamma_1
$$

where $n_x$ and $n_y$ are components of normal vector, and constraint boundary conditions on boundary $\Gamma_2$ formed as:

$$
c(x,y) = g(x,y) ; \ (x,y) \in \Gamma_2
$$

The Finite Elements Method was used to solve this mathematical problem.

Weak formulation used in this model is determined assuming that there is no diffusion on open boundaries.

$$
\left( D_x \frac{\partial c}{\partial x} \right) n_x + \left( D_y \frac{\partial c}{\partial y} \right) n_y = 0 ; \ (x,y) \in \Gamma_1
$$

and it is formed as:

$$
\int_\Omega \left( v_x \frac{\partial c}{\partial x} + v_y \frac{\partial c}{\partial y} \right) w d\Omega + \int_\Gamma \left( D_x \frac{\partial c}{\partial x} \frac{\partial w}{\partial x} + D_y \frac{\partial c}{\partial y} \frac{\partial w}{\partial y} \right) d\Gamma + \int_\Omega K c w d\Omega = 0
$$

where $w$ are test functions.

Selected weak formulation allows certain flexibility in formulation of constraint boundary conditions. Formulation allows omitting of boundary conditions through open boundaries where exists the flow of parameter mass due to streams within recipient. It is assumed there is no diffusion of mass through these boundaries, which means that only convective component exists through these boundaries. Possible error due to this assumption is several times smaller that possible error due to arbitrary defined constraint boundary conditions. In order to secure uniformity of solution, it is enough to define constraint condition in only one of the nodes.

SDGM (space discontinuous Galerkin method) [6] is used to find the solution in form of linear combination of localized basic functions:

$$
c = c_r \phi_r ; \ r = 1,2,\ldots,n
$$

where $\phi_r$ is localized basic function for node $r$ of finite elements net, and $n$ is total number of nodes in the net. Test functions are given in following form:

$$
w_s = \phi_s + \delta v_s \frac{\partial \phi_s}{\partial x} + \delta v_s \frac{\partial \phi_s}{\partial y} ; \ s = 1,2,\ldots,n
$$

where:

$$
\delta = \left| \frac{v_x \Delta x + v_y \Delta y}{v_x^2 + v_y^2} \sqrt{1 - \frac{\Delta x \Delta y}{15} (1 - e^{-Pe})} \right|
$$

$$
Pe = \frac{v_x \Delta x + v_y \Delta y}{D_x + D_y} \ - \text{Peclet-number}
$$
In previous expressions $\Delta x$ and $\Delta y$ are characteristic lengths of elements in $x$ and $y$ directions. Test functions will retain the form of standard Galerkin method in regard to boundary conditions.

The following system of linear equations is formed:

$$M_s c_r = 0 ; \quad r,s=1,2,...,n$$

where matrix is:

$$M_s = \int_{\Omega} \left( D_x \frac{\partial^2 \phi_r}{\partial x^2} + D_y \frac{\partial^2 \phi_r}{\partial y^2} + \nu \frac{\partial^2 \phi_r}{\partial x^2} w_r + \nu \frac{\partial^2 \phi_r}{\partial y^2} w_r + K \phi_r w_r \right) d\Omega$$

Uniformity of solutions is secured with constraint boundary conditions. If functions are linear, the last member of matrix $M_s$ is canceled. Matrices and vectors of upper (global) system are built of finite elements matrices and vectors. Frontal procedure is used to arrange and solve global vectors and matrices.
Calculation of submarine outfall “Stobroč”

Input data and analyzed alternatives

Maximum discharge of wastewater at this submarine outfall is 880 l/s. Wastewater will be mechanically purified prior to discharge. It is assumed that the concentration of coliform bacteria in wastewater after mechanical purification will be $8 \times 10^6$ MPN/100ml. Wastewater density is around 1000 kg/m$^3$.

Selected alternative of submarine outfall is situated around 1600 m from the shore, diffuser length is 400 m, and depth of discharge is around 37 m.

From the results of oceanographic research of Brač and Split Channel sea water conducted in September of 1990. and April of 1991. for purposes of pollution modeling, the following facts can be observed:

- at the location in front of Stobroč there is distinct vertical stratification of sea density, it can be accepted that the average sea density is around 1028 kg/m$^3$, a thermocline is present at depth of around 10 m.
- time of bacterial decay $T_{20}$ in surface layers is between 3 and 5 hours, and it is gradually increasing with the depth,
- based on results of measuring of sea currents in Brač and Split Channel in front of Stobroč (measuring station is situated 2–3 km south from the outfall location), stream velocities in the surface layer were chosen that are, in regard to their frequency and duration, acceptable for calculation of propagation of bacterial pollution. Critical stream directions are toward the shore and therefore only these values will be given:
  - direction N $v_N=13.9$ cm/s,
  - direction NE $v_{NE}=11.8$ cm/s,
  - direction NW $v_{NW}=20.2$ cm/s,
  - direction E $v_E=11.6$ cm/s,

Minimum velocities are around 1.5 cm/s.

Initial dilution will be determined on parametric models and results will be used as input data for secondary dilution model.

According to already existing “Directive concerning classification of water and coastal sea water”, open sea of Brač and Split Channel is classified as III. category, while the coastal sea belt of 300 m width is classified as II. category. That means that submarine outfall must have such characteristics to secure that bacterial concentration in the outfall area is lower than maximum allowable for sea water of III category (20000 MPN/100 ml). Diffuser must be installed on such distance from the shore to secure that bacterial concentration within polluted plume that would reach the coastal area is less than maximum allowable for sea water of II. category (500 MPN/100 ml).

Two characteristic alternatives were analyzed:

- first alternative examined the winter period, analyses were conducted assuming there was no vertical stratification of density within the recipient,
- second alternative analyzed the summer period when vertical stratification is distinct assuming that recipient is unstratified under the thermocline (thermocline is present at depth of around 10 m).
For calculation of initial dilution bottom stream velocities were used, while for calculation of secondary dilution surface velocities were used. Values of bottom velocities were used as half of surface ones.

For first alternative calculation was conducted for all four previously mentioned critical directions of surface streams toward the shore:
- direction N, surface velocity 13.9 cm/s, bottom velocity 7 cm/s,
- direction NE, surface velocity 11.8 cm/s, bottom velocity 5.9 cm/s,
- direction NW, surface velocity 20.2 cm/s, bottom velocity 10.1 cm/s,
- direction E, surface velocity 11.6 cm/s, bottom velocity 5.8 cm/s.

For these four alternatives Brooks Model and CDR-2D Model were used to calculate secondary dilution.

Area covered with CDR-2D Model (figure with discretisation model is given in Appendices) was the surface layer of sea water around the outfall, and its part toward the shore that was appropriate for determination of the concentration of coliform bacteria at the entrance to coastal sea area. Thus, this model wasn’t analyzing only the coastal sea belt where sea water was classified as II category (200 m away from the shore), but the area out of that zone. Modeled area was discreted with the net consisted of 720 finite elements. Nine-nodal 2D elements were selected, therefore the net consisted of 2993 nodes. In order to decrease the oscillations of the solutions where differences in concentrations are the greatest, the finite element net was made more dense at the outfall location.

Since this model was not requiring it, boundary conditions were not defined on boundaries that were in contact with discarded part of the continuum, it was assumed that there was no diffusion of mass through these boundaries. Model required solution values to be defined in only one of the nodes of the net which was fulfilled in the model by assigning the results of initial dilution.

Results of initial dilution were assigned as known values at the diffuser location. These values were assigned to seven nodes situated on that location. In that way, the impact of wastefield width on secondary dilution, and impact of diffuser position in regard to wind direction were included in a model to a certain degree.

Coefficient of diffusion was selected according to Brooks Model. For diffuser of 400 m its value is: \( D_x = D_y = 1 \text{ m}^2/\text{s} \).

Assumed time for 90% of bacterial decay on the surface is \( T_{90}=3.5 \text{ hours} \).

During the summer polluted plume will be retained and spread under the thermocline layer, and there would be no possibility of its passing above that layer. Due to that reason calculation of initial dilution using parametric models for second alternative was conducted using the assumption that sea depth was reduced for thermocline height.

Second alternative analyzed three critical directions of streams toward the shore. Bottom velocities were used to determine initial and secondary dilution:
- direction N, bottom velocity 9 cm/s,
- direction NE, bottom velocity 8 cm/s,
- direction NW, bottom velocity 10 cm/s.

As additional alternative, that was acceptable for outfall location, calm recipient with minimum velocity in the area of plume upwelling of 1.5 cm/s was also analyzed. For this alternative only the Brooks Model was used to calculate secondary dilution.

Assumed time for 90% of bacterial decay under the thermocline is \( T_{90}=5 \text{ hours} \).
Results

The modeling results are presented on figures and tables that are given in Appendices. Results of CDR-2D Model are presented as isolines. Assigned line presents the bacterial concentration of 500 MPN/100ml, since it is maximum allowable concentration (according to existing legislature) in the coastal sea area (coastal sea belt of 200 m width). Selected step for drawing of isolines is 500 MPN/100ml. Some winding of isolines and appearance of isolines of 0 concentrations are the result of smaller numerical oscillations.

Results of initial dilution modeling show that bacterial concentration after the process of initial dilution has ended, for the most critical alternative of stagnant recipient, are around 20000 MPN/100ml, which is maximum allowable concentration for sea water of III category. For other alternatives these values are below legally required. Thus, diffuser fulfills legal bacterial criteria at the outfall location. The same can be concluded for suspended solids. Their concentration are significantly below legally required of 60 mg/l for sea water of III category.

Results of secondary dilution modeling using both models show that for neither alternative bacterial concentration in the coastal sea area hasn’t exceeded 500 MPN/100ml, which is maximum allowable concentration for the sea water of II category. Concentrations of suspended solids are significantly lower than required 20 mg/l for the sea water of II category. That implies that chosen distance of diffuser from the shore is acceptable in regard to the preservation of coastal sea area from pollution.
Calculation of submarine outfall “Čiovo”

Input data and analyzed alternatives

Maximum discharge of wastewater is 650 l/s. It is assumed that the concentration of coliform bacteria in wastewater will be $10^7$ MPN/100ml. Wastewater density is around 1000 kg/m$^3$.

Selected alternative of submarine outfall is situated around 2050 m from the shore (measured from the spot where submarine outfall enters the sea), diffuser length is 400 m, and depth of discharge is around 52 m.

From the results of oceanographic research of Brač and Split Channel conducted in September of 1990 and April of 1991, the following facts can be observed:
- at the outfall location there is a distinct vertical stratification of sea density, and it can be accepted that the average sea density is around $1028$ kg/m$^3$, a thermocline is present at depth of around 12 m,
- time of coliform bacterial decay $T_d$ in surface layers is between 3 and 5 hours, and it is gradually increasing with the depth,
- based on results of measuring of sea currents in Brač and Split Channel at the outfall location, stream velocities in the surface layer were chosen that are, in regard to their frequency and duration, acceptable for calculation of propagation of bacterial pollution. They are:
  - direction N $v = 15$ cm/s,
  - direction NE $v = 16$ cm/s,
  - direction NW $v = 16$ cm/s,

Minimum velocities are around 1.5 cm/s.

Initial dilution will be determined on parametric models and results will be used as input data for secondary dilution model.

Two characteristic alternatives were analyzed:
- first alternative examined the winter period, analyses were conducted assuming there was no vertical stratification of density within the recipient,
- second alternative analyzed the summer period when vertical stratification is distinct and thermocline is present at depth of around 12 m, assuming that recipient is vertically unstratified under the thermocline

For calculation of initial dilution bottom stream velocities were used, while for calculation of secondary dilution surface velocities were used. Values of bottom velocities were used as half of surface ones.

For first alternative calculation was conducted for three previously mentioned critical directions of surface streams toward the shore:
- direction N, surface velocity 15 cm/s, bottom velocity 7.5 cm/s,
- direction NE, surface velocity 16 cm/s, bottom velocity 8 cm/s,
- direction NW, surface velocity 15 cm/s, bottom velocity 8 cm/s.

For these alternatives Brooks Model and CDR-2D Model were used to calculate secondary dilution.

Area covered with CDR-2D Model (figure with discretisation model is given in Appendices) was the surface layer of sea water around the outfall, and its part toward the shore that was appropriate for determination of the concentration of coliform bacteria at the entrance to coastal sea area. Modeled area was discreted with the net consisted of 720 finite
elements. Nine-nodal 2-D elements were selected, therefore the net consisted of 2993 nodes. The finite elements net was made more dense at the outfall location.

Boundary conditions were defined similarly as for the previous outfall. Results of initial dilution were assigned as known values at the diffuser location. These values were assigned to seven nodes situated on that location.

Coefficient of diffusion was selected according to Brooks Model. For diffuser of 400 m its value is: \( D_x = D_y = 1 \text{m}^2/\text{s} \).

Assumed time for 90% of bacterial decay on the surface is \( T_{90} = 3.5 \) hours.

During the summer polluted plume will be retained and spread under the thermocline layer, and there is no possibility of its passing above that layer. Due to that reason calculation of initial dilution using parametric models for alternative with thermocline was conducted using the assumption that sea depth was reduced for thermocline height, and recipient was unstratified.

Three critical stream directions toward the shore were analyzed for second alternative. Bottom velocities were used to calculate initial and secondary dilution:
- direction N, bottom velocity 9.5 cm/s,
- direction NE, bottom velocity 10 cm/s,
- direction NW, bottom velocity 10 cm/s,

As additional alternative, a calm recipient with minimum velocity in the area of plume upwelling of 1.5 cm/s was also analyzed. Assumed time for 90% of bacterial decay under the thermocline is \( T_{90} = 6 \) hours.

Results

The modeling results are presented in Appendices. Results of CDR-2D Model are presented as isolines the same way as it was done for previous outfall.

Results of initial dilution modeling show that bacterial concentration after the process of initial dilution has ended, for neither alternative has not exceeded maximum allowable concentration for sea water of III category. The same is valid for suspended solids. Their concentration are significantly below legally required ones.

Results of secondary dilution modeling using both models show that for neither alternative bacterial concentration in the coastal sea area hasn’t exceeded maximum allowable concentration for the sea water of II category. The same can be concluded for suspended solids. That implies that chosen distance of diffuser from the shore is acceptable in regard to the preservation of coastal sea area from pollution.
Bibliography


RESULTS FOR THE NEARFIELD AND THE FARFIELD MIXING ZONE

STOBREC: Unstratified ambient, north-west current 20.2 cm/s

- effluent flowrate: 880 l/s
- effluent density: 1000 kg/m³
- diffuser length: 400 m
- angle between diffuser and current 90°
- depth: 37 m
- height to the top of the wastefield: 37.00 m
- current velocity at the bottom level: 0.1 m/s
- current velocity at the level of the top of the wastefield: 0.2 m/s
- ambient density:
  - bottom level: 1028 kg/m³
  - surface level: 1028 kg/m³
- effluent composition:
  - MPN: 8000000 (coli/100ml)
  - BOD-5: 235 (mg/l)
  - Suspended total: 280 (mg/l)

Results for the nearfield zone:

| Minimum dilution: 975 | MPN: 8201 (coli/100ml) | BOD-5: 0.241 (mg/l) | Suspended total: 0.287 (mg/l) |

Results for the farfield zone:

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<th>Distance (m)</th>
<th>Minimum dilution</th>
<th>MPN (coli/100ml)</th>
<th>BOD-5 (mg/l)</th>
<th>Susp. tot. (mg/l)</th>
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RESULTS FOR THE NEARFIELD AND THE FARFIELD MIXING ZONE

STOBREĆ: Unstratified ambient, north current 13.9 cm/s

- effluent flowrate: 880 l/s
- effluent density: 1000 kg/m³
- diffuser length: 400 m
- angle between diffuser and current: 45°
- depth: 37 m
- height to the top of the wastefield: 37.00 m
- current velocity at the bottom level: 0.07 m/s
- current velocity at the level of the top of the wastefield: 0.139 m/s
- ambient density:
  - bottom level: 1028 kg/m³
  - surface level: 1028 kg/m³
- effluent composition:
  MPN: 8000000 (coli/100ml)
  BOD-5: 235 (mg/l)
  Suspended total: 280 (mg/l)

Results for the nearfield zone:

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RESULTS FOR THE NEARFIELD AND THE FARFIELD MIXING ZONE

STOBREC: Unstratified ambient, east current 11.6 cm/s

- effluent flowrate: 880 l/s
- effluent density: 1000 kg/m³
- diffuser length: 400 m
- angle between diffuser and current 45°
- depth 37 m
- height to the top of the wastefield 37.00 m
- current velocity at the bottom level: 0.06 m/s
- current velocity at the level of the top of the wastefield: 0.116 m/s
- ambient density:
  - bottom level: 1028 kg/m³
  - surface level: 1028 kg/m³
- effluent composition:
  - MPN: 8000000 (coli/100ml)
  - BOD-5: 235 (mg/l)
  - Suspended total: 280 (mg/l)

Results for the nearfield zone:

<table>
<thead>
<tr>
<th>Minimum dilution</th>
<th>MPN (coli/100ml)</th>
<th>BOD-5 (mg/l)</th>
<th>Suspended total (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>540</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MPN:</td>
<td>14806</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BOD-5:</td>
<td>0.435</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Suspended total:</td>
<td>0.518</td>
<td></td>
<td></td>
</tr>
</tbody>
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Results for the farfield zone:

<table>
<thead>
<tr>
<th>Distance (m)</th>
<th>Minimum dilution</th>
<th>MPN (coli/100ml)</th>
<th>BOD-5 (mg/l)</th>
<th>Susp tot. (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>570</td>
<td>10251</td>
<td>0.403</td>
<td>0.491</td>
</tr>
<tr>
<td>400</td>
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<td>6223</td>
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<td>0.409</td>
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<td>600</td>
<td>832</td>
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<td>0.337</td>
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<td>2800</td>
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<td>0.089</td>
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<tr>
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<td>3389</td>
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<td>0.048</td>
<td>0.083</td>
</tr>
</tbody>
</table>
RESULTS FOR THE NEARFIELD AND THE FARFIELD MIXING ZONE

STOBREČ: Unstratified ambient, north-east current 11.8 cm/s

- effluent flowrate: 880 l/s
- effluent density: 1000 kg/m³
- diffuser length: 400 m
- angle between diffuser and current: 0°
- depth: 37 m
- height to the top of the wastefield: 37.00 m
- current velocity at the bottom level: 0.06 m/s
- current velocity at the level of the top of the wastefield: 0.118 m/s
- ambient density:
  - bottom level: 1028 kg/m³
  - surface level: 1028 kg/m³
- effluent composition:
  - MPN: 8000000 (coli/100ml)
  - BOD-5: 235 (mg/l)
  - Suspended total: 280 (mg/l)

Results for the nearfield zone:

| Minimum dilution: 540 | MPN: 14806 (coli/100ml) | BOD-5: 0.435 (mg/l) | Suspended total: 0.518 (mg/l) |

Results for the farfield zone:

<table>
<thead>
<tr>
<th>Distance (m)</th>
<th>Minimum dilution</th>
<th>MPN (coli/100ml)</th>
<th>BOD-5 (mg/l)</th>
<th>Susp. tot. (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
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</tr>
<tr>
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<td>5904</td>
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<td>0.038</td>
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<td>0.005</td>
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</table>
RESULTS FOR THE NEARFIELD AND THE FARFIELD MIXING ZONE

STOBREČ: Stratified ambient (thermocline 10 m), north-west current 10 cm/s

- effluent flowrate: 880 l/s
- effluent density: 1000 kg/m³
- diffuser length: 400 m
- angle between diffuser and current: 90°
- depth: 27 m
- height to the top of the wastefield: 27.00 m
- current velocity at the bottom level: 0.1 m/s
- current velocity at the level of the top of the wastefield: 0.1 m/s
- ambient density:
  - bottom level: 1028 kg/m³
  - surface level: 1028 kg/m³
- effluent composition:
  - MPN: 8000000 (coli/100ml)
  - BOD-5: 235 (mg/l)
  - Suspended total: 280 (mg/l)

Results for the nearfield zone:

<table>
<thead>
<tr>
<th>Minimum dilution</th>
<th>MPN</th>
<th>BOD-5</th>
<th>Susp. total</th>
</tr>
</thead>
<tbody>
<tr>
<td>712</td>
<td>11239 (coli/100ml)</td>
<td>235 (mg/l)</td>
<td>280 (mg/l)</td>
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</tbody>
</table>

Results for the farfield zone:

<table>
<thead>
<tr>
<th>Distance (m)</th>
<th>Minimum dilution</th>
<th>MPN (coli/100ml)</th>
<th>BOD-5 (mg/l)</th>
<th>Susp. total (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
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<td>0.308</td>
<td>0.377</td>
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<tr>
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<td>1600</td>
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<td>0.131</td>
</tr>
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<td>1800</td>
<td>2386</td>
<td>336</td>
<td>0.077</td>
<td>0.117</td>
</tr>
<tr>
<td>2000</td>
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<td>0.067</td>
<td>0.106</td>
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<td>3000</td>
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<td>0.038</td>
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</table>
RESULTS FOR THE NEARFIELD AND THE FARFIELD MIXING ZONE

STOBREČ: Stratified ambient (thermocline 10m), north current 9 cm/s

- effluent flowrate: 880 l/s
- effluent density: 1000 kg/m^3
- diffuser length: 400 m
- angle between diffuser and current: 45°
- depth: 27 m
- height to the top of the wastefield: 27.00 m
- current velocity at the bottom level: 0.09 m/s
- current velocity at the level of the top of the wastefield: 0.09 m/s
- ambient density:
  - bottom level: 1028 kg/m^3
  - surface level: 1028 kg/m^3
- effluent composition:
  - MPN: 8000000 (coli/100ml)
  - BOD-5: 235 (mg/l)
  - Suspended total: 280 (mg/l)

Results for the nearfield zone:

<table>
<thead>
<tr>
<th>Distance (m)</th>
<th>Minimum dilution</th>
<th>MPN (coli/100ml)</th>
<th>BOD-5 (mg/l)</th>
<th>Susp. tot. (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
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</tr>
<tr>
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</table>

Results for the farfield zone:
RESULTS FOR THE NEARFIELD AND THE FARFIELD MIXING ZONE

STOBREČ: Stratified ambient (thermocline 10m), north-east current 8 cm/s

- effluent flowrate: 880 l/s
- effluent density: 1000 kg/m³
- diffuser length: 400 m
- angle between diffuser and current: 0°
- depth: 27 m
- height to the top of the wastefield: 27.00 m
- current velocity at the bottom level: 0.08 m/s
- current velocity at the level of the top of the wastefield: 0.08 m/s
- ambient density:
  - bottom level: 1028 kg/m³
  - surface level: 1028 kg/m³
- effluent composition:
  - MPN: 800000 (coli/100ml)
  - BOD-5: 235 (mg/l)
  - Suspended total: 280 (mg/l)

Results for the nearfield zone:

<table>
<thead>
<tr>
<th>Distance (m)</th>
<th>Minimum dilution</th>
<th>MPN (coli/100ml)</th>
<th>BOD-5 (mg/l)</th>
<th>Susp. tot. (mg/l)</th>
</tr>
</thead>
<tbody>
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</table>
RESULTS FOR THE NEARFIELD AND THE FARFIELD MIXING ZONE

STOBREČ: Stratified stagnant ambient (thermocline 10 m)

- effluent flowrate: 880 l/s
- effluent density: 1000 kg/m³
- diffuser length: 400 m
- angle between diffuser and current 90°
- depth 27 m
- height to the top of the wastefield 27.00 m
- current velocity at the bottom level: 0.015 m/s
- current velocity at the level of the top of the wastefield: 0.015 m/s
- ambient density:
  - bottom level: 1028 kg/m³
  - surface level: 1028 kg/m³
- effluent composition:
  - MPN: 8000000 (coli/100ml)
  - BOD-5: 235 (mg/l)
  - Suspended total: 280 (mg/l)

Results for the nearfield zone:

<table>
<thead>
<tr>
<th>Distance (m)</th>
<th>Minimum dilution</th>
<th>MPN (coli/100ml)</th>
<th>BOD-5 (mg/l)</th>
<th>Susp. tot. (mg/l)</th>
</tr>
</thead>
<tbody>
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<td>0.001</td>
<td>0.010</td>
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</table>
RESULTS FOR THE NEARFIELD AND THE FARFIELD MIXING ZONE

ČIOVO: Unstratified ambient, north-west current 16 cm/s

- effluent flowrate: 650 l/s
- effluent density: 1000 kg/m³
- diffuser length: 400 m
- angle between diffuser and current: 30°
- depth: 52 m
- height to the top of the wastefield: 52.00 m
- current velocity at the bottom level: 0.08 m/s
- current velocity at the level of the top of the wastefield: 0.16 m/s
- ambient density:
  - bottom level: 1028 kg/m³
  - surface level: 1028 kg/m³
- effluent composition:
  - MPN: 10000000 (coli/100ml)
  - BOD-5: 235 (mg/l)
  - Suspended total: 280 (mg/l)

Results for the nearfield zone:

<table>
<thead>
<tr>
<th>Distance (m)</th>
<th>Minimum dilution</th>
<th>MPN (coli/100ml)</th>
<th>BOD-5 (mg/l)</th>
<th>Susp. tot. (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
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<td>2200</td>
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<td>0.051</td>
<td>0.074</td>
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<tr>
<td>3000</td>
<td>5261</td>
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<td>0.034</td>
<td>0.053</td>
</tr>
</tbody>
</table>
RESULTS FOR THE NEARFIELD AND THE FARFIELD MIXING ZONE

ČIOVO: Unstratified ambient, north-east current 16 cm/s.

- effluent flowrate: 650 l/s
- effluent density: 1000 kg/m$^3$
- diffuser length: 400 m
- angle between diffuser and current: 60°
- depth: 52 m
- height to the top of the wastefield: 52.00 m
- current velocity at the bottom level: 0.08 m/s
- current velocity at the level of the top of the wastefield: 0.16 m/s
- ambient density:
  - bottom level: 1028 kg/m$^3$
  - surface level: 1028 kg/m$^3$
- effluent composition:
  
<table>
<thead>
<tr>
<th>MPN</th>
<th>BOD-5</th>
<th>Suspended total</th>
</tr>
</thead>
<tbody>
<tr>
<td>10000000 (coli/100ml)</td>
<td>235 (mg/l)</td>
<td>280 (mg/l)</td>
</tr>
</tbody>
</table>

Results for the nearfield zone:

<table>
<thead>
<tr>
<th>Minimum dilution</th>
<th>MPN</th>
<th>BOD-5</th>
<th>Suspended total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1286</td>
<td>7777 (coli/100ml)</td>
<td>0.183 (mg/l)</td>
<td>0.218 (mg/l)</td>
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</table>

Results for the farfield zone:

<table>
<thead>
<tr>
<th>Distance (m)</th>
<th>Minimum dilution</th>
<th>MPN (coli/100ml)</th>
<th>BOD-5 (mg/l)</th>
<th>Susp. tot. (mg/l)</th>
</tr>
</thead>
<tbody>
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<td>200</td>
<td>1300</td>
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<td>0.178</td>
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<td>400</td>
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<td>4473</td>
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<tr>
<td>600</td>
<td>1598</td>
<td>3155</td>
<td>0.140</td>
<td>0.175</td>
</tr>
<tr>
<td>800</td>
<td>1811</td>
<td>2217</td>
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<td>0.155</td>
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<td>1000</td>
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<td>1565</td>
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<td>0.137</td>
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<tr>
<td>1200</td>
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<td>0.122</td>
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<td>0.110</td>
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<td>1600</td>
<td>2812</td>
<td>573</td>
<td>0.073</td>
<td>0.100</td>
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<td>1800</td>
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<td>0.065</td>
<td>0.091</td>
</tr>
<tr>
<td>2000</td>
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<td>303</td>
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<td>0.083</td>
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<td>2200</td>
<td>3670</td>
<td>221</td>
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<td>0.076</td>
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<tr>
<td>2400</td>
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<td>0.070</td>
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<td>2800</td>
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<td>4930</td>
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<td>0.037</td>
<td>0.057</td>
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</table>
RESULTS FOR THE NEARFIELD AND THE FARFIELD MIXING ZONE

ČIOVO: Unstratified ambient, north current 15 cm/s

- effluent flowrate: 650 l/s
- effluent density: 1000 kg/m³
- diffuser length: 400 m
- angle between diffuser and current 15 °
- depth 52 m
- height to the top of the wastefield 52.00 m
- current velocity at the bottom level: 0.075 m/s
- current velocity at the level of the top of the wastefield: 0.15 m/s
- ambient density:
  - bottom level: 1028 kg/m³
  - surface level: 1028 kg/m³
- effluent composition:
  MPN: 10000000 (coli/100ml)
  BOD-5: 235 (mg/l)
  Suspended total: 280 (mg/l)

Results for the nearfield zone:

<table>
<thead>
<tr>
<th>Distance (m)</th>
<th>Minimum dilution</th>
<th>MPN (coli/100ml)</th>
<th>BOD-5 (mg/l)</th>
<th>Susp. tot. (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>1071</td>
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<td>0.119</td>
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<td>0.070</td>
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<td>1600</td>
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</table>
RESULTS FOR THE NEARFIELD AND THE FARFIELD MIXING ZONE

ČIOVO: Stratified ambient (thermocline 12 m), north-west current 10 cm/s

- effluent flowrate: 650 l/s
- effluent density: 1000 kg/m³
- diffuser length: 400 m
- angle between diffuser and current: 30°
- depth: 40 m
- height to the top of the wastefield: 40.00 m
- current velocity at the bottom level: 0.1 m/s
- current velocity at the level of the top of the wastefield: 0.1 m/s
- ambient density:
  - bottom level: 1028 kg/m³
  - surface level: 1028 kg/m³
- effluent composition:

<table>
<thead>
<tr>
<th>MPN</th>
<th>BOD-5</th>
<th>Suspended total</th>
</tr>
</thead>
<tbody>
<tr>
<td>10000000 (coli/100ml)</td>
<td>235 (mg/l)</td>
<td>280 (mg/l)</td>
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</tbody>
</table>

Results for the nearfield zone:

<table>
<thead>
<tr>
<th>Minimum dilution</th>
<th>MPN (coli/100ml)</th>
<th>BOD-5 (mg/l)</th>
<th>Suspended total (mg/l)</th>
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</thead>
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Results for the farfield zone:

<table>
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<th>Distance (m)</th>
<th>Minimum dilution</th>
<th>MPN (coli/100ml)</th>
<th>BOD-5 (mg/l)</th>
<th>Susp. tot. (mg/l)</th>
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<td>800</td>
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RESULTS FOR THE NEARFIELD AND THE FARFIELD MIXING ZONE

ČIOVO: Stratified ambient (thermocline 12 m), north-east current 10 cm/s

- effluent flowrate: 650 l/s
- effluent density: 1000 kg/m³
- diffuser length: 400 m
- angle between diffuser and current: 60°
- depth: 40 m
- height to the top of the wastefield: 40.00 m
- current velocity at the bottom level: 0.1 m/s
- current velocity at the level of the top of the wastefield: 0.1 m/s
- ambient density:
  - bottom level: 1028 kg/m³
  - surface level: 1028 kg/m³
- effluent composition:
  - MPN: 1000000 (coli/100ml)
  - BOD-5: 235 (mg/l)
  - Suspended total: 280 (mg/l)

Results for the nearfield zone:

<table>
<thead>
<tr>
<th>Minimum dilution</th>
<th>MPN (coli/100ml)</th>
<th>BOD-5 (mg/l)</th>
<th>Suspended total (mg/l)</th>
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Results for the farfield zone:

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<th>Distance (m)</th>
<th>Minimum dilution</th>
<th>MPN (coli/100ml)</th>
<th>BOD-5 (mg/l)</th>
<th>Susp. tot. (mg/l)</th>
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</thead>
<tbody>
<tr>
<td>200</td>
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<td>0.178</td>
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</table>
RESULTS FOR THE NEARFIELD AND THE FARFIELD MIXING ZONE

ČIOVO: Stratified ambient (thermocline 12 m), north current 9.5 cm/s

- effluent flowrate: 650 l/s
- effluent density: 1000 kg/m³
- diffuser length: 400 m
- angle between diffuser and current: 15°
- depth: 40 m
- height to the top of the wastefield: 40.00 m
- current velocity at the bottom level: 0.095 m/s
- current velocity at the level of the top of the wastefield: 0.095 m/s
- ambient density:
  - bottom level: 1028 kg/m³
  - surface level: 1028 kg/m³
- effluent composition:
  - MPN: 10000000 (coli/100ml)
  - BOD-5: 235 (mg/l)
  - Suspended total: 280 (mg/l)

Results for the nearfield zone:

<table>
<thead>
<tr>
<th>Distance (m)</th>
<th>Minimum dilution</th>
<th>MPN (coli/100ml)</th>
<th>BOD-5 (mg/l)</th>
<th>Susp. tot. (mg/l)</th>
</tr>
</thead>
<tbody>
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<td>0.134</td>
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<td>0.102</td>
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<td>1000</td>
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<tr>
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<td>0.011</td>
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RESULTS FOR THE NEARFIELD AND THE FARFIELD MIXING ZONE

ČIOVO: Stratified stagnant ambient, (thermocliña 12 m)

- effluent flowrate: 650 l/s
- effluent density: 1000 kg/m³
- diffuser length: 400 m
- angle between diffuser and current 90°
- depth 40 m
- height to the top of the wastefield 40.00 m
- current velocity at the bottom level: 0.015 m/s
- current velocity at the level of the top of the wastefield: 0.015 m/s
- ambient density:
  - bottom level: 1028 kg/m³
  - surface level: 1028 kg/m³
- effluent composition:
  MPN: 10000000 (coli/100ml)
  BOD-5: 235 (mg/l)
  Suspended total: 280 (mg/l)

Results for the nearfield zone:

<table>
<thead>
<tr>
<th>Minimum dilution</th>
<th>MPN:</th>
<th>BOD-5:</th>
<th>Susp. tot.</th>
</tr>
</thead>
<tbody>
<tr>
<td>715</td>
<td>13989 (coli/100ml)</td>
<td>0.329 (mg/l)</td>
<td>0.392 (mg/l)</td>
</tr>
</tbody>
</table>

Results for the farfield zone:

<table>
<thead>
<tr>
<th>Distance (m)</th>
<th>Minimum dilution</th>
<th>MPN (coli/100ml)</th>
<th>BOD-5 (mg/l)</th>
<th>Susp. tot. (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>1827</td>
<td>480</td>
<td>0.107</td>
<td>0.153</td>
</tr>
<tr>
<td>400</td>
<td>3585</td>
<td>21</td>
<td>0.045</td>
<td>0.078</td>
</tr>
<tr>
<td>600</td>
<td>5700</td>
<td>1</td>
<td>0.024</td>
<td>0.049</td>
</tr>
<tr>
<td>800</td>
<td>8120</td>
<td>0</td>
<td>0.014</td>
<td>0.034</td>
</tr>
<tr>
<td>1000</td>
<td>10810</td>
<td>0</td>
<td>0.009</td>
<td>0.026</td>
</tr>
<tr>
<td>1200</td>
<td>13744</td>
<td>0</td>
<td>0.006</td>
<td>0.020</td>
</tr>
<tr>
<td>1400</td>
<td>16904</td>
<td>0</td>
<td>0.004</td>
<td>0.017</td>
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<td>1600</td>
<td>20275</td>
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<td>0.003</td>
<td>0.014</td>
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<td>1800</td>
<td>23845</td>
<td>0</td>
<td>0.002</td>
<td>0.012</td>
</tr>
<tr>
<td>2000</td>
<td>27602</td>
<td>0</td>
<td>0.001</td>
<td>0.010</td>
</tr>
<tr>
<td>2200</td>
<td>31538</td>
<td>0</td>
<td>0.001</td>
<td>0.009</td>
</tr>
<tr>
<td>2400</td>
<td>35646</td>
<td>0</td>
<td>0.001</td>
<td>0.008</td>
</tr>
<tr>
<td>2600</td>
<td>39917</td>
<td>0</td>
<td>0.001</td>
<td>0.007</td>
</tr>
<tr>
<td>2800</td>
<td>44347</td>
<td>0</td>
<td>0.000</td>
<td>0.006</td>
</tr>
<tr>
<td>3000</td>
<td>48930</td>
<td>0</td>
<td>0.000</td>
<td>0.006</td>
</tr>
</tbody>
</table>
1.1 Sea currents and sea exchange

The Brac and Split channels form a semi-closed basin where the water is exchanged from three sides: from the direction of the Brac channel, i.e. from the East, and through the Solta and Drvenik channel in the West. The exchange of the sea through the Split strait and the Kastela Bay is negligible compared with the previously mentioned ones. The average period of the sea exchange in these channels has been estimated to 2.25 months. The most significant currents are from the East westward which is also the direction of the main sea exchange. These currents are the strongest along the central axis and particularly in the surface layer. The measured maximum velocities range about 50 cm/s with a westward frequency of 49%. The most frequent velocities are from 6-20 cm/s, with a decrease from the surface towards the bottom.

Under the influence of long-lasting winds the currents field changes, both in the surface and bottom layer, where compensation currents are formed. Hence, eastern currents are significant in the summer months, with a smaller intensity than the western ones, as well as southern currents. In the central area, where the channel is the widest, and in front of Stobrec, cyclonic vortices are formed, caused by the bottom configuration. Thus, it can be concluded that both global currents and the sea exchange are oriented westwards.

1.2 Hydrological system and waste water

The transportation of pollution is mainly effected through the hydrological system and partly through the air. This system consists of three main segments (Fig. 1):

- natural fresh water subsystem
- natural sea water subsystem
- communal subsystem.

The area of the Brac-Split Channel is relatively abundant in fresh water; the average precipitation is ca 0.8 m. Significant quantities of rainfall and its frequency (more than 100 days a year), result in great quantities of fresh water which flows into the sea (2510.78 million m³/year as average).

The fresh water flows from the three main catchment areas:

- directly, by precipitation, upon the sea surface (189 million m³/year as average),
- indirectly from the coastal catchment area (local watershed) (215 million m³/year as average),
- by tributaries whose catchment area is beyond border of the coastal watershed line (2106 million m³/year as average).

The most significant inflows are from the Cetina river (average flow 25.22 m³/s), Jadro river (9.2 m³/s) and Zrmanjica river (2.1 m³/s) whose catchments are farther away in the hinterland. Smaller inflows are from the local coastal area, mainly during the rainy period of the year, whereas in summer these inflows are almost negligible.

The main characteristic of all these fresh water inflows is a great fluctuation in the course of the year, with the exception of the Cetina River whose inflow is partly regulated by a system of reservoirs and is, thus, uniform during the entire year.

The fresh water from the local gravitating regions is relatively clean, so that it does not significantly influence the sea water quality. The water from the Cetina and Jadro River is clean and mainly belongs to the first category. The influence of the rivers and stream flows is evident in decreased salinity and temperature, and to a smaller extent, in increased concentration of oxygen and nutrient salts. This, however, does not apply to the streamflows which drain parts of the urban and agricultural areas. The water from these regions is polluted and significantly influences the coastal sea water quality in the areas around its discharge point, and to a smaller extent, in wider areas as well.

From the pollution standpoint the most significant is the communal hydrologic system which includes the sewerage system of both waste water and storm run-off. These waters exert the greatest permanent influence upon the sea quality so that they are most important from the sea protection standpoint.

The sea hydrologic system unifies the influences of a wider boundary region, the natural fresh water hydrological system and the communal hydrological system of the considered area. The influence of the boundary regions is exerted through the sea water exchange with the Brac Channel, the Solta Channel, the Drvenik Channel, through the Split strait and through the exchange with the Kastela and Trogir Bays.

Consequently, it can be concluded that the hydrologic system of the Brac-Split Channel is complex and varying; and hence it is difficult to analyze all types of influences upon the sea quality. In the analyze the sea boundary areas represent diffuse elements of that influence, whereas the rivers and similar the elements in the fresh water hydrologic subsystem are treated as point sources of pollution. The communal hydrologic system as a whole represents a point source of the influence upon the Channel sea quality.

All these elements in hydrologic systems and all their characteristics are taken into account when analyzing the sea water quality. It means it is necessary to consider both their quantity and quality, the average values and a specific time period.

1.3 The concept of the solution for the sewerage system

The entire area for the waste water disposal covering towns: Split, Solin, Kastela and Trogir includes two independent sewer systems: Split-Solin and Kastela-Trogir. The solution concept is such that all waste water in each system should be delivered to one central treatment plant and one submarine outfall. Consequently, in the future this area will have only two treatment plants and two outfalls.
The planned sewer system is of separate type. The industrial waste water is delivered to the urban sewer system, under the condition that its quality is the same or better than the quality of typical domestic waste water (except considering BOD), which has been prescribed by the respective municipal regulations.

The storm run-off is collected by a separate sewer system and is discharged into the coastal sea by satisfying the sea standards at each outfall.

The waste water disposal system includes the treatment plant and the respective submarine outfall. The plants and outfalls form a unique technological unit which will be constructed in phases in accordance with needs. Four main phases have been planned:

1. Mechanical treatment with sub-phases:
   - partial mechanical
   - complete mechanical treatment
2. A phase of AB physic-biological process
3. B phase of AB process
4. Denitrification, dephosphatization and disinfection.

Each phase includes the construction of a respective submarine outfall which, together with the treatment level, should satisfy the required sea standards.

The present state of the system is such that the planned concept could not be completely realized in less than 10 years, even if all the necessary funding was available at once. In addition, it should be born in mind that the inhabitants of this area, i.e. their standard, will not for a long time be able to finance the functioning of the sewer system and payment of the loans, according to the planned final solution which will ensure a high standard of sea protection. This primarily refers to the cost of the plant construction and operation. Consequently, system construction in phases has been planned, considering both the network and the treatment plant. The objective of this construction in phases is that each new investment, i.e. structure, immediately has positive effects upon the coastal sea quality, which is the particularly attractive for the local population. This objective will be achieved by the construction of long submarine outfalls which dislocate the disposal of waste water from the coastal sea into the farther off regions.

A question to be asked is: what will happen with those other parts of the sea? Since the greatest part of the Brac-Split Channel is safe and clean, the following question arises: will this conceptual solution ensure that the sea quality remains the same i.e., to what extent will the sea quality be changed? It means that not only short-term but also long-term effects of waste water discharge upon the sea quality should be considered.

The analysis of long-term effects includes the processes identified by the oxygen and BOD concentration. The oxygen concentration as a parameter is used to describe the state of the sea with regard to the released organic matter, which is dominant in domestic waste water, and with regard to nutrients and possible environmental long-term hazardous effects.
Short-term effects are related to bacteriological and physical pollution (oil and suspension materials). The analysis of short-term effects makes it possible to determine the necessary length and location of submarine outfalls and the characteristics of the mechanical plant which is usually constructed also as a protective measure for the functioning of the submarine outfall itself.

The objective of the presented analysis is to determine the allowable pollution quantities which can be released into the Brac-Split Channel according to the planed solution concept for the sewer system in this region.

This paper presents the analysis of long-term effects by applying a simulation model for calculation of oxygen concentration in the sea water.

2. MAIN CHARACTERISTICS OF THE MODEL

The analysis was performed using the HARO-3 model developed at the United States Environmental Protection Agency [2]. It is a three-dimensional stationary model which implies that the pollution is completely mixed both horizontally and vertically in each element of the system. Theoretically, the model is based upon the mass conservation law with the possibility of modeling two reaction variables in the feed forward form for the first order kinetics. The program has been primarily developed in order to model the system BOD-dissolved oxygen (Fig.2), so that the model can be used also for determining the concentrations of other parameters for analogous processes such as: chloride, polyphosphates, orthophosphates, coliform bacteria, i.e. all conventional pollution parameters, and the parameters which decompose according to the first order kinetics. This is a regional model is used for defining global states in a wider area so that the elements are relatively large.

![Diagram](image)

**Figure 2. Schematic representation of the computation for oxygen concentration by the HARO-3 model**

The mathematical basis of the model is the equation of convective diffusion including the elements which describe the reaction, sinks and sources of the analyzed pollution parameters:

\[
\begin{align*}
\frac{dc}{dx} + \frac{dc}{dy} + \frac{dc}{dz} &= E_x \frac{\partial^2 c}{\partial x^2} + E_y \frac{\partial^2 c}{\partial y^2} + E_z \frac{\partial^2 c}{\partial z^2} + k_x \pm S_x
\end{align*}
\]

where:
- \( x, y, z \) - coordinate directions
- \( v_x, v_y, v_z \) - flow velocities in directions \( x, y, z \)
- \( E_x, E_y, E_z \) - dispersion in directions \( x, y, z \)
- \( c \) - concentration of the treated parameter
- \( S_x \) - sources and sinks of the parameter
- \( k \) - coefficient of the first order reaction

The element in the equation which describes the reaction depends upon the simulated parameter, so that the expression \((kc)\) for oxygen budget is as follows:

\[
k_c(c_2 - c) - k_cL_c = \frac{k_cL_c}{H} + k
\]

for the carbon phase of BOD (CBOD=\(L_c\)):

\[
-k_cL_c
\]

for the nitrogen phase of BOD (NBOD=\(L_n\)):

\[
-k_nL_n
\]

where:
- \( k_c \) - reaction coefficient for CBOD (1/day)
- \( k_n \) - reaction coefficient for NBOD (1/day)
- \( k_r \) - reaction coefficient (1/day)
- \( k_o \) - benthos demand (gO2/m2/day)
- \( k_2 \) - oxygen production (gO2/m2/day)
- \( c_o \) - oxygen saturation value (g/m3)

The reaction coefficients are corrected according to the actual temperature applying the relation:

\[
k_c = k_c\Theta^e^{t-20}
\]

where:
- \( k_c \) - temperature coefficient
- \( k_{20} \) - temperature coefficient at 20°C
- \( \Theta \) - coefficient dependent upon the simulated reaction
Developing the equation for each discretization element of the system by the finite differences method it is possible to obtain "n" linear equations of the system with "n" unknowns:

\[ [C] = [A]^{-1} [W] \]  

(6)

with the matrices:

- \([C]\) - matrix for the computed values of the pollution parameter
- \([W]\) - matrix of external effects/loads (boundary conditions)
- \([A]\) - matrix of the elements of effects (coefficients).

3. MODEL OF THE BRAC-SPLIT CHANNEL

The model of the Brac-Split Channel covers the area of the western part of the Brac Channel and the entire Split Channel westward up to the Drvenik and Solta Channel. The model does not include the Kastela and Trogir Bays, but it includes the sea exchange occurring through the straits of these bays. The model includes the sea exchange occurring through the Brac, Solta and Drvenik Channel, whereas the exchange through the Split strait is not taken into account, since it is not significant. The channel area has been divided into 139 elements with three depth layers or fewer, according to bottom configuration (Fig.3).

The system of currents is determined for each element by using a hydraulic model or by adjusting it to the actual values of the sea exchange and the distribution of velocities according to measurements as it was done in this case. Since this is a stationary regional model it uses the average expected values. The adjustment procedure starts from the quantity of the sea exchange in the channels, the measured values and the determined global currents. Such approach proved very useful since it made it possible to introduce into the model all the specific features of the currents in this area including the vortices and the compensation currents. The average channel discharge of 3500 m³/s was obtained. The dispersion coefficient which gives the best results in the greatest part of the model, compared with the one measured at the gauging stations, is 20 m²/s. The only exception are the parts of the sea around the Solta and Drvenik Channels which are directly influenced by the open sea, so that the coefficient should be gradually increased to the value of 100 m²/s towards these regions. The vertical dispersion is significantly smaller and it was taken with a value of 1 m²/s between the first and second layer, and with the value of 3 m²/s between the second and third layer.

The model employs a parameters and coefficients:

- Re-aeration coefficient \((k_a)\)

The re-aeration coefficient which includes the oxygen exchange between the surface sea layer and the atmosphere; \(k_a(c_r-c)\) includes the saturation value of dissolved oxygen \((c_r)\) and the current value \((c)\). The saturation value was computed according to equation:

\[ c_r = 10.8127 - 0.7496 t + 0.03718 r - 0.00008 t^3 \]  

(7)

where \(t\) is temperature, which is obtained according to the measurement results at the stations, by processing data using the least squares method. The reaeration coefficient \((k_a)\) was chosen according to the average wind velocity and is 0.2 (l/day) for the entire surface layer.

- Benthos demand \((k_b)\)

Since only general recommendations for these values were given by oceanographers, the coefficient values were determined by the model calibration ranging between 0.25 and 1.0 (gO₂/m²/day).

- Reaction coefficients \((k_r)\)

The adopted coefficient values for the first phase of organic matter decomposition CBOD (\(k_r\)) and for the second phase of NBOD decomposition (\(k_r\)), are as follows:

\[ k_r = 0.1 \text{ (l/day)} \]
\[ k_r = 0.005 \text{ (l/day)} \]

- Oxygen production \((k_p)\)

The oxygen production was computed according to the chlorophyll production and amounts to between 0.01 and 0.02 (gO₂/m²/day) for the surface layer. No production was assumed to occur in the deep layers.

The pollution quantities were taken according to waste water disposal alternatives which were analyzed and according to the expected future situations in the area.

Table I presents the main input data for the urban waste water and pollution quantities.

<table>
<thead>
<tr>
<th>Sewage system</th>
<th>Quantity (l/s)</th>
<th>Waste water quality</th>
<th>Daily quantities</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>BOD-5 (mg/l)</td>
<td>N-total (mg/l)</td>
</tr>
<tr>
<td>Split-Trogir</td>
<td>2000</td>
<td>250</td>
<td>40</td>
</tr>
<tr>
<td>Trogir-Kastela</td>
<td>650</td>
<td>270</td>
<td>40</td>
</tr>
<tr>
<td>Solta</td>
<td>120</td>
<td>270</td>
<td>40</td>
</tr>
<tr>
<td>Brac</td>
<td>230</td>
<td>270</td>
<td>40</td>
</tr>
</tbody>
</table>

Table I. Quantities of waste water and organic pollution

The industrial waste water quantities were not specifically taken into account since they were considered in the sewer systems solutions, i.e. all industrial waste water is delivered to the urban communal sewer system.

The pollution delivered into the sea with the urban storm run-off was computed and the following average loads were obtained:

- BOD-5 1968 kg/day
- N total 118 kg/day

The pollution entering the sea by diffuse flows from the remaining parts of the respective catchment area was introduced into the computation through the boundary conditions, i.e. the sea quality in the boundary areas.

Pollutant loads, such as those flowing by the ground water or settling from the atmosphere, which cannot be easily predicted, were introduced into the model through the existing state of the sea quality in the area under consideration.

In order to make it possible to apply the model it was necessary to perform the model calibration and verification. The quantity and quality of the available data were not quite satisfactory, but could be considered sufficient for a global evaluation of future states. By adapting the dispersion and reaction coefficients within the normal values it was possible to achieve good agreement with the measured values.

Apart from dispersion, the greatest influence upon the results was exerted by the process of benthos oxygen demand followed by the oxygen production by photosynthesis; thus, special attention was paid to the analysis and selection of these parameters.

4. RESULTS AND DISCUSSION

According to the results obtained by calibration, present state and planned solutions for the waste water disposal into the Brač-Split Channel, it was possible to perform the simulation of the sea water quality for several alternatives related to the waste water treatment level.

Fig.3 present the results obtained according to the alternative in which the waste water will be treated only mechanically.

The presented show that the sea quality regarding the percentage of oxygen saturation corresponds to the 1. category of sea water (O₂ % of saturation > 70%).

The greatest decrease in oxygen concentration occurs in the bottom sea layers and in the areas around the outfall (4%), as well as on the elements (sea areas) influenced by the Cetina and Zrnovnica Rivers. The greatest increase in the nutrient salts concentration, however, occurs downstream from the Stobrec outfall, in front of the Split city port, where the currents stagnation is the greatest. Considering the vertical distribution of nitrogen and BOD compounds, the model reflects quite well the influence of the thermocline. The concentration increases in the bottom layers of the sea near the discharge points, whereas it becomes vertically uniform towards more distant...
elements. In the surface layers the oxygen concentration exceeds 100% saturation which results from the biological processes on the surface, whereas in the bottom sea layers the concentration decreases as the consequence of the benthos oxygen demand. Such oxygen distribution is common and the obtained values do not significantly differ from the current state.

The obtained results show that the greatest positive changes with regard to the present state will occur in the coastal parts of the sea, whose quality will be significantly improved and retained within the limits of the required standards. The greatest negative changes (adverse effects) occur in the channel areas, around the outfalls themselves and in the central part of the Brac channel in front of the Split city port; however the degree of changes is not significant and these effects do not threaten the required sea standard.

According to the obtained results it can be concluded that the planned concept of waste water disposal, even with mechanical treatment only, will not cause long-term adverse effects upon the sea quality in the Brac-Split Channel regarding oxygen and BOD concentration. At the same time it will ensure the realization of the planned objective, i.e. the protection of the coastal sea and the achievement of the required sea quality in accordance with its function. Consequently, it can be concluded the sea in the Brac-Split Channel has a satisfactory recipient capacity for the expected quantities of organic pollution load.

In order to confirm this statement and to determine the sensitivity of the aquatorium to organic pollution an analysis of the sea quality (oxygen concentration) was performed using a simulation model for the following pollution loads at the main Stobrec outfall:

1. Pollution corresponding to 90% treatment level with regard to BOD-5 (equivalent to flow of 0.2 m$^3$/s of row water).
2. Pollution corresponding to 50% treatment level regarding BOD-5 (equivalent to flow of 1.0 m$^3$/s of row water).
3. Pollution twice larger than the load obtained by mechanical waste water treatment (equivalent to flow of 2.0 m$^3$/s of row water).
4. Pollution load three times greater than the load obtained by mechanical waste water treatment (equivalent to flow of 6.0 m$^3$/s of row water).

The results point to the changes which are relatively significant but still do not threaten the required standard of the sea, (Fig.4).

A similar analysis was performed for the changed state under boundary conditions (exchange rate of the sea water in the channel), and particularly for the southern entrance into the Brac Channel (Fig.5).

All the obtained results prove the relatively high recipient capacity related to organic load of the Brac-Split Channel and show there is no danger of significant long-term changes if the waste water is treated only mechanically and discharged into the sea by long submarine outfalls.
average channel discharge of 3500 m³/s

Figure 5. Oxygen deficit in the critical elements dependent upon exchange period of the sea water in the channel

5. CONCLUSIONS

According to the mentioned facts and the experience obtained in the course of this project, the following conclusions can be reached:

- The recipient capacity of the Brac-Split Channel, considering organic pollution is high, and the expected organic pollution loads, according to the conceptual solution for the sewer system in the catchment area, will not endanger the sea quality oxygen concentration for the planned function.
- The planned concepts for the realization of the sewer system (sewers, treatment plant and submarine outfall) are satisfactory, and their construction will lead to significant improvement in the quality of the coastal sea water in the Brac-Split Channel, which makes it possible to use it for the proposed functions (recreation and swimming).
- The applied simulation model has proved useful and precise enough for defining long-term global sea states (regarding organic load and thus it justifies its application for defining long-term effects of waste water discharge (organic load) to the sea of the Brac-Split Channel.
- The model is simple and easily applicable. More complex models would require more input data which should be collected to satisfy modeling which is not considered necessary at the present moment of the problem solution (preliminary phase).
- Consequently, continuous monitoring of the changes in the sea state should be effected and data should be collected to satisfy modeling, requirements by applying either this model or other models; the modeling results should be used for determining the monitoring program (location, parameters, periods).
- The applied simulation model as well as the methodology of the problem solution can be equally useful for defining long-term global states and changes in the sea quality for other parts of the Adriatic Sea and wider.

REFERENCES:

APPENDIX 3

ANNEX I, II, III TO THE PROTOCOL FOR THE PROTECTION OF THE MEDITERRANEAN SEA AGAINST POLLUTION FROM LAND-BASED SOURCES
ANNEX I

A

The following substances, families and groups of substances are listed, not in order of priority, for the purposes of article 5 of this Protocol. They have been selected mainly on the basis of their:

Toxicity;
Persistence;
Disaccumulation.

1. Organohalogen compounds and substances which may form such compounds in the marine environment.

2. Organophosphorus compounds and substances which may form such compounds in the marine environment.

3. Organometallic compounds and substances which may form such compounds in the marine environment.

4. Mercury and mercury compounds.

5. Cadmium and cadmium compounds.

6. Used lubricating oils.

7. Persistent synthetic materials which may float, sink or remain in suspension and which may interfere with any legitimate use of the sea.

8. Substances having proven carcinogenic, teratogenic or mutagenic properties in or through the marine environment.

9. Radioactive substances, including their wastes, when their discharges do not comply with the principles of radiation protection as defined by the competent international organizations, taking into account the protection of the marine environment.

B

The present annex does not apply to discharges which contain substances listed in section A that are below the limits defined jointly by the Parties.

* With the exception of those which are biologically harmless or which are rapidly converted into biologically harmless substances.

ANNEX II

A

The following substances, families and groups of substances, or sources of pollution, listed not in order of priority for the purposes of article 6 of this Protocol, have been selected mainly on the basis of criteria used for annex I, while taking into account the fact that they are generally less noxious or are more readily rendered harmless by natural processes and therefore generally affect more limited coastal areas.

1. The following elements and their compounds:

   1. zinc
   2. copper
   3. nickel
   4. chromium
   5. lead
   6. selenium
   7. arsenic
   8. antimony
   9. molybdenum
   10. titanium
   11. tin
   12. barium
   13. beryllium
   14. boron
   15. uranium
   16. vanadium
   17. cobalt
   18. thallium
   19. tellurium
   20. silver

2. Biocides and their derivatives not covered in annex I.

3. Crude oils and hydrocarbons of any origin.


5. Non-biodegradable detergents and other surface-active substances.

6. Inorganic compounds of phosphorus and elemental phosphorus.


8. Thermal discharges.

9. Substances which have a deleterious effect on the taste and/or smell of products for human consumption derived from the aquatic environment, and compounds liable to give rise to such substances in the marine environment.

10. Substances which have, directly or indirectly, an adverse effect on the oxygen content of the marine environment, especially those which may cause eutrophication.

11. Acid or alkaline compounds of such composition and in such quantity that they may impair the quality of sea-water.

12. Substances which, though of a non-toxic nature, may become harmful to the marine environment or may interfere with any legitimate use of the sea owing to the quantities in which they are discharged.

B

The control and strict limitation of the discharge of substances referred to in section A above must be implemented in accordance with annex III.
ANNEX III

With a view to the issue of an authorization for the discharge of wastes containing substances referred to in annex II or in section B of annex I to this Protocol, particular account will be taken, as the case may be, of the following factors:

A. CHARACTERISTICS AND COMPOSITION OF THE WASTE

1. Type and size of waste source (e.g. industrial process).
2. Type of waste (origin, average composition).
3. Form of waste (solid, liquid, sludge, slurry).
4. Total amount (volume discharged, e.g. per year).
5. Discharge pattern (continuous, intermittent, seasonally variable, etc.).
6. Concentrations with respect to major constituents, substances listed in annex I, substances listed in annex II, and other substances as appropriate.
7. Physical, chemical and biochemical properties of the waste.

B. CHARACTERISTICS OF WASTE CONSTITUENTS WITH RESPECT TO THEIR HARMFULNESS

1. Persistence (physical, chemical, biological) in the marine environment.
2. Toxicity and other harmful effects.
3. Accumulation in biological materials or sediments.
4. Biochemical transformation producing harmful compounds.
5. Adverse effects on the oxygen content and balance.
6. Susceptibility to physical, chemical and biochemical changes and interaction in the aquatic environment with other sea-water constituents which may produce harmful biological or other effects on any of the uses listed in section E below.

C. CHARACTERISTICS OF DISCHARGE SITE AND RECEIVING MARINE ENVIRONMENT

1. Hydrographic, meteorological, geological and topographical characteristics of the coastal area.
2. Location and type of the discharge (outfall, canal outlet, etc.) and its relation to other areas (such as amenity areas, spawning, nursery, and fishing areas, shellfish grounds) and other discharges.
3. Initial dilution achieved at the point of discharge into the receiving marine environment.

4. Dispersion characteristics such as effects of currents, tides and wind on horizontal transport and vertical mixing.
5. Receiving water characteristics with respect to physical, chemical, biological and ecological conditions in the discharge area.
6. Capacity of the receiving marine environment to receive waste discharges without undesirable effects.

D. AVAILABILITY OF WASTE TECHNOLOGIES

The methods of waste reduction and discharge for industrial effluents as well as domestic sewage should be selected taking into account the availability and feasibility of:

(a) Alternative treatment processes;
(b) Re-use or elimination methods;
(c) On-land disposal alternatives; and
(d) Appropriate low-waste technologies.

E. POTENTIAL IMPAIRMENT OF MARINE ECOSYSTEMS AND SEA-WATER USES

1. Effects on human health through pollution impact on:
   (a) Edible marine organisms;
   (b) Bathing waters;
   (c) Aesthetics.
2. Effects on marine ecosystems, in particular living resources, endangered species and critical habitats.
3. Effects on other legitimate uses of the sea.