GEF - Black Sea Environmental Programme

Netherlands collateral contribution

Integrated Water Resources Management Azov Sea

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delft hydraulics

Integrated Water Resources Management Azov Sea

Main report

H.W. Balfoort

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1 Introduction to the project

1.1 The Black Sea problem

The Azov Sea is an integral part of the Black Sea water system. The Black Sea is semi-enclosed, the only exchange with the Mediterranean and the worlds oceans being the Bosporus. The catchment basin of the Black Sea (figure I.1) covers an area of 2.2 million km^2 , includes territories of morte than 17 nations and is inhabited by approximately 162 million people. Economic developments in its drainage basin have affected the quantity and quality of the freshwater flow into the sea. Economic developments included the development of agriculture and industry in the drainage basin and on its sea shores, the exploration and transport of oil and increases in fishery efforts on the sea itself. Because of the enclosed nature, these developments have resulted in a severe stress of the Black Sea ecosystem.

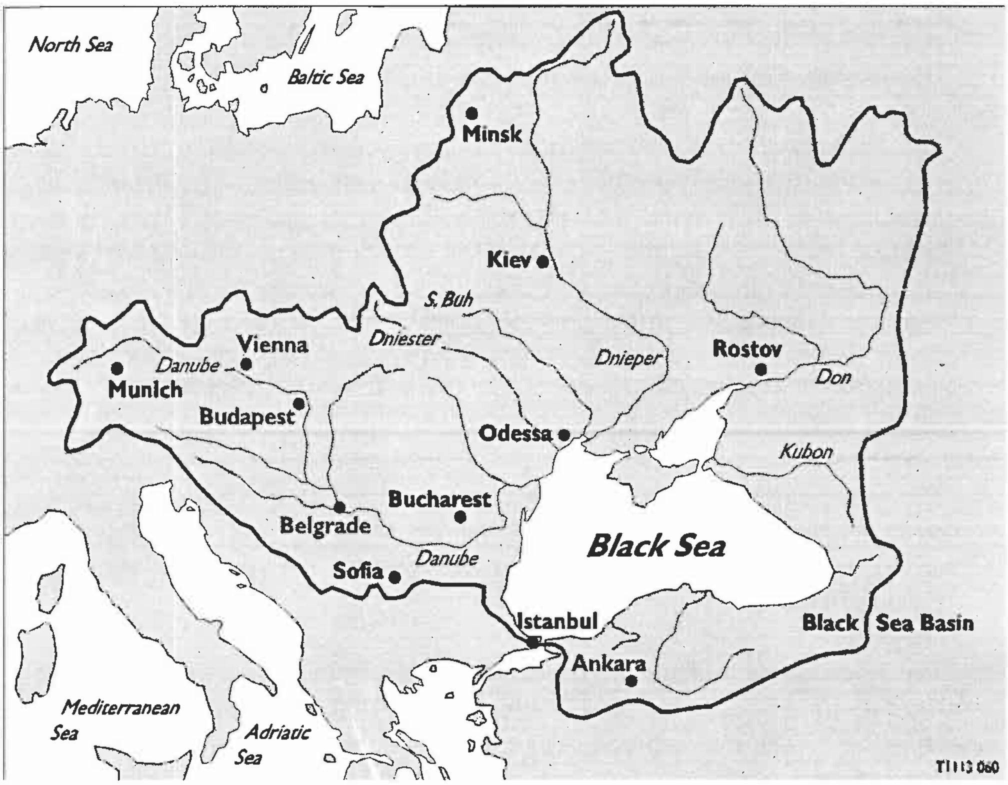


Fig. 1.1: Black Sea drainage basin

The coastal nations on the Black Sea have become aware that the present state of the Black Sea is damaging economic growth, clear examples being fisheries and tourism. However, environmental measures taken by one nation will not have much effect when not supported by similar measures in the other coastal nations and might even lead to an economic disadvantage.

It is the purpose of the Black Sea Environmental Programme (BSEP) to increase the awareness of the governments and the general public in the coastal nations on environmental issues related to the Black Sea ecosystem and to start with a coordinated approach to the environmental management of the Black Sea.

The problems of the Azov Sea are an integral part of those in the Black Sea. Approximately 20% of the catchment area of the Black Sea is formed by the Azov Sea drainage basin (figure 2.1). A net yearly exchange of 16 km^3 in the direction of the Black Sea exists through the narrow Kerch Strait. Economic development in the Azov Sea drainage basin has been even more intensive than in the rest of the Black Sea basin and it has severely changed the seas ecosystem.

After the break-up of the Soviet-Union, the Azov Sea has become international waters. Only through co-operation between its two coastal states Ukraine and Russia can further developments be brought in line with the needs of the seas ecosystem.

1.2 The Black Sea Environmental Programme

The Black Sea Environmental Protection Programme (BSEP) of the Global Environmental Facility (GEF) was started in 1993 to address the problem of the ongoing destruction of the Black Sea environment. The programme allowed collateral partners to identify, finance and execute specific projects within the general framework of the GEF and thereby strengthen the activities of the BSEP itself. To facilitate coordination between the activities, a Programme Coordination Unit (PCU) became operational from the beginning of 1994.

The Netherlands collateral contribution contained two separate projects. One project was supporting the development of a database containing information on environmental institutions in the Black Sea coastal states Turkey, Bulgaria, Romania, Ukraine, Russia and Georgia (Delft Hydraulics, 1996). The other project focused on the environmental management problems in the Azov Sea, an inland sea on the North-East side of the Black Sea. The methods and instruments developed by the Netherlands for the management of the North Sea were considered applicable for the Azov Sea. The experience gathered by the international management of the North Sea was hoped to be beneficial for the Azov Sea coastal states (Russia and Ukraine).

The organisation of the Azov Sea project started in 1993 with discussions between representatives from Russia, Ukraine and the Netherlands on the contents and organisation of the project and with an inception workshop in the spring of 1994. The project was finished in the spring of 1996.

The Netherlands collateral contribution to the BSEP was supervised by the Netherlands Institute for Management of Coast and Sea (RIKZ). The main institute involved was Delft Hydraulics. The International Centre for Water Studies (ICWS) was a partner in the Azov Sea project.

1.3 Project objectives and organisation

When the project was started in 1993, there were hardly any relations on scientific and management level between the Netherlands and the Azov Sea region. The break-up of the Soviet Union and the subsequent economic decline and political instability dominated the first phase of the project. Based upon relations, established under the Memorandum of Understanding on Water Management between Russia and the Netherlands, discussions were organised on the objectives and set-up of the project. In March '94 an inception workshop was organised in Delft, where the approach to integrated water resources management was presented and discussed with high level policy makers from Russia and Ukraine (report 5). The following project objectives were agreed upon:

- Strengthening and support of the institutional network of scientific institutes and management authorities, involved in the development of water resources policies for the Azov Sea, from Russia and Ukraine.
- Presentation of an integrated water resources management approach and supporting methods in the Azov Sea region by:
  - development of methods and tools to assist the decision making process;
  - integration of scientific disciplines;
  - translation of scientific expertise to the management level.
- Support for the implementation of this approach.

Early in the project it became clear that the Azov Sea had been intensively studied. Because of the abundance of scientific information the set-up of an institutional network was an important objective for two reasons: to effectively provide support to the local authorities and to co-ordinate local support for the study itself. Furthermore, an early involvement of environmental management authorities was essential for the exchange of information about the needs at the management level and the state of scientific expertise. It was realised that later adoption of the project results would depend upon the level of acceptance at the management level.

In the institutional network, each scientific discipline was represented by a specialist from both Ukraine and Russia, together with a specialist from the Netherlands. In this way the network contained many duplications of expertise, but facilitated later acceptance of the results. The network (see figure I.3 and appendix 3) is described in detail in report 6.

The first meeting of the experts was organised in Odessa in September '94. Regional environmental managers, water resources specialists and scientists discussed the management requirements, the available data and mathematical models (report 7). A pilot model, developed especially for this workshop was used to illustrate the aims of the project and the necessary steps. A work division and a time table was established for the gathering of additional data during the rest of '94.

The first model development and calibration was performed during the second expert meeting in Delft in March '95, where Russian and Ukrainian experts received initial training to work with the chosen models. Data gathering activities were continued for much of '95, simultaneous with further model developments. A third expert meeting in Delft in August '95 was used to discuss the addition of economic evaluation techniques to the set of tools.

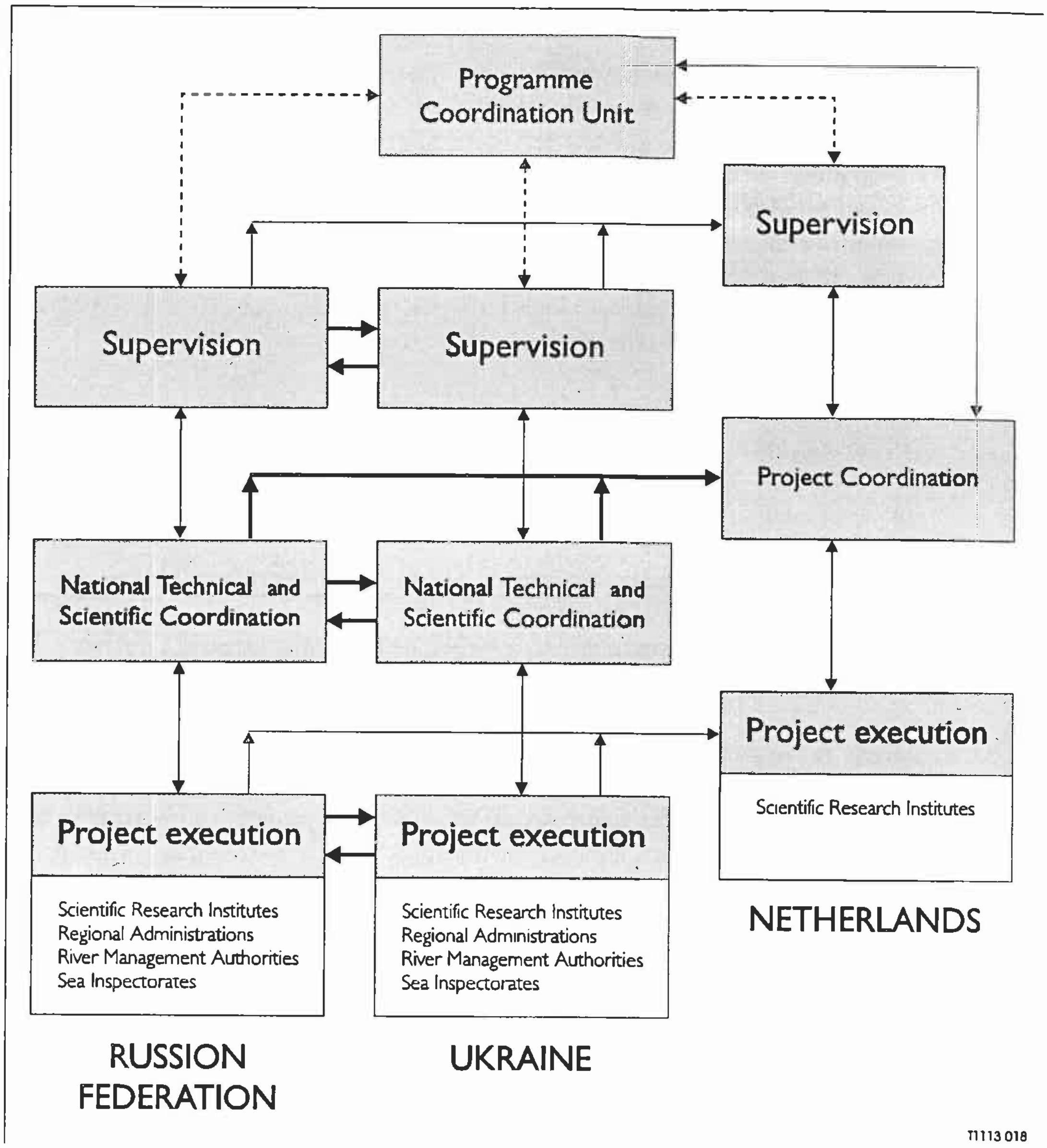


Figure I.3: Institutional network

A final selection of test cases was made during the fourth expert meeting in Delft in October 1995. The test cases were run during November and December, to be used as an illustration of the application of the tools.

So between the spring of 1994 and the spring of 1996, representatives from Russian and Ukrainian research institutes and management authorities co-operated closely with representatives from the Netherlands. The results of their activities are presented in this report. Information gathered on the characteristics of the Azov Sea water system and the environmental management problems in the Azov Sea area are described in chapter 2 together with the set-up of the project. The methods and instruments developed for the project are presented in Chapter 3. Results from test cases, selected to test these methods and instruments and to present are described in Chapter 4. The integrated analysis of water management policies is described in chapter 5. Finally, in Chapter 6 the results of the project are evaluated and recommendations for implementations of the results and future activities are presented.

2 Introduction to the Azov Sea

This chapter has been compiled with information gathered by the Russian and Ukrainian participants in the project, especially by S.P Volovik, G. Sukhorukov, A. Kosolapov and A. Tkachev.

Approximately 20% of the Black Sea catchment area is a part of the Azov Sea drainage basin (figure 2.1). Problems in the Azov Sea are often similar to those in the Black Sea. Because of the special hydrological conditions, there are also differences.

2.1 Overview of the Azov Sea problem

The Azov Sea is a shallow inland sea on the North-East corner of the Black Sea. Its size is approximately 300 x 150 km, with an average depth of no more than 9 meters.

The main influencing rivers are the Don and Kuban (figure 2.1), which attribute approximately 90% of the fresh water flow.

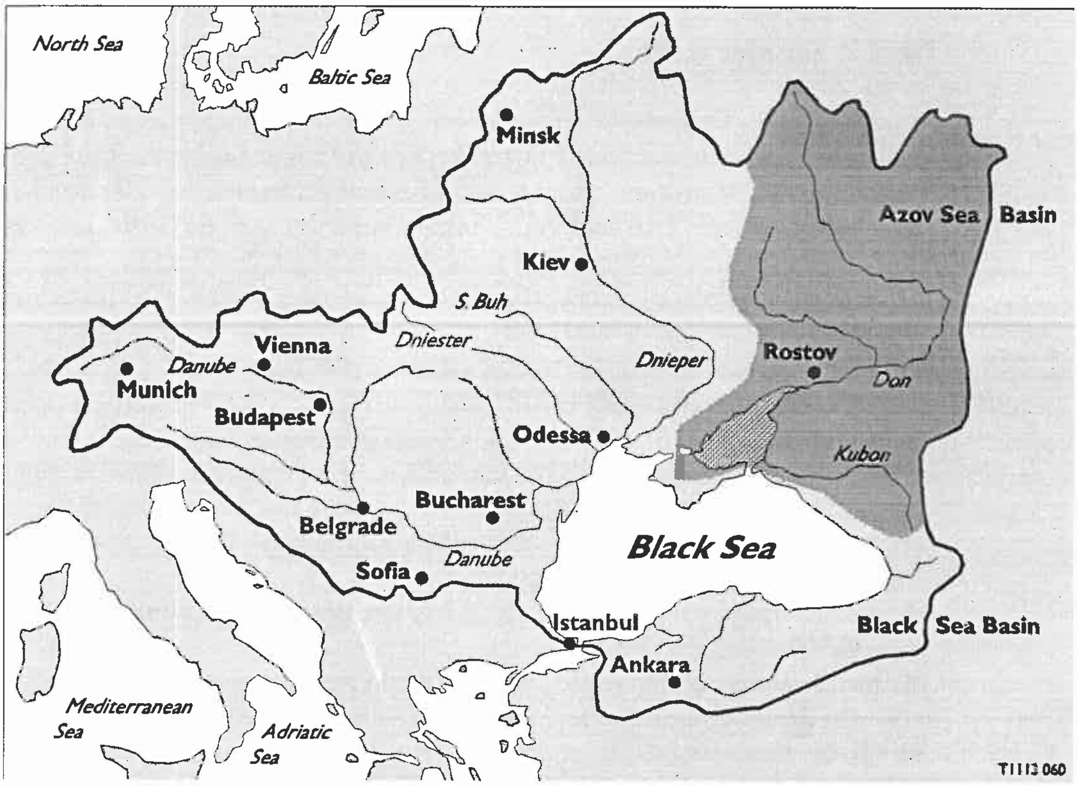


Fig. 2.1: Azov Sea drainage basin

The remaining inflow comes from more than 20 small rivers. Historically, inflow into the Azov Sea was characterised by high fluctuations in flow, both seasonally and yearly. This caused a dynamic environment especially in the lower reaches of the Don, the estuary and in Taganrog Bay (figure 2.2). With an estimated residence time of between 10 - 20 years, the quality of the Azov Sea watersystem is very much dependent upon the quantity and quality of the fresh water runoff from its drainage basin.

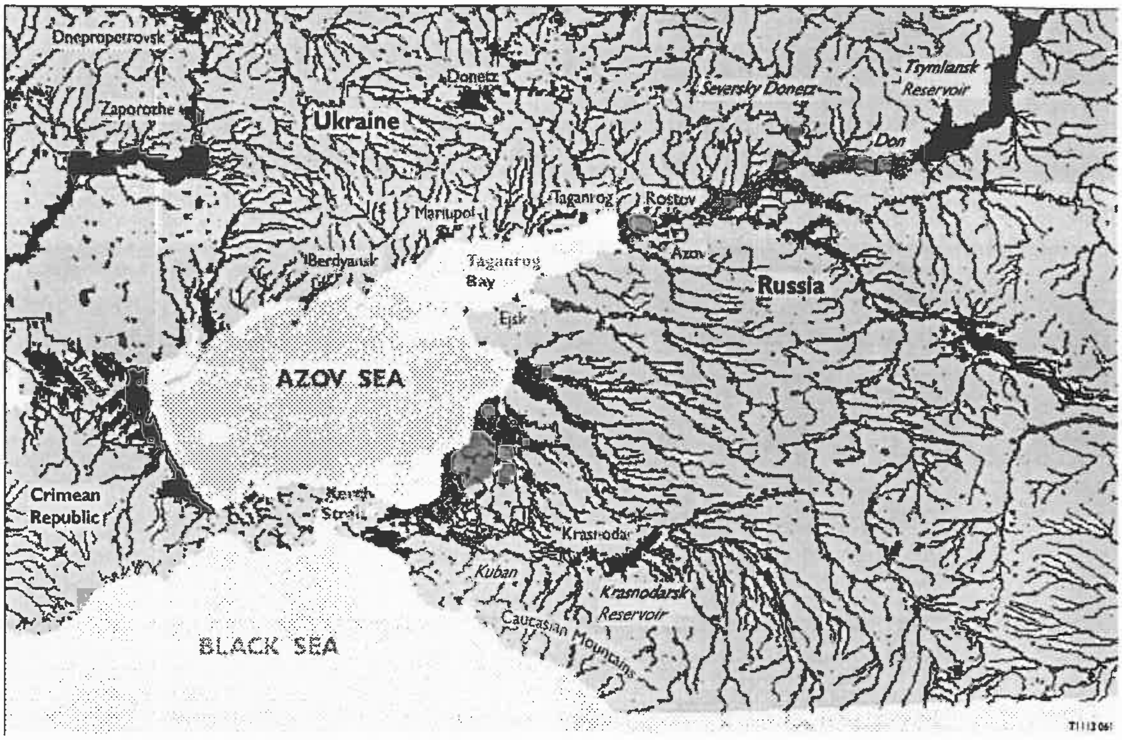


Fig. 2.2: Azov Sea region

At present, approximately 12 million people live in the drainage basin of the Azov Sea. This number has been reached after a fast growth of the population in the 1920's and after 1945. Simultaneously agriculture, industry and urban settlements have been developed at a large scale in the region. The need for a steady water supply for irrigation, drinking water, industrial use and navigation called for the construction of reservoirs. At present there are 130 reservoirs in the basin, containing up to a maximum of 35 km^3 of fresh water.

It is estimated that 50% of the annual runoff in the Azov Sea Basin is used for economic activities. The nonretrievable use has resulted in a reduction of the freshwater flow into the sea of more than 20% and has caused a steady increase in salinity from an average of 10‰ in the 1930's to almost 14‰ in the 1970's. The remaining flow is highly regulated, decreasing the frequency and severity of spring flooding. The quality of the remaining flow has been affected by emission of insufficiently treated or untreated waste water from industrial, domestic and agricultural sources. Concentrations of heavy metals, pesticides and oil products have been steadily rising until the economic decline of the 1990's.

The human impact on the water resources of the drainage basin has affected the habitats of species in the ecosystem. For many migrating fish species access to spawning areas has been cut off by the construction of dams. Other spawning areas have decreased due to the decrease of frequently flooded land. Habitats have become unsuitable by the increase in salinity and concentrations of toxic substances.

Historically, the ecosystem in the eutrophic waters of the Azov Sea could sustain very high fish catches up, to 300,000 ton in the 1930's (Volovik, 1993). Now the annual catches are between 10,000 - 30,000 ton. The species diversity of primary producers and higher trophic levels has decreased, making the ecosystem more vulnerable to disturbances like the introduction of the ctenophore *Mnemiopsis leidyi* from the Black Sea. The habitat conditions for this jellyfish have apparently become more favourable and have resulted in periods of total dominance, in which it outcompetes all other planktivorous species for food sources. The timing of these blooms is critical for the survival of newly hatched fish larvae and young fish.

The responsibility for management, monitoring and research is distributed among a large number of national and local authorities, each with different objectives and operating under the jurisdiction of different ministries. The recent establishment of the Russian Federation and Ukraine as separate and independent nations has further increased the number of institutional parties involved in management of the sea. No single authority or committee is responsible for the co-ordination of Azov Sea management issues.

In the present situation, only through the development of a coherent strategy and the adoption of concerted actions on the management of the Azov Sea can the economic and natural value of the sea be protected and restored.

2.2 Azov Sea system characteristics

2.2.1 Hydrology

The Azov Sea has a size of approximately 300 x 150 km, with a surface area of 37,000 km^2 and the depth ranges from 3 to 14 meters. The sea project into small waterbodies, the "limans" (coastal lagoons) and wetlands in the lower reaches and deltas of the inflowing rivers. Bottom relief is monotonous and the sediments consist mainly of combinations of silts, sands and accumulations of shells. There is no discernible tidal movement. Water movement is mainly wind driven and can result in sea level changes of more than 2 meters. The same wind driven motion accounts for the exchange with the Black Sea through the Kerch Strait. Due to the unstable wind regime the current pattern is generally unstable. The overall movement is cyclonic: out of Taganrog Bay westward along the northern side of the sea proper, south along the Sivash area and east across Kerch Strait. The flow speed is approximately 0.10 - 0.15 m/s for wind speeds of 5 - 10 m/s.

In severe winters parts of the sea can be covered by ice, while in summer temperatures can reach up to 30 degrees C. Due to the shallow depth even moderate wind speeds can create turbulent mixing of the whole water column and can cause resuspension of bottom sediments. Transparency of the water column is therefore dependent on the wind regime. Average values in the centre of the Sea are 1.8 - 2.7 meters. The lowest values are observed in Taganrog Bay and the highest near the Kerch Strait.

The salinity of the Azov Sea is subjected to considerable spatial and temporal variations. The overall gradient ranges from almost zero in the eastern part of Taganrog Bay to 15 - 17 g/l near the Kerch Strait. The main driving factors for salinity are the inflow of fresh water from the drainage basin and the exchange with the Black Sea through Kerch Strait.

The total area the drainage basin is approximately 570,000 km^2. The average natural flow of fresh water into the Azov Sea is 43 km^3 per year, with large yearly fluctuations between 30 - 50 km^3. The main influencing river is the Don . In its catchment area of more than 400.000 km^2, an average volume of 28 km^3 is collected annually. This is 65% of the total fresh water volume collected in the Azov Sea basin. Historically, the Don was characterised by high fluctuations in flow, both seasonally and yearly, causing a dynamic environment in its lower reaches, the estuary and in Taganrog Bay. The construction of reservoirs has stabilised the flow considerably (figure 2.4). The main reservoir at Tsymlyansk is for instance capable of accumulating 50% of the annual flow. The Kuban river contributes approximately 12 km^3 (27%) of fresh water annually, with a more stable flow regime. The remaining inflow comes from more than 20 small rivers. A more detailed description of the hydrology of the Azov Sea is presented in report 2.

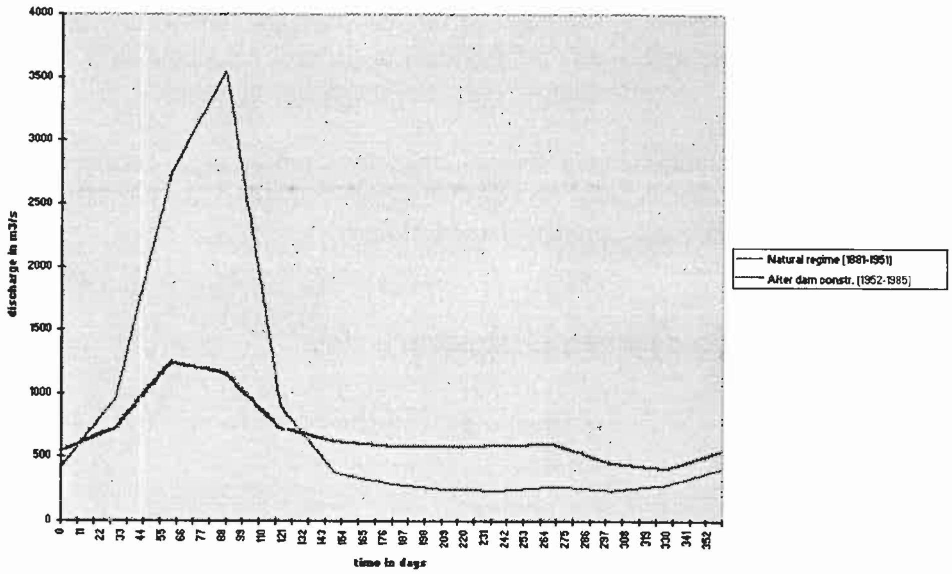


Figure 2.4: Historic and present flow regime of the river Don

2.2.2 Hydrochemistry

Biogenous components

The high fish catches in the Azov Sea which were reported at the beginning of this century indicate that the Azov Sea has always been eutrophic. Early monitoring data seem to confirm this. Present concentration ranges of total nitrogen are estimated at 600 - 1300 mg/m^3 (an increase of approximately 50%) and of total phosphorus at 40 - 110 mg/m^3 (an increase of approximately 40%). Since the 19080's no further increase of eutrophication has been reported. The occurrence of oxygen deficiencies, which are more frequent since the 1960's are clearly related to the high productivity and the eutrophic conditions.

Mineral oil

The Azov Sea is subjected to heavy pollution by mineral oil products from the Don and from industrial areas on the coast and from the Black Sea. Total input is estimated at 25000 to 35000 tons/year, of which a substantial fraction accumulates in the bottom sediments. During recent years a decrease of oil pollution has been observed.

Pesticides
Due to the development of agriculture, application of pesticides is causing increased loads into the sea. Considerable amounts of chlorinated pesticides can be found in the sediments at depths of 20 cm and more. In some cases acute toxic effects were found from dumping of pesticides into offshore and nearshore areas. Monitoring data from different areas of the sea show large ranges of concentrations with strong seasonal variations, ranging from 0.01 to 185 mg/l total chlorinated pesticides. Averaged trends indicate a gradual rise in pollution between 1984-1988 and a gradual lowering in recent years.

Heavy metals
Most heavy metals enter the sea with river runoff or through the abrasion of shores and bottom. Discharge water from industrial areas, dust-storms and Black Sea water contribute additional important quantities. The copper content of bottom sediments increased from 25-30 ug/l in 1960 - 1970's to 50-200 ug/l to the end of the 1980's. The concentrations in the waterphase amounted to 5-12 ug/l in the 1980's. In the waterphase the zinc concentration increased from 12-13 ug/l in the 1960's to 20-50 ug/l in the 1980's. In the sediments concentration ranges are 50-200 ug/l including 1990 data.

2.2.3 Ecology of the coastal area

The ecology of the Azov Sea is characterised by the very high spatial and temporal variability in physical, chemical and morphological conditions. The system in the sea itself is linked to the ecosystem in the estuaries and the rivers. The coastal zone has extensive wetland ecosystems which form the transitional interface connecting the terrestrial drainage basin and the Sea of Azov itself. These wetlands are dynamic and highly productive ecosystems whose formation, functioning and characteristics are controlled by water; they support a unique diversity of flora and fauna that can survive being wet for long or intermittent periods.

The Sea of Azov coastal wetlands include habitats such as reeddominated marshes, forested riverine flood plains, inland lakes and lagoons, limans (a coastal lagoon with a salinity gradient), deltas, coastal lagoons and bays, and associated mud and sand flats, as well as artificial wetlands such as fish ponds, rice paddies and salt ponds (Wilson 1994). Within many of the wetland complexes, terrestrial habitats also occur, such as barrier islands and sand dunes. These wetlands have adapted to various hydrological, nutrient and salinity regimes influenced by the extensive catchment basin and semi-enclosed sea. They provide a variety of critical functions, which sustain both the people and the biodiversity of the region.

The most important rivers related to the Sea of Azov are the Don and Kuban rivers.

Don Delta

This delta has a total area of 54,800 ha of which 46,200 ha is occupied by wetland habitats, and includes a system of channels of varying size and character, and salt lakes. In the last decade a number of commercial fish farms have been built in the Delta (with an area of 10,000 ha). The flora of the Delta is varied and includes 419 species, belonging to 245 genera and 68 families. They are found not only in the wetlands but also in other sections of the Delta. The vegetation of the wetlands is more diverse than that of the reservations and floodplain but the dominant species are the same. The delta is an important breeding site for mallard *Anas platyrhynchos*, coot *Fulica atra*, cormorant *Phalacrocorax carbo*, and grey heron *Ardea cinerea*.

This is the most polluted section of the Don river with nitrogen, phenols and pesticides all violating norm standards, and affecting both wildlife and human health. The character of the delta has also been affected by upstream hydrological works. Before the construction of the Tsymlyansk reservoir the average flooded area used as a spawning ground for fluvial anadromous fish was 95.000 ha with a flood period lasting for 49 days. In the period after the dam construction (after 1952), the flooded area was reduced to 27.000 ha with a duration of flooding of 11 days. Furthermore, dam construction has changed the temperature regime of the lower Don area, influencing the spawning cycle of species.

Kuban Delta

An extensive area of wetlands occurs here. The different salt lake systems have different hydrological and hydrochemical characteristics depending on their water source, depth and link with the sea. The area of the Delta salt lakes in the 1930s was up to 300,00 ha; then, under the influence of economic activity, it decreased considerably (190,000 ha, including 87,000 ha of foredelta zone in 1969; 157,600 ha including 77,900 ha floodplain zone in the mid-1970s).

As a result of the development of rice growing and massive irrigation schemes in the Kuban Delta a significant number of the salt lakes were opened up to rice cultivation, and water form the rice fields began to collect in some groups of salt lakes. The run-offs contained large quantities of fertilisers and harmful chemicals used in rice cultivation. This caused significant eutrophication and transformation of the salt lakes' ecological systems. Part of this area is protected by state sanctuaries (zapovedniks). The delta is extremely important for nesting waterbirds (e.g. herons, dabbling and diving ducks, Dalmatian pelican *Pelecanus crispus*, spoonbill *Platalea leucorodia*, glossy ibis *Plegadis falcinellus*, gulls etc.). It is also an important staging, moulding and wintering area for waterbirds, particularly ducks and white-fronted goose *Anser albifrons*. Up to 1,000,000 ducks occur during the moulding period.

Influenced by development of agriculture and increased population density, the amount of fresh water used for irrigation and other needs has increased. On the whole 40% of runoff waters is used in economic activities. In the Kuban basin the total water consumption exceeds the river flow. The irretrievable consumption of Kuban water amounts to more then 60% of the annual historical mean flow.

Other areas

Furthermore, coastal lagoons (limans) in the Sea of Azov are of importance to the biodiversity of the ecosystem. The two main coastal lagoons (limans) in the Russian part of the Sea of Azov are Jejskij and Bejsugskij Limans. They are characterised by a changing salinity from fresh water where the rivers (with the same name) empty into them, to corresponding marine salinity (Jejskij - 5-7‰, Bejsugskij - 13‰) in the channels which connect them to the sea. The change in salinity determines the composition of the flora and fauna of the limans. The foredelta sections of the lagoons have a typical floristic composition, while in the saline sections there is poor marine vegetation. There are many wetlands on the floodplains inland of the two lagoons. Most frequently they are low lying marshy areas largely overgrown with *Phragmites*, *Typha* and *Scirpus*. They differ considerably in size, from several hundred to several thousand hectares in area.

The Sivash is the largest united lagoon system in Europe, covering about 2500 km2 of open water, mudflats and saltmarshes. The lagoons are non-tidal and not influenced by large river systems. Most are shallow and brackish with indented shoreline, spits and islands, including dominant habitats of saltmarsh and steppe with halophytic vegetation and extensive reedbeds. There is a gradual change in salinity from east (brackish) to west (hypersaline). The area is largely isolated from the Sea of Azov by a low spit, resulting in varying water levels and evaporation. Water flow is also altered by a dam and from agriculture development for rice and fish ponds, which have all increased the freshwater content. The economic activity is minimal except for industrial fishing, salt extraction and overfishing by recreation. The virgin steppe is often ploughed, used for hay and grazed by sheep. There are numerous species of breeding birds. In spring, the Bay is important for waterbirds, especially ducks, red-breasted goose *Branta ruficollis* and waders (0,5 million including important populations of dunlin *Calidris alpina* and broad-billed sandpiper *Limicola falcinellus*).

Part of the area is protected as the Azov-Sivash National Park (45,700 ha) with less than 1% having protection as a strict nature or hunting reserve. An important priority must be to extend these protected areas. This site was designated as a Ramsar site until Ukraine became independent.

2.2.4 Ecology and fisheries

The decline of the ecosystem of the Azov Sea is most prominent in the decline of fisheries. The present total catch is less than 2% of the catch reported in the 1930's.
In the Azov Sea and the river mouths 114 species and subspecies of fishes occur (Volovik et al. 1993). Another 18 species, primarily of commercial importance, have been or are being introduced by man. The fish populations of the sea are genetically non-uniform, they include representatives of the freshwater complex, the Ponto-Caspian relicts and the Atlantic-Mediterranean immigrants. The following biological groups may be singled out:

- migratory fish, 10 representatives of 5 families;
- fluvial anadromous fish, 12 representatives of 3 families;
- freshwater fish, 35 representatives of 6 families;
- marine (pelagic and bottom) fish, permanently living in the sea, 26 species of 10 families;
- marine fish (pelagic and bottom) coming only in warm seasons from the Black Sea, 31 species of 23 families.

In the years of the highest salinity, some species emerge in the Azov Sea that have never occurred there before or occurred very rarely, thereby increasing the list of the ichthyofauna to 145-150.

Only few species have a commercial value. Some of these, reaching a length of 15-20 cm and more, represent the targets of sport-fishing, while commercial catches are aimed at massive accumulations of fish (such as anchovy, kilka, gobies, atherinids and others) or highly valuable species (sturgeons, bream, pike-perch, goby, herring, flounder, mullet and others).

Over the 1930-1990 period, more than 10 million tonnes of fish were caught in the Azov Sea (not taking into account the years 1942-43), with the annual averages being 171000 tonnes. Marine fishes account for 7.6 million tonnes and 129000 tonnes respectively. In the 1920s and early 1930s, the migratory and fluvial anadromous fish represented the main bulk of the catches (Table 10). Their maximum harvest was registered in 1936 and 1937, 164000 and 134000 tonnes. These were the species that suffered the first and greatest losses caused by certain economic activities of man. The human impact violated reproduction conditions in the river system and worsened the environment in the sea. Catches of some species very quickly diminished during one decade after the dam construction on the Don, and they have remained at that low level ever since.

At the same time the stocks and catches of the marine fish continued to be relatively high. However, in the mid and late 1960s the harvest of goby, a marine bottom fish, decreased, and in the late 1980s the reproduction and stocks of anchovy and kilka (both marine pelagic fishes) decreased. Thus, at present all populations of commercial fish live under conditions of greatly changed environment and sharply disturbed reproduction, which affects the fish production. As a result, total catches dropped in 1990 to 13000 tonnes, with migratory and fluvial anadromous fish accounting for 5000 tonnes only.

The most important, in economic terms, of the twelve Azov fluvial anadromous fish are pike-perch, bream and Azov Sea roach whose catches used to reach 140000 tonnes. The remainder of the fluvial anadromous fishes, which in the 1930s-1950s had a commercial importance, have virtually disappeared in the last two decades (except *Pelecus cultratus* and *Caspiolosa caspia*). The main reason for this loss is the total destruction of the reproduction conditions.

In the 1930s and 1940s the most numerous representatives of the 10 Azov Sea migratory fish were sturgeons, herrings, vimba, shemaia; the rest occurred infrequently and sporadically. In the 1970s and 1980s, only sturgeons and herring were of commercial importance.

Sturgeons are the most valuable component of the Azov ichthyofauna: they comprise sturgeon, stellate sturgeon and great sturgeon. In this century, highest catches were made in the 1930s (7300 tonnes) and the lowest in 1961 (500 tonnes). After the extensive dam construction on the Don and then on the Kuban resulting in worsening of conditions for the reproduction of sturgeons, their catches were limited starting from 1966. In the 1970s when these fishes began to be more abundant, this limitation was abolished and the harvest increased to 1000-1300 tonnes annually. The total commercial return of the natural spawning did not exceed in the 1960s 500 tonnes, and in the 1970s and 1980s 200 tonnes. At present the predominant role in maintaining the stock of sturgeons belongs to farming with 80-95% of each generation of sturgeon and 60-98% of stellate sturgeon consisting of young fish grown at fish farms.

It is noted, however, that the biomass and production of the Azov sturgeons are 5-7 times lower than the potentially possible values based on the feeding supply. Even though certain positive developments with respect to the restoration of the sturgeon stock are important, the changes in the regime of the sea were definitely not favourable for these fish. This is seen in the changed spectrum of their feeding, the reduction in fat content and the deterioration of other physiological characteristics of the fry and the mature specimens, which, however, have not so far exceeded the limits of their adaptability. In the mid-197Os cases were known of the death of sturgeons in their wintering places, caused by nearly critical values of some parameters of the environment, for example, by the fact that the temperature of freezing of water at the salinity of 13.0-13.5% and that of the intercellular lymph in sturgeon is the same.

The spreading of the ctenophore *Mnemiopsis leidiy* affected adversely the Azov anchovy, their eggs and larvae were eaten by the intruder and the depletion of the feeding resources in the postspawning and premigrational periods sharply increased natural lethality. In the last three years, anchovy has ceased to be a fishery target. All this evidence shows that the conditions for the Black Sea intruders proved unfavourable in the period of intensive transformations of the ecosystem. At same time the permanent inhabitants of the marine complex, flounder, Sygnathus and others extended their habitat a good deal increasing their abundance and biomass two- to fourfold. But on the whole their biomass remained low (about 10 000 t) and they occupied a moderate place among the Azov fishery targets.

As already mentioned, in recent years summer asphyxiation of animal life has intensified in the Azov Sea, involving also sturgeons, both fry and mature specimens. Thus, among the dead fish found on the shore in 1990, about 55000 individuals of sturgeon were estimated to be present. In the dead fish different pesticides were found, for example, chloro-organic substances in concentrations from 0.0022 to 0.1 mg/kg (wet weight), organophosphorus substances 0.008-0.01 mg/kg as well as heavy metals. This bears witness to the chronic toxicosis in sturgeon and other fishes found there.

Table 2.1: Commercial catches of Azov fish (tonnes)

Species	tonnes	year	1990	1991	1992	1993	1994
Russian sturgeon	4500	1937	677	759	756	893	874
Starred sturgeon	1400	1937	334	262	246	307	348
pike-perch	73700	1936	1446	1266	975	699	1092
breach	16500	1936	1715	1663	1564	1387	1025
roach	18200	1936	182	101	129	140	476
gobies	91700	1957	208	432	106	249	305
anchovy	142600	1974	43	46	11853	12909	20382
kilka	125800	1982	1370	27055	3018	281	4500
turbot	1800	1986	530	403	365	273	263
mullet	435	1994	-	-	52	140	435

Mullet is a new fish for the Azov Sea Basin and its commercial catches began only from 1992.

2.3 Economic activity and water users

The present economic decline in Russia and Ukraine has decreased the level of economic activity in the Azov Sea region. This is often reflected in decreased pollution loads. However, the most important economic sectors are still operating and many plans are being developed to restore old or build new economic enterprises. Some of these plans are initiated by the division of the Azov Sea region into two different zones, due to the break-up of the Soviet Union.

Russia is stimulating the development of the harbour of Taganrog to compensate for the loss of the ports of Mariupol and Berdyansk. There are even plans to make Taganrog a tax-free zone, in the hope that this will stimulate economic activity. All three ports and the river Don can only be reached by a special route through the sea, which is regularly dredged to a depth of 14 m. The sludge is dumped elsewhere in the sea. The Don attracts an increasing volume of shipping from areas deep in Russia and even from the Caspian Sea, through the Wolga-Don Canal. The shipping activity is believed to cause oil pollution (7000 tons annually) and pollution from losses during the loading, unloading and storage of cargo.

Even though the drainage basin of the Azov Sea is heavily industrialised, in the coastal region itself only Mariupol is characterised by steel industry. This conglomerate of plants (Azovsteel) emits of waste directly into the sea, though a neighbouring small river or though the atmosphere. Many of the environmental problems in the region are attributed to Azovsteel by the local population (AzNIIRKH documentary 1).

There is some activity in the production of oil and natural gas, causing local disturbances and pollution (AzNIIRKH documentary 2).

The Azov Sea coast is not very intensively used for tourism. The main areas are for day trippers, near the main coastal towns. Most of the small holiday colonies are also situated there. At present, most of the coastal regions are developing plans to construct hotels and holiday resorts hoping to attract nor only regional tourists but also from other CIS countries and even from western countries. In the meantime construction sites for dacha's are scattered along the coastline.

Economic developments in the Azov Sea region are presently dominated by the general economic stagnation of the CIS countries. In all economic fields there are numerous plans and projects ready to be initiated once the economic circumstances have improved. If these new developments are not linked to an environmental strategy and environmental investments, a further decline of the Azov Sea ecosystem and a further waste of the countries resources are inevitable. The development of environmental strategies is the responsibility of the environmental managers.

2.4 The water resources management system

Recent history has shown that the status of the Azov Sea is affected by management decisions in the drainage basin and on the sea itself. These decisions concern authorities in economic sectors like agriculture, industry, urban planning, fisheries, tourism etc. The decisions also concern environmental management authorities.

The responsibility for the development of environmental legislation lies primarily at the State level, with the Ministry for Protection of the Environment and Nuclear Safety of Ukraine and the Ministry for Environmental Protection and Natural Resources of Russia. In both countries the basis for environmental legislation stems from the Soviet legislation. Since the recent establishment of Russia and Ukraine as independent nations separate legislation is being developed (see annex 1).

Enforcement of environmental legislation and environmental management (issuing permits for water use and emissions, the purification of waste water and monitoring) is distributed among a large number of national and local authorities, each with different objectives and operating under the jurisdiction of different ministries. The same accounts for research (table 2.2).

Table 2.2: Environmental management authorities and research institutes in the Azov Sea region

National Level	Local level	Activity
Min. for Environm. Prot. and Nat. Res. of the RF	Rostov Oblast Environm. Comm.	Manag., monit. and enforc.
	Krasnodar Environm. Comm.	Manag., monit. and enforc.
Min. for Environm. Prot. and Nucl. Safety of UKR	Mariupol Oblast Environm. Comm.	Manag., monit. and enforc.
	Donetz Oblast Environm. Comm.	Manag., monit. and enforc.
	Zaporozhe Oblast Environm. Comm.	Manag., monit. and enforc.
	Cherzon Oblast Environm. Comm.	Manag., monit. and enforc.
	Environmental Dept. of the Republic Crimea	Manag., monit. and enforc.
	Azov Sea Inspectorate	Monitoring and enforcement
	UKR Scient. Centre for Prot. of Waters	Research and monitoring
	UKR Scient, Centre for Ecol. of the Sea	Research and monitoring
State Comm. for Water Man. of the RF	Don Water Management Agency	Management and monitoring
	NCB of the Research and Manag. Inst.	Research and monitoring
	Kuban Water Management Agency	Management and monitoring
State Comm. for Water Man.of UKR	Seversky Donetz Water Management Agency	Management and monitoring
State Comm. for Fisheries of RF	Research Institute of Azov Sea Fishery Problems (AzNIIRKH)	Research and monitoring
State Comm. for Fisheries of UKR	Southern Scientific Research Institute of Marine Fishery and Oceanography	Research and monitoring

Some of the authorities are co-operating on a regular basis, but until very recently there were no initiatives for a common environmental strategy or plans to establish a co-ordinating environmental authority for the Azov Sea.

2.5 Summary of the problems and remedies

The large scale economic development of the Azov Sea drainage basin in the 20th century was attended with the unbalanced allocation of the available water resources and a disregard for the natural requirements of the water system. This caused a general decline of the ecosystem and damaged the economic interests of water users.

In the near future the availability of water will only remain stable, while the demand in the region will grow, especially after an economic recovery. A stable regional economy can only be attained by the sustainable development of regional water resources, taking into account the needs of all the water users as well as the needs of the water system itself. The optimisation of water resources management requires rationalisation and integration of management activities.

2.5.1 Integration of management

The status of a water system is influenced by management activities such as the setting of environmental and public health standards, issuing permits for water use and emissions, the purification of waste water, monitoring and enforcement. Many national and local authorities are involved in the development of management strategies and policies, the implementation and enforcement of management decisions, each authority with a different perspective of the water system. A common perspective of the characteristics and functions of the water systems should provide a basis for the integration of management activities.

2.5.2 Integration of scientific expertise

Successful water management should be based on an adequate understanding of the characteristics and the functioning of a regions natural water resources system. This involves scientific disciplines such as hydrodynamics, hydrochemistry, biology and toxicology. Even though many water systems have been studied intensively, scientific research efforts are often focused on specific aspects. The results of those separate research efforts do not always meet the demand at the management level. Furthermore, the scientific knowledge is not distributed evenly across different aspects of a water system (figure 2.5). For an adequate understanding of the water system scientific research efforts have to be co-ordinated and the results have to be integrated. Again, a common perspective between scientists is essential to identify and exchange relevant research results and agree upon information lacunas.

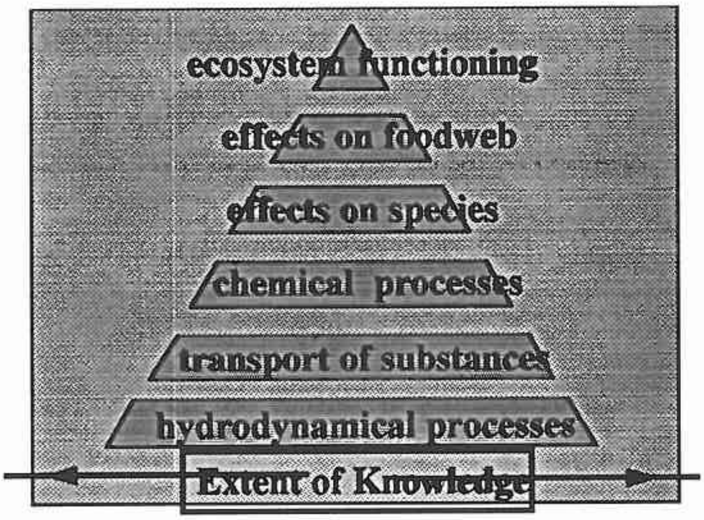


Figure 2.5: Distribution of knowledge on different aspects of the water system

2.6 Project objectives

The authorities and institutes in the Azov Sea region often have more than adequate knowledge about the specific scientific and management aspects of the water system within their field. The Azov Sea project was therefore focused on the

- facilitation of the cooperation between Russia and Ukraine for the development of a common strategy on the management of the Azov Sea
- integration of different management aspects and scientific discipline.

To reach these objectives, the project aimed for the development and presentation of an integrating management support instrument: a Decision Support System for the Azov Sea.

3 Supporting methods: the Azov Sea DSS

Supporting methods are increasingly used to provide discussion platforms to reach a common perspective between scientists and between managers. Furthermore, these methods help to bridge the gap between science and management. In the last decade, mathematical simulation models, databases, expert systems and geographical information systems all have been applied as separate tools in the research and management of water resources. A Decision Support System (DSS) aims to integrate these tools and thereby provide an adequate scientific description of water systems for the comparison of different strategies and measures. A DSS is an important tool to:

- integrate research efforts in different scientific disciplines and translate the results to the management level;
- increase the understanding at the management level of the relations between users of a water system and the system itself;
- provide different authorities with a common framework for the analysis and comparison of management decisions;
- facilitate the comparison of many different management options and measures;
- repeat the decision making process after additional or different information has become available.

Decision support systems have been developed for different water systems like rivers (Hron, Slovakia), estuaries (Hang Zhou Bay, China) and seas (North Sea, W-Europa). The systems are different because each water system has unique characteristics, or because of different management requirements. The set-up and the possibilities of modern decision support systems are illustrated here with the Azov Sea DSS.

3.1 Modules of the Azov Sea DSS

The computational framework of the Azov Sea decision support system includes the following models:

- Hydrodynamic model (TRISULA), a two dimensional simulation of the sea water hydrodynamics, based on input of bathymetry, fresh water flows and wind conditions on a curvi-linear grid, (report 2);
- Waste load model (WLM), a model to calculate waste loads from domestic and industrial production as well as non-point (atmospheric deposition, agricultural) sources. The input of contaminants and nutrients is determined by local outfalls directly discharging in the Azov Sea, measured loads in major and minor rivers, and estimated atmospheric deposition;
- Water quality model (DELWAQ), a two dimensional dynamic model to calculate advective and dispersive transport of dissolved substances, including all relevant water quality processes and exchanges between water and sediment. DELWAQ uses results of the TRISULA and WLM models, for the identical curvi-linear grid. Substances included are dissolved oxygen, salinity, suspended solids, biological oxygen demand, nutrients, phytoplankton, copper, zinc and mineral oil. Processes included are the oxygen cycle, the nutrient cycle, sedimentation, resuspension, adsorption, desorption, primary production, decay, and so forth, (report 2);

- Local outfall module: a program that allows calculation of contaminant and nutrient concentrations as a result from the Azov sea background and local discharges. This local outfall approach is used in Russian and Ukrainian permit system for local outfalls. The model uses concentrations calculated by DELWAQ as background;
- Ecological model (DELGEM), a program that allows the evaluation of habitat quality, quantifying the effects of changes in environmental factors such as water quality to selected key species. The procedure uses concentrations calculated by DELWAQ as input. It calculates the habitat suitability indexes for all areas of the Azov Sea where feeding, spawning and breeding habitats are found for the selected species (report 3).

3.2 Operation of the Azov Sea DSS

The user is led step by step through a series of menus (fig 3.1).

1. Selection of a certain hydrometeorological scenario (e.g. a low annual runoff).
2. Different management options can be selected (e.g. an overall decrease of emissions, a decrease of emissions of a certain substance or at a specific point source). For each of the selected options, the DSS calculates a one-year time series of the resulting water quality for more than 1000 grid cells of the Azov Sea.
3. For the selected options, the results for each cell can be presented graphically or in maps (fig.3.2).
4. The water quality results for each sector (e.g. minima, maxima or averages) can also be compared to water quality standards or to other sets of requirements (e.g. for biological habitats of commercial fish species or tourism).
5. The results from the analyses can be scored (using Habitat Suitability Indexing techniques). To facilitate comparison between management options, the scoring results can be aggregated per cell or substance according to general accepted techniques for Environmental Impact Analysis.

3.3 Potential applications of the Azov Sea DSS

The Azov Sea DSS has been designed to address the problems of the Azov Sea. Important applications are:

- The evaluation of the quality of existing information about the Azov Sea water system and its relevance for environmental management. Comparisons should be made of:
  - registered pollution load versus monitored water quality;
  - ecologic threats versus monitored substances;
  - model requirements versus spatial and temporal monitoring frequency.

  This evaluation should lead to recommendations for new or more effective research and monitoring efforts to support the environmental decision processes.

- The DSS should be used by environmental managers in the Azov Sea region to focus on a specific problem and select the most effective (set of) measures, for instance to:
  - protect the sea at a specific beach against the violation of sanitary standards;
  - improve the quality of spawning habitats of commercially important fish species.

- At the national level of environmental management, the effectiveness of policies should be compared, for instance the effect of:
  - autonomous economic growth versus growth accompanied by environmental measures
  - the management of river quantity versus river quality;
  - the treatment of waste water from specific industrial point sources versus the introduction of better manufacturing practices;
  - the enforcement of present environmental legislation versus the introduction of new legislation

- Finally, the DSS should be applied in present initiatives by the Worldbank for environmental investment projects on the Azov Sea and the Don river. The effectiveness of environmental measures can be evaluated at the level of the water system in general or for specific components of the water system. The results should be used in the priorisation of investments.

Figure 3.1: The operation of the Azov DSS and the consecutive tasks
Green: task is finished
Yellow: task should be run
Red: task cannot be run, other tasks should run first

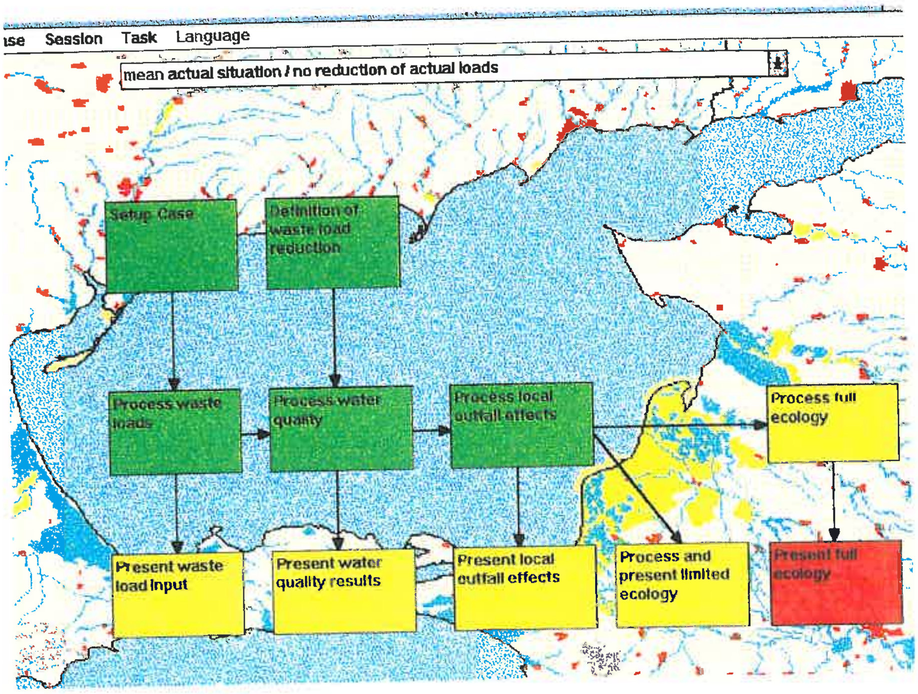
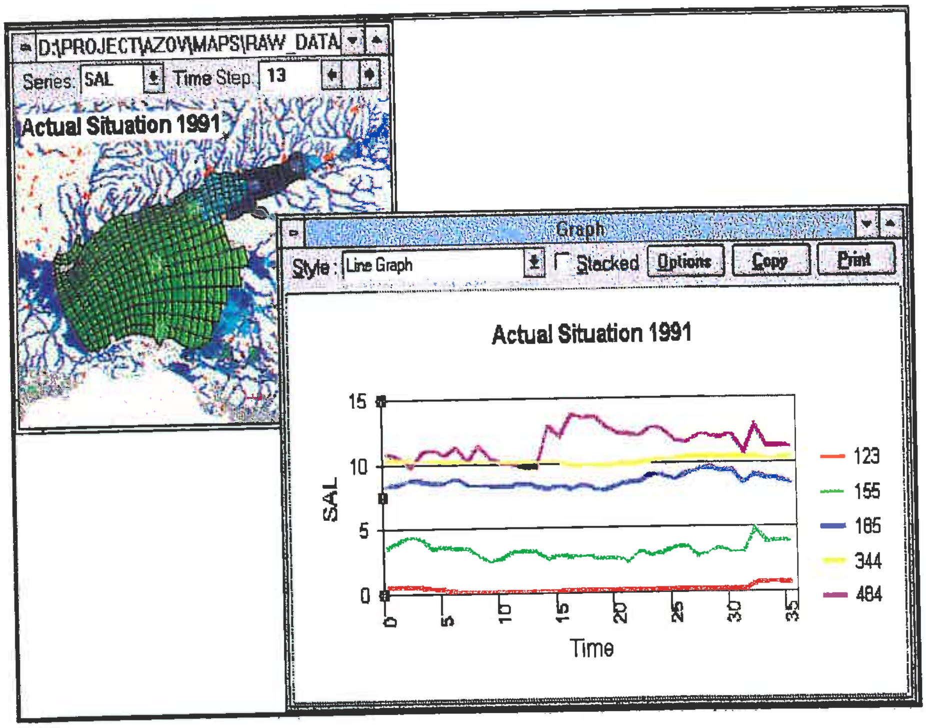


Figure 3.2: Evaluation of results on maps and graphs
(salinity distribution derived from model calculations)



4 Calculation of test cases with the DSS

The Azov Sea environmental problems are related to poor water quality and a reduced fresh water inflow due to the construction of reservoirs and irretrievable water losses in agriculture. Adverse effects can be described in terms of economical losses for fisheries and the touristic sector. Apart from a few significant discharges from the coast direct into the sea as well as operational discharges from sea ship traffic, the Azov Sea environmental problems originate in the river basins. In thinking about solving the environmental problems of the Sea of Azov, one should consider the demands of the sea - quality and quantity of inflowing fresh water- as boundary conditions for human activities in the river basins.

To screen policy options with regard to their potential to solve the Sea of Azov environmental problems, a number of test cases was formulated. A test case can be described as a distinct set of policy goals, for example: an increase of fresh water inflow by twenty per cent, or a reduction of riverine input of contaminants by twenty per cent. Such a test case will demonstrate the effect of a package of specific measures to cut the emissions of contaminants and the increase of the efficiency of human water use. On the other hand, the harmful effects of a further worsening could be illustrated. In this test case a further reduction of fresh water flow and an increase of riverine input of contaminants will be evaluated. The effects of a certain test case can be described by means of calculated concentrations of contaminants, salinity, oxygen content of the sea water column, suitability of habitats for fish species, or suitability of coastal waters for bathing.

4.1 Management strategy: test cases

In close cooperation with the Russian and Ukrainian counterparts the following hydrological scenarios have been formulated:

- Pristine situation (situation before 1952), representing the situation that no reservoirs were in use.
- Actual situation (situation after 1952), representing the situation that reservoirs are in use in the Don and Kuban, regulating the flow regime.
- Actual Flow minus 20%; in this case the average present river discharges have been reduced by 20%, representing increased water use in the catchments. For this case the river concentrations have been increased by 20% in order to keep the same loads by comparison with the actual situation.
- Flow regime in between pristine and actual situation. In this case a flow regime has been generated representing less regulation by the reservoirs. The total discharge has been increased by 20%, mainly caused by a higher spring flood.

Despite the lack of sufficient model input data and field knowledge (especially related to the contribution of atmospheric deposition and sediment-water exchange) calibration results demonstrate a sound comparison with observed phenomena for most parameters, giving confidence in using the modelling framework to estimate the effects of different management scenarios.

4.2 Water quality analysis

4.2.1 Methodology

A stepwise approach has been carried out to develop the integrated water quality modelling system, including:

- Bathymetry and meteorological (wind, temperature, solar radiation, precipitation and evaporation) information.
- Hydrodynamics, described with the hydrodynamic model TRISULA.
- Estimation of pollution loads for which a waste load model (WLM) has been used. Various loads via riverine inflow (Don, Kuban, Protoka, Yeya (Russia) and Berda, Kalmius, Lotovatka, Molochnaya, Obytochnaya (Ukraine)), industrial or municipal waste water discharges (The cities of Taganrog, Temryuk, Primosko-Akhtarsk, Yeisk (Russia) and Berdyansk, Genitschesk, Kertch, Mariupol (Ukraine) and the industrial loads of Azovstal (Ukraine)) and atmospheric deposition have been distinguished.
- Transport of dissolved substances and particulates, pollution transport and water quality processes for which the water quality model DELWAQ is used.
- Local outfall module to calculate water quality concentrations near waste water outfalls.
- Data export for impact analysis.

The list of parameters modelled with the water quality model is based on their political relevance, the extent of threat of the specific substances in the environment, the availability of waste load data and the availability of water quality monitoring data. During the Expert Meeting in Odessa (report 7) the participants drew up a priority list on water quality parameters, including salinity, suspended solids, dissolved oxygen, biological oxygen demand, nutrients, phytoplankton, the heavy metals copper and zinc and mineral oil. All these substances have been dealt within the water quality modelling.

For calibration of the Azov Sea water quality model salinity data of 33 monitoring locations (three times a year), year averaged tabulated data for the Taganrog Bay and the Sea proper for the period 1985 -1991 and maps for some nutrient for 1989 and 1991 (April, July, October) have been used. Scarce data were available for NH4-N, NO3-N, organic-N, tot-N, PO4-P, tot-P, Si and phytoplankton species composition. Out of these data it can be concluded that nutrient concentration levels in the sea proper are lower in comparison with the bay. From '87 there has been a decline in the average total nitrogen content in Taganrog Bay, while no changes in the sea proper are found. At the same time the total phosphorus content seems to increase.

4.2.2 Test cases

Before comparison of the four different management scenario's the waste loads and simulation results of the actual situation scenario are described in more detail. Also some recent trends regarding waste loads are mentioned.

Actual situation

Loads

Suspended solids mainly enter the sea via riverine input from the Don, Kuban, Protoka and Kalmius. The sediment inflow increases during the spring floods and is low during the low water period in summer and fall. The average yearly inflow is about 1.800.000 tonnes per year.

The average total nitrogen load to the sea in the period 1985-1991 is about 60.000 tonnes each year. The most important contributors are the rivers Don, Kuban, Protoka and Kalmius, loads from the municipal waste water treatment plants of Mariupol, Berdyansk and Taganrog, the industrial load from Azov steel and atmospheric deposition.

The municipal and industrial waste loads, as well as atmospheric deposition, are assumed to be constant in time. As the total nitrogen load due to riverine inflow tends to decrease, the relative influence of these sources gains in importance.

The average total phosphorous load is about 4.500 tonnes each year. The main contributors are the river Don (about 50%) and atmospheric deposition (about 32%). Other significant loads are from the Kuban, the Protoka and the Kalmius. Municipal and industrial waste loads are almost neglectable in comparence with the total load, but they still can exert an important local influence. Regarding copper riverine input covers about 93% of the total load, atmospheric deposition about 5%. The Don is by far the most important source (50-70%), although an increase is found in the contribution of the rivers Kuban and Protoka. The total average load is about 100 tonnes each year. Regarding zinc the load via the river Don has sharply decreased since '87, whereas the contribution via the Kuban and the Protoka has increased. Other important loads enter the sea via the industrial waste load of Azov-Steel (about 10%, 3 tn/yr), atmospheric deposition (10%) and the river Kalmius (1-5%). The total average load is about 300 tonnes per year.

The mineral oil load is highly variable and dominated by river Don input. The contribution of the Kalmius is rather high considering its relative small flow. The waste load near Taganrog city is the main non-river point source of mineral oil. The yearly average mineral oil load via river runoff is estimated at 5000 tonnes.

The average BOD5 load is about 80.000 tonnes each year and originates from the river Don. From the considered non-river point sources the Azov-Steel discharge is a significant contributor.

Simulated water quality

The salinity level range from 2 to 4 psu in the Upper Bay to 10 to 11 psu from the Sea proper. The fresh water peak flow during April-May cause a slight decrease in the salinity content of Taganrog Bay in this period. During this period also a high input of suspended solids via river runoff is found. Its influence, however, is restricted to the vicinity of the inflow areas. The development of the total suspended solids concentration is mainly determined by bottom-water exchange and phytoplankton production during the summer period. Erosion areas, mainly caused by wind-induced erosion, are found along the northern shore and in the southern area near the Kuban inflow.

Regarding nutrients, dissolved nitrogen reduces to limiting concentrations for primary production in the summer period. Very high diatom concentrations, representing all silicate using phytoplankton species, are found in the Bay, up to levels of 2.5 mg/l. After a pronounced spring peak the biomass levels decrease slightly, followed by an increase in summer/autumn. In the Bay diatoms start blooming much earlier in the year than is the case in the sea proper (light limitation due to suspended solids). The spatial variability in Taganrog Bay is very high. Near Mariupol the chlorophyll concentrations are dominated by a blue/green-algae bloom (values up to 2.0 mgC/l) after a short predominance of diatoms in spring.

The BOD5 concentrations strongly relate to the phytoplankton biomass. The daily average oxygen concentrations follow the saturation levels quite closely. In the upper part of Taganrog Bay and Yeisk Bay the minimal daily oxygen concentration sometimes drop below 5 mg/l, a concentration considered critical for the ecological functioning of the system. In some shallow eutrophic areas incidentally oxygen concentrations below 2 mg/l are found.

Dissolved heavy metals determining the bio-availability seem to increase in summer/autumn, caused by a decrease of the suspended solid concentrations. In November the concentrations suddenly drop sharply, due to high wind velocities and consequent high suspended solids concentrations.

Mineral oil concentrations are highest in spring, corresponding to the highest discharges on the river Don. The concentrations in the north-western part of Taganrog Bay are influenced by mineral oil loads via river Kalmius and the discharge from Azov-steel. In the sea proper the mineral oil contents almost reduces to zero.

Water Quality Simulation Results for Various Scenarios

Loads

Compared to the present situation nitrogen and phosphorous loads are approximately 6 times higher as before 1952. For BOD5 present loads are almost three times higher. For mineral oil, Cu and Zn no natural loads have been considered. Loads from municipal and industrial discharges have been neglected in the pristine situation and atmospheric deposition is reduced to a natural background concentration. Waste loads in the 20% reduction scenario and in the intermediate case are assumed at the same level as present.

Simulated water quality

In the pristine situation a total amount of fresh water input is about 41 km^3 per year. The salinity in the Upper Bay drops to almost zero psu in spring, due to the higher spring flood of the Don river.

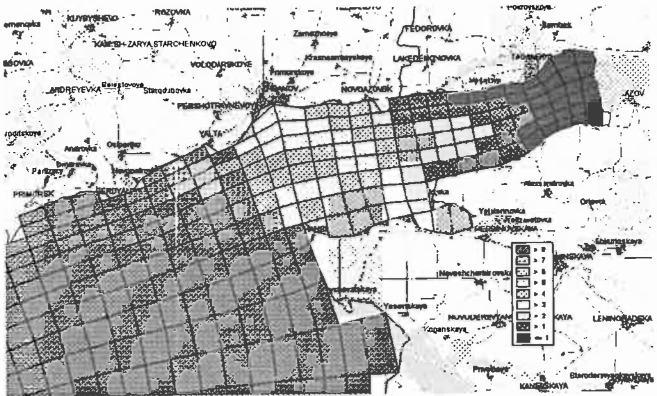


Figure 4.2a: Model calculations for Taganrog Bay in actual situation: Salinity in g/l

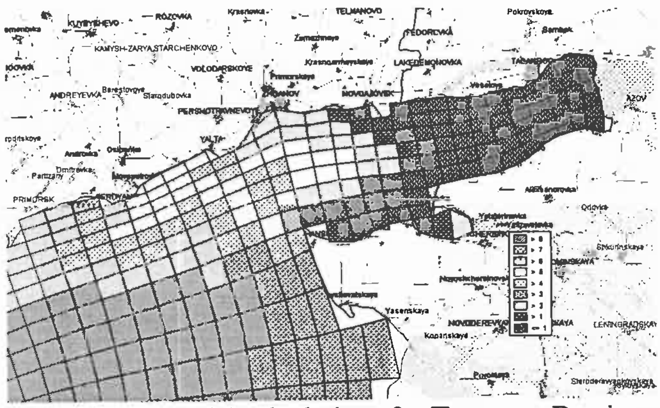


Figure 4.2b: Model calculations for Taganrog Bay in pristine situation: Salinity in g/l

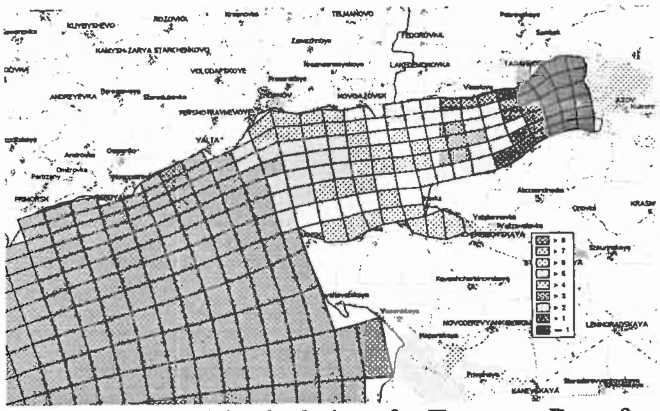


Figure 4.2c: Model calculations for Taganrog Bay after 20% flow reduction: Salinity in g/l

Figure 4.2d: Model calculations for Taganrog Bay in intermediate situation: Salinity in g/l

In the average present situation, when the rivers are more regulated and about 31 km^3 per year enters the sea via riverine inflow, the salinity in the upper Bay increases to some 2 to 3 psu. Due to dam construction the runoff is much more smoothened causing less seasonal variation compared to the pristine situation. In case of extra water use, i.e. 20% reduction scenario, in which an amount 24 km^3 fresh water enters the sea yearly, the average salinity level in the upper Bay increases to approximately 4 psu due to a greater intrusion from the sea.

In the sea proper much smaller variation is found. On average the salinity reaches some 10 psu for the actual and intermediate situation, 9 psu for the pristine situation and 11 psu for the 20% reduction scenario. Due to the higher river spring floods in the pristine situation hardly any water from the Black Sea enters the sea in this period. In summer and fall, with extreme low river runoff, more Black Sea water (salt) will enter the sea in comparison with the present situation. Further reduction of riverine input also causes an increase in salt water intrusion from the Black Sea.

For the nutrients some concentration differences are found for the post 1952 situation. Impact of minor N and P changes (respectively 0.4 mgN/l and 0.1 mgP/l in the Upper Bay may lead to at maximum some 25 ug/l difference in chlorophyll-a. Some effect can be seen on the occurrence of the spring bloom. Present levels are approximately 5 times as high as found for the pristine situation. For the sea proper the present chlorophyll-a levels are almost twice as high compared to the pristine situation. The lower concentrations seem to be caused by a decreased nitrogen availability. In figure 4.3a-d maximum simulated chlorophyll-a concentration levels for four different scenario's are presented.

Nowadays the minimum daily oxygen concentrations are 2 to 3 mg/l lower in summer than found in the pristine situation, where the concentrations never seem to drop below 5 mg/l.

Due to the absence of inputs for mineral oil, copper and zinc in the pristine situation concentration differences in the Bay are great, while in the sea proper which is far less influenced by land-based sources (very low levels) the differences are much less.

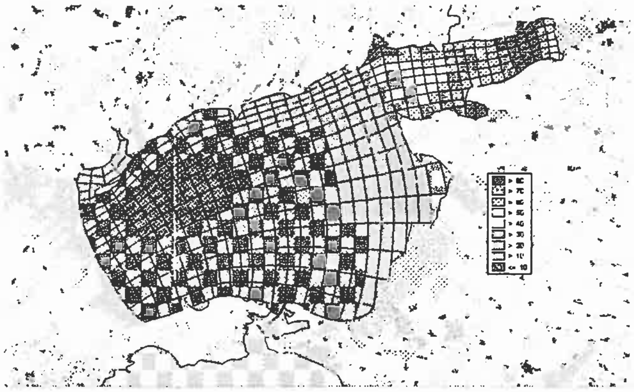


Figure 4.3a: Model calculations for actual situation: Chlorophyll concentrations in g/l

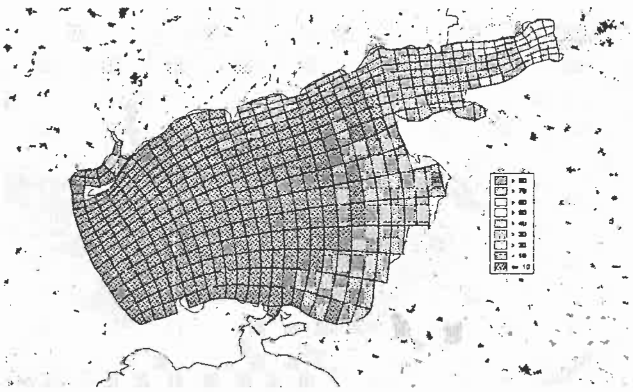


Figure 4.3b: Model calculations for pristine situation: chlorophyll concentrations in ug/l

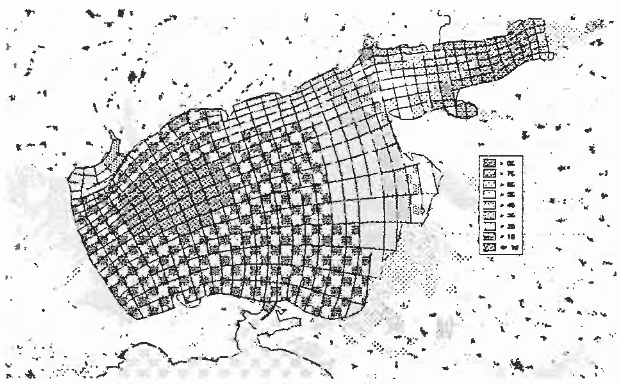


Figure 4.3.c: Model calculations after 20% flow reduction: chlorophyll concentrations in ug/l

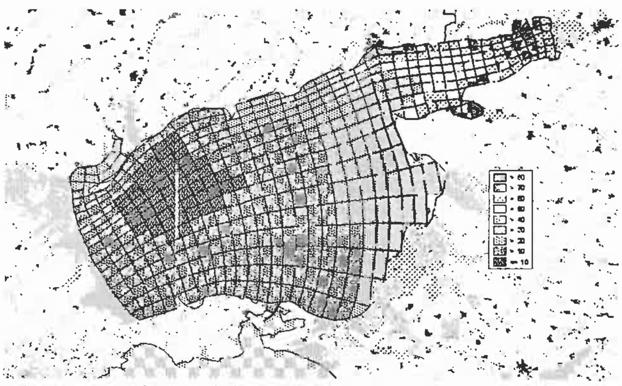


Figure 4.3.d: Model calculations in intermediate case: chlorophyll concentrations in ug/l

4.3 Summary of the water quality results

Based on the results some general conclusions regarding water quality can be made:

- The present situation clearly demonstrates a severe degree of eutrophication in the Upper Bay. Based upon long term simulations the situation seems to get worse in time, indicating a significant accumulation of pollutants in the system. In the ecological report a further discussion on comparison with standards and objectives is provided.
- The simulation results show a severe underestimation of contamination of micropollutants and mineral oil in comparison with the available field data. Most probably this is caused by unawareness of many pollution sources and the unknown influence of sediment-water exchange (adsorption) due to lack of suspended solid data.
- Although many of the characteristics of the Sea of Azov have been revealed, still uncertainties do exist in the importance of specific physical, chemical and/or biological processes. Despite the present lack of data and field knowledge to fill in these gaps in knowledge (loads, atmospheric deposition, sediment-water exchange, present sediment concentrations, etc.), the calibration results as discussed compare reasonably well with available field data, giving confidence in the application of the model to analyze the effects of different management scenarios on water quality and ecology. The strength of the approach followed is that the state-of-the-art-modelling tools as used have been successfully applied to many similar water systems.

4.4 Effects on ecology and tourism

For environmental management, the effect of decisions on water users is more important than the direct effects on water quality. Central objective of the ecological analysis is to gain an understanding of the present ecological status of the Sea of Azov, its natural functions and the relationships between physico-chemical characteristics and the impact upon the life-cycles of key-species within the study area. The careful selection of key-species is central within this task, based on the assumption that the selected species represent the status of the ecosystem as a whole. On the basis of hydrodynamic and waterquality models and the identification of ecological requirements and toxicological quality thresholds for each species, the present and future quality of the ecosystem and its habitats for key-species are quantified.

4.4.1 Methodology

A number of key-species are identified that are considered characteristic for the Azov Sea ecosystem. Species selection is based upon either the commercial value of the species, the influence of its functioning on the ecosystem, its geographical distribution and/or its sensitivity to changing environmental conditions. For each key-species important habitats in relation to its life-cycle were identified as much as possible in the data collection phase of the project. Furthermore a description of the ecology of the species was realized. This covers (a) a description of the lifecycle and physiology of the species, (b) a description of the requirements of the species for sustainable well-being of the population expressed as thresholds for optimal and impeded suitability of habitats per parameter, (c) a quantification of production and consumption rates and (d) a quantification of carrying capacity for the study area in a non disturbed situation. For Algae and Zooplankton species, the total area is considered as a potential habitat.

For Zoobenthos species and fish species, habitats are defined based upon recent data on distribution of each species. For Zoobenthos the characteristics of habitats are not further defined ("all-functions"). For fish, "spawning", "feeding" and "wintering" habitats are defined if possible.

The evaluation of habitat suitability within the scope of this study is based on standard Habitat Evaluation Procedure (HEP) as described in US Fish and Wildlife Service (1980). In this study ecotopes (comparable with cover types in HEP), are not pre-defined in the study area. Instead, species habitats are identified and located in the study area (therefore including all ecotopes that provide habitat to the species). On the basis of distribution of habitats, identification of species habitat requirements and determination of suitability defining factors such as the hydrodynamics, morphology and quality of the water system, a Habitat Suitability Index (HSI) is derived. Habitat requirements are derived from field observations and life history studies. The HSI is expressed as an index rating between 0.0 and 1.0, expressing the suitability of for each environmental factor in the habitat. For toxicants these thresholds are defined by chronic NOEC-values and LC50-values. The overall habitat suitability is determined by combination of separate indices per environmental factor.
The potential carrying capacity (PCC) of the habitat for a species is derived from the overall HSI in combination with the habitat area (A), expressed in habitat units (HU) and a given actual carrying capacity (CC) of the species (Duel et al., 1995).

$$pHSI = Function \{ field\ value, habitat\ requirements \}$$
$$HSI = minimum\ (pHSI_1, pHSI_2, pHSI_{...}, pHSI_n)$$
$$HU = HSI * A$$
$$PCC = (HU_c / HU_a) * CC$$

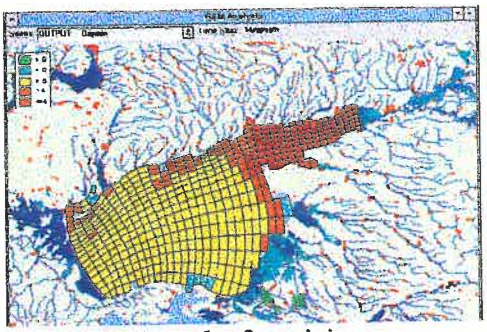
where

HSI = habitat suitability index
$pHSI_1$ = partial HSI for environmental factor 1
HU = habitat units (ha)
HU_c= habitat units of a case
HU_a= habitat units of the actual situation
A = habitat area (ha)
PCC = potential carrying capacity (biomass or catch)
CC = carrying capacity of the actual situation

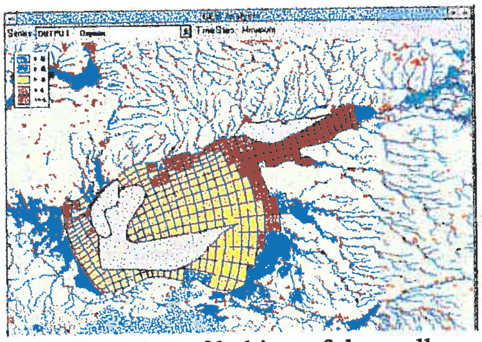
For each species, actual averaged biomasses (invertebrates) or catches (fish species) were gathered and are used as a basis to estimate potential biomass or catch for case's. Therefore, the habitat suitability index (HSI) calculated for each species in the present situation ("actual" case) is used to extrapolate the potential optimal biomass or catch for an ideal situation of HSI=1.0. It is assumed that biomass and catch equals zero if HSI=0.0. For fish species, biomass and catch are related to suitability of different habitats. It is assumed that the minimum HSI-value over those relevant habitats defines the maximum potential biomass or catch. The degree of suitability is calculated for each parameter-species combination by comparing model results with given thresholds. In order to enable analysis of policy options and measures, the selected parameters should be available as output from the models encorporated within the DSS. Based on these parameters, promising policy options and measures can be assessed, that could improve the suitability of habitats and therefore could improve the biomass and production of species.

Analysis of results for all other case's will be related to the results for case 1, the actual situation. It is assumed that given habitats of species can improve or deteriorate in quality (expressed as an increased or reduced HSI value) but cannot change it present location and area. This is assumption is based on the hypothesis that unknown and therefore not modelled parameters will be relevant to present distribution of habitats.

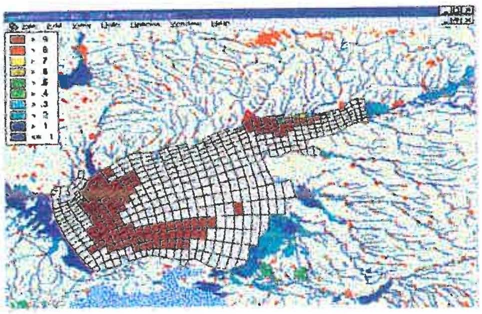
Figure 4.4: Example of comparison of water quality model results to habitat requirements.



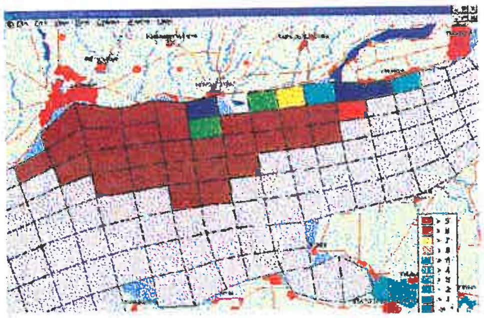
4.4a: Model results for minimum oxygen concentrations during spring and summer



4.4b: Location of habitat of the mollusc *Cerastoderma lamarckii*



4.4c: Habitat suitability of *Cerastoderma* for minimum oxygen concentration



4.4d: Habitat suitability of *Cerastoderma* for minimum oxygen concentration between Mariupol and Taganrog

4.4.2 Species selection

The following species were selected for further assessment:

Phytoplankton
- *Sceletonema costatum*
- *Microcystis pulverea*

Zooplankton
- *Oithona nana*
- *Calanipeda aqua-dulcis*
- *Mnemiopsis leidyi*

These species were selected for the availability of optimum salinity and temperature ranges. The species represent typical marine/brackish and typical fresh water types of both micro-algae and zooplankton. In principle, the whole sea area is available for these species. Salinity and temperature gradients will decide where the most suitable areas will be located within the sea of Azov. Mnemiopsis is included for its major impact on the functioning of the present ecosystem.

Zoobenthos
- *Balanus improvisus*
- *Cerastoderma lamarci*
- *Mytilaster lineatus*
- *Nereis succinea*

The selected species constitute a large percentage of total biomass of zoobenthos in the sea of Azov. Furthermore, a distribution between the species on the basis of salinity requirements is realized with this choice. In principle, actual distributions are approximately known and will be used for analysis. Salinity, temperature and oxygen gradients will decide where the most suitable areas will be located within the present habitats of these species.

Fish species

- Fluvial anadromous species: Bream (*Abramis brama*), Roach (*Rutilus r.*), Pike-perch (*Stizostedion l.*)
- Migratory: Sturgeon, *Acipenser stellatus, A. guldenstadti*
- Marine fish: Turbot (*Scophtalmus m.), Anchovy (Engraulis e.), Mugil, Kilka (Clupeonella sp.), Gobius sp.*

For each species separate maps on spawning-, feeding and wintering areas are available. For Sturgeon, the distribution of the juvenile stage was identified because this lifestage is much more sensitive to elevated salinity ranges then the adult stage.

Recreation

In addition to the key-species listed above, information is assessed on the quality of beaches surrounding the Sea of Azov for recreational purposes. Therefore, accepted standards for sanitary hygiene are used to evaluate the quality of seawater near beaches. For each parameter a block-function is used, resulting in 1.0 HSI values if none of the parameters is above or equal to its standard (based on average + 2 x Standard Deviation, 15 April-end of august). If any parameter is above the standard within the given time-period, the HSI value will be 0.0. In the latter case the total length of the beach adjoining the gridcell violating the standard will be designated unfit for recreational purposes. This method could be interpreted as a worst case approach. In this first analysis no specific high intensity or low intensity beaches are distinguished. The local water quality was checked for its compliance with locally accepted standards. In this study the accepted Russian water quality standards for sanitary hygiene and commercial fisheries are used.

4.4.3 Results of the ecologic analysis

Results of the assessment are based upon the output of hydrodynamic and waterquality models for four modelled cases. The following cases are studied:

1 Actual situation 1991 ("actual")
2 Worst case with 20% further reduction of river inflow ("20%rrf")
3 Best case with natural river flow ("pristine")
4 Intermediate case with 20% increased river flow in spring ("intermed")

On the basis of the description of species requirements, the crucial spawning and larval feeding period (approx. the second week of April to end of August for most key species) was used to subselect data from the model dataset. The following parameters are used in the ecological assessment:

- Salinity
- Temperature
- Oxygen
- Dissolved Copper[2]
- Dissolved Zinc[2]
- Total Oils[2]

In order to assess the suitability for recreation the following additional parameters were used and checked against accepted standards for sanitary hygiene:

- Suspended Solids
- Ammonium
- Nitrate

[1] - absolute night-time minimum is calculated and used
[2] - model results underestimate concentrations due to lack of input data from all point sources.

In table 4.1 an overview is given on available field data on the distribution of species habitats, present biomass and present catch:

Table 4.1

Species	*Habitat function*	*Biomass/catch*	*Quantity*
Microcystis	ALL_FUNCTIONS	est. production	500000 ton
Scenedesmus	ALL_FUNCTIONS	est. production	25000000ton
Calanipeda	ALL_FUNCTIONS	avg-biomass 90-94	5800 ton
Heterocope	ALL_FUNCTIONS	avg-biomass 90-94	1000 ton
Balanus larvae	ALL_FUNCTIONS	avg-biomass 90-94	1000 ton
Acartia	ALL_FUNCTIONS	avg-biomass 90-94	300000 ton
Oithona	ALL_FUNCTIONS	avg-biomass 90-94	1000 ton
Mnemiopsis	ALL_FUNCTIONS	avg-biomass 90-94	3000000 ton
Cerastoderma	ALL_FUNCTIONS	avg-biomass 90-94	4500000 ton
Nereis	ALL_FUNCTIONS	avg-biomass 90-94	500000 ton
Balanus	ALL_FUNCTIONS	avg-biomass 90-94	1000000 ton
Mytilaster	ALL_FUNCTIONS	avg-biomass 90-94	3500000 ton
Humans	RECREATION	beach-length	1000 km
Humans	ALL_FUNCTIONS	area-total	50000 km2
Anchovy	FEEDING	catch90-94	15000 ton/yr
Anchovy	BREED_SPAWN	catch90-94	15000 ton/yr
Bream	WINTERING	catch90-94	1500 ton/yr
Bream	FEEDING	catch90-94	1500 ton/yr
Bream	BREED_SPAWN	catch90-94	1500 ton/
Goby-sp	WINTERING	catch90-94	250 ton/yr
Goby-sp	FEEDING	catch90-94	250 ton/yr
Goby-sp	BREED_SPAWN	catch90-94	250 ton/yr
Kilka	WINTERING	catch90-94	2000 ton/yr
Kilka	FEEDING	catch90-94	2000 ton/yr
Kilka	BREED_SPAWN	catch90-94	2000 ton/yr
Mugil	WINTERING	catch90-94	435 ton/yr
Mugil	FEEDING	catch90-94	435 ton/yr
Pike-perch	WINTERING	catch90-94	1000 ton/yr
Pike-perch	FEEDING	catch90-94	1000 ton/yr
Pike-perch	BREED_SPAWN	catch90-94	1000 ton/yr
Roach	WINTERING	catch90-94	200 ton/yr
Roach	FEEDING	catch90-94	200 ton/yr
Roach	BREED_SPAWN	catch90-94	200ton/yr
R -Sturgeon	WINTERING	catch90-94	750 ton/yr
R -Sturgeon	FEEDING	catch90-94	750 ton/yr
S-Sturgeon	WINTERING	catch90-94	300 ton/yr
S-Sturgeon	FEEDING	catch90-94	300 ton/yr
Turbot	WINTERING	catch90-94	300 ton/yr
Turbot	FEEDING	catch90-94	300 ton/yr
Turbot	BREED_SPAWN	catch90-94	300 ton/yr

HSI's calculated per theme

For each combination of a species and its habitats (themes, as listed above) a HSI is calculated. The HSI is the aggregation of indices for individual parameters over all gridcells within a theme. Depending on the habitat requirements of species, changes in the environment will improve or deteriorate the suitability of its habitat. Given a set of environmental conditions, described within a case, some species will benefit, others will be negatively impacted. From the four cases studied, "20%rrf" will tend to increase salinity by reduced river flow (when compared to actual). The cases "Intermed" and "Pristine" will result in a reduced salinity for large parts of the study area by increased river flow. This reasoning clearly indicates that impacts to typical fresh or marine species may be expected if salinity is the most limiting parameter. Furthermore, it should be noted that the distribution of the habitats for each theme is fixed to the present distribution.

Table 4.2

HSI-values per case per theme					
Theme	Group	Actual	20%rrf	Intermed	Pristine
Sceletonema costatum_A	Algae	0.55	0.66	0.36	0.07
Microcystis aeruginosa_A	Algae				
Calanipeda acua-dulcis_A	Zooplankton	0.37	0.23	0.41	0.61
Heterocope caspia_A	Zooplankton	0.06	0.01	0.11	0.41
Balanus larvae_A	Zooplankton	0.94	0.96	0.93	0.90
Acartia (Azov Sea)_A	Zooplankton	0.80	0.75	0.80	0.89
Oithona nana_A	Zooplankton	0.38	0.75	0.14	0.01
Mnemiopsis leidyi_A	Zooplankton	0.80	0.80	0.80	0.86
Cerastoderma l._A	Zoobenthos	0.82	0.81	0.82	0.81
Nereis succinea_A	Zoobenthos	0.82	0.81	0.82	0.80
Balanus improvisus_A	Zoobenthos	0.71	0.90	0.61	0.26
Mytilaster lineatus_A	Zoobenthos	0.60	0.90	0.44	0.08
Engraulis encrasicolus_F	Fish species	0.20	0.20	0.20	0.19
Engraulis encrasicolus_B	Fish species	0.20	0.20	0.20	0.19
Abramis brama_W	Fish species	0.27	0.21	0.28	0.90
Abramis brama_F	Fish species	0.27	0.21	0.28	0.90
Abramis brama_B	Fish species				
Gobius niger_W	Fish species	0.75	0.86	0.72	0.62
Gobius niger_F	Fish species	0.73	0.81	0.70	0.60
Gobius niger_B	Fish species	0.68	0.72	0.64	0.53
Clupeonella sp._W	Fish species	0.26	0.25	0.28	0.30
Clupeonella sp._F	Fish species	0.19	0.19	0.19	0.19
Clupeonella sp._B	Fish species	0.15	0.13	0.15	0.02
Mugil so-iuy_W	Fish species				
Mugil so-iuy_F	Fish species	0.23	0.29	0.20	0.10
Stizostedion lucioperca_W	Fish species	0.41	0.37	0.43	0.90
Stizostedion lucioperca_F	Fish species	0.42	0.38	0.44	0.90
Stizostedion lucioperca_B	Fish species	0.64	0.51	0.68	0.92
Rutilus rutilus_W	Fish species	0.20	0.18	0.22	0.85
Rutilus rutilus_F	Fish species	0.20	0.18	0.22	0.85
Rutilus rutilus_B	Fish species	0.61	0.70	0.68	0.80
Acipenser guldenstadtii_W	Fish species	0.48	0.37	0.52	0.62
Acipenser guldenstadtii_F	Fish species	0.43	0.35	0.45	0.68
Acipenser stellatus_W	Fish species	0.47	0.36	0.51	0.61
Acipenser stellatus_F	Fish species	0.43	0.35	0.45	0.68
Scopthalmus m._W	Fish species	0.14	0.94	0.02	0.01
Scopthalmus m._F	Fish species	0.14	0.72	0.06	0.03
Scopthalmus m._B	Fish species	0.24	0.82	0.16	0.00
_A - All Functions	_F - Feeding	_N - Nature			
W - Wintering	_B - Breeding/Spawning	_R - Recreation			

Due to lack of ecological data some themes could not be calculated within the scope of this study. From the table it becomes clear that for typical marine species such as (in **bold** case) *Oithona*, *Mytilaster*, *Scopthalmus* (Turbot) habitat suitability increases drastically for the reduced river flow case. On the other hand, with increasing river flow, the suitability is reduced strongly. For fresh water species such as *Calanipeda*, *Rutilus* (Roach), *Abramis* (Bream), the opposite result is shown (underlined). Furthermore, some zooplankton and zoobenthos species such as *Acartia, Mnemiopsis, Cerastoderma* and *Nereis* are not strongly affected by any changes in environmental conditions between cases.

Calculation of potential biomass and catch for all cases

On the basis of HSI values presented above, an optimum biomass (or catch) for each theme is calculated. Field data on actual biomass and catch are used as a reference for HSI's calculated for the actual situation. The optimum biomass is related to the actual biomass on the basis of the ratio between the HSI for the actual situation and HSI=1.0. All cases can now be assessed. The (assumed linear) relation between actual HSI, actual biomass and optimum biomass is defined is used to relate any case HSI's to any case biomass. In the following table potential biomasses (and catches) are presented that were derived on the basis of this assumption.

Table 4.3

Total potential biomass or catch per theme						
Theme	Actual=field	20%rrf	Intermed	Pristine	Optimum	Unit
Sceletonema costatum_A	5000000	5973597	3296333	669717	9090909	ton/yr
Microcystis aeruginosa_A	25000000					ton/yr
Calanipeda aqua-dulcis_A	5800	3629	6370	9621	15676	ton
Heterocope caspia_A	1000	218	1909	6873	16667	ton
Balanus larvae_A	1000	1021	992	954	1064	ton
Acartia (Azov Sea)_A	300000	283050	300531	333556	375000	ton
Oithona nana_A	1000	1977	365	21	2632	ton
Mnemiopsis leidyi_A	3000000	3013584	3005919	3229454	3750000	ton
Cerastoderma l._A	4500000	4464047	4485699	4430187	5487805	ton
Nereis succinea_A	500000	494525	499646	489773	609756	ton
Balanus improvisus_A	1000000	1265320	852385	370433	1408451	ton
Mytilaster lineatus_A	3500000	5238810	2550326	452247	5833333	ton
Engraulis encrasicolus_F	15000	14828	14872	14478	75000	ton/yr
Engraulis encrasicolus_B	15000	14828	14872	14478	75000	ton/yr
Abramis brama_W	1500	1140	1555	5006	5556	ton/yr
Abramis brama_F	1500	1140	1555	5006	5556	ton/yr
Abramis brama_B	1500					ton/yr
Gobius niger_W	250	285	239	208	333	ton/yr
Gobius niger_F	250	278	238	205	342	ton/yr
Gobius niger_B	250	266	237	195	368	ton/yr
Clupeonella sp._W	2000	1939	2120	2274	7692	ton/yr
Clupeonella sp._F	2000	1998	2014	1967	10526	ton/yr
Clupeonella sp._B	2000	1789	1948	306	13333	ton/yr
Mugil so-iuy_W	435					ton/yr
Mugil so-iuy_F	435	539	369	194	1891	ton/yr
Stizostedion lucioperca_W	1000	912	1039	2190	2439	ton/yr
Stizostedion lucioperca_F	1000	908	1043	2138	2381	ton/yr
Stizostedion lucioperca_B	1000	802	1055	1430	1563	ton/yr
Rutilus rutilus_W	200	185	222	849	1000	ton/yr
Rutilus rutilus_F	200	185	222	849	1000	ton/yr
Rutilus rutilus_B	200	230	224	262	328	ton/yr
Acipenser guldenstadtii_W	750	571	806	966	1563	ton/yr
Acipenser guldenstadtii_F	750	614	792	1182	1744	ton/yr
Acipenser stellatus_W	300	228	325	391	638	ton/yr
Acipenser stellatus_F	300	246	317	473	698	ton/yr
Scopthalmus m._W	300	2013	48	30	2143	ton/yr
Scopthalmus m._F	300	1550	134	73	2143	ton/yr
Scopthalmus m._B	300	1020	198	0	1250	ton/yr

_A - All Functions
_W - Wintering
_F - Feeding
_B - Breeding/Spawning
_N - Nature
_R - Recreation

From the table it can be seen that biomass or catch is calculated for each theme separately. However, themes for the same species are essentially interrelated habitats during the life cycle of that species. This means that the habitat with the worst suitability will determine the maximum biomass or catch of that species. For instance, the three given Clupeonella habitats (wintering, feeding and breeding) result in respectively 2274, 1976 and 306 ton/yr catch for case "Intermed". Therefore 306 ton/yr is used as the maximum catch to be expected for this case. In the case "Pristine", the situation is reversed: 7692, 10526, 13333. Here suitability of the wintering habitat seems to be most limiting.

4.4.4 Analysis of impact of cases per species group

In the next paragraphs a short overview of results per species group is given. Results for each case relative to the optimum biomass are presented in the radar plot figure within this paragraph. For fish exclusively, a figure is added giving the potential catch-change per species relative to the actual situation.

Phytoplankton

Only results for *Sceletonema* are available. It is clear that this species benefits from further reduction of the river inflow. A very strong decline is expected for natural conditions, "pristine" case. On the basis of given requirements, salinity is limiting the habitat suitability of the species. Production of *Sceletonema* is in the actual situation <20% of *Microcystis*-production. It is expected that this ratio will be reduced further at decreasing salinities. However, total primary production is not expected to be reduced when salinity is decreased. In the latter case, more river inflow will result in more nutrients available for production.

Zooplankton

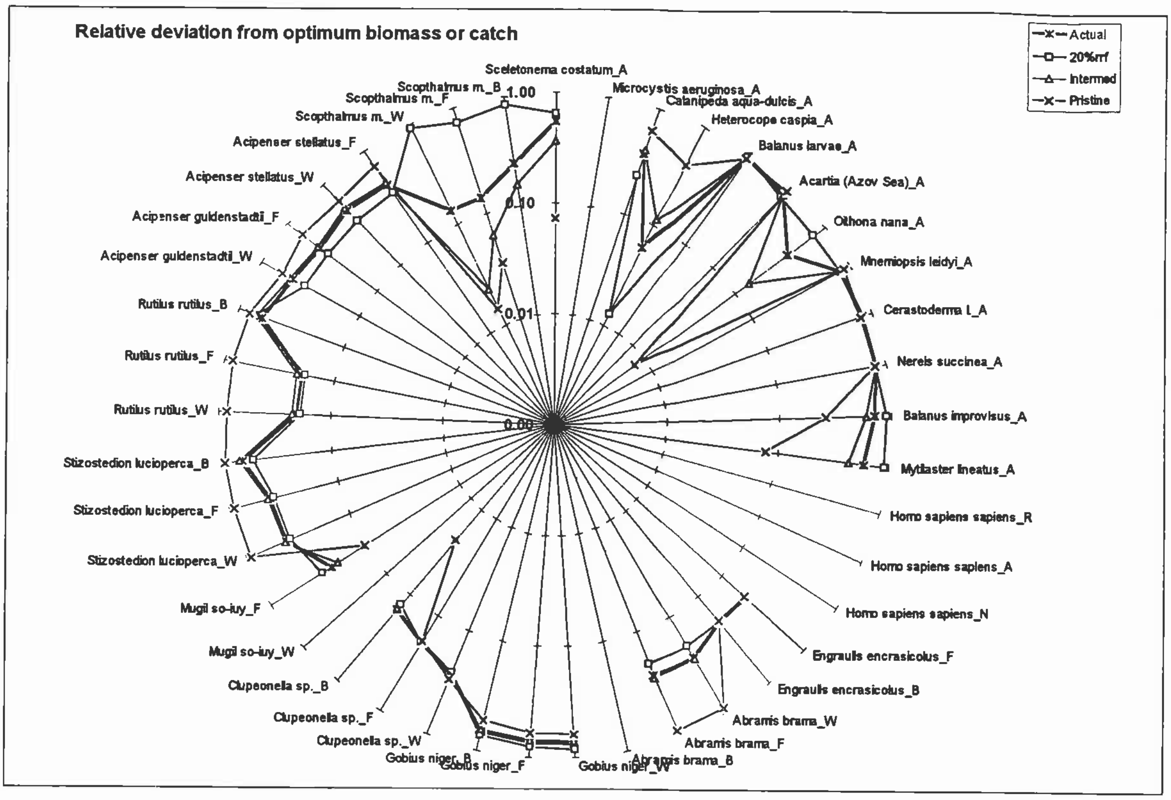
Oithona nana is affected strongly by both increasing or decreasing salinity. However its production is small when compared to *Acartia*. The latter species seem not be affected strongly within the available cases. The same accounts for *Balanus* larvae and *Mnemiopsis*. Both for *Calanipeda* as for *Heterocope* habitat suitability improves with decreasing salinity. For *Acartia* and *Mnemiopsis* minimum night time oxygen concentration is now the limiting factor on habitat suitability.

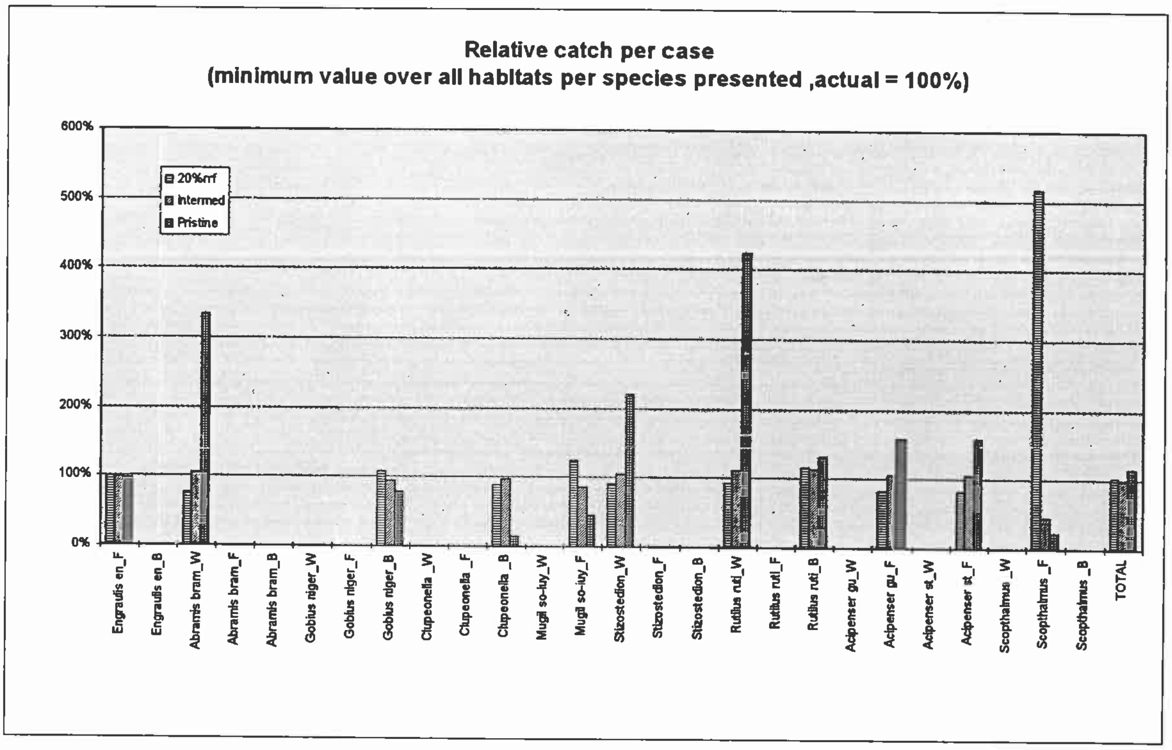
Zoobenthos

Both *Cerastoderma* and *Nereis* seem not to be affected by changing of salinities between cases. *Balanus* is negatively affected by decreasing salinity. *Mytilaster* shows an even stronger decline. Present production is mainly realized by both *Cerastoderma* and *Mytilaster*. Total benthos biomass will therefore decline when these four species are totalled. However, it is to be expected that fresh water species not included in this list will compensate this decline at least partly. For these species oxygen is not a major limiting factor for its habitat suitability.

Fish

For *Abramis, Rutilus* and *Stizostedion* habitat suitability is increasing strongly with decreasing salinity. *Engraulis, Gobius sp.* and Clupeonella are not strongly affected within the four cases studied. *Mugil* and *Scophtalmus* encounter worse habitat suitability with decreasing salinity. For *Acipenser* the habitat suitability increases, but relatively moderate (Feeding: Actual 0.43 - Pristine 0.68). Note that *Acipenser* breeding habitat is not enclosed within the study area. Therefore increasing feeding and wintering habitat suitability will not increase catch if breeding habitat suitability is not affected. The next figure shows all results as deviation from optimum biomass.


Relative deviation from optimum biomass or catch
Actual
20%rrf
Intermed
Pristine


Relative catch per case
(minimum value over all habitats per species presented ,actual = 100%)
20%rrf
Intermed
Pristine

4.4.5 Impact of modelled parameters

From the results of the ecological assessment it is concluded that salinity is the factor most strongly affecting the habitat suitability for most species. However, for species less sensitive to salinity changes, minimum oxygen concentrations are the next important factor. However, by using the extreme 2 x standard deviation value of the data-distribution this concentration will occur approximately 5 days out of 100. This value could be too strict, but the use of this limit can be interpreted as a worst case situation.

Considering micro-pollutants, oil pollution resulted in parameter indices of minimal 0.72 (Mugil-wintering) to 0.80-0.89 for all other fish habitats. Both copper and zinc did not affect the habitat suitability of any species. From the results of the water quality modelling (not reported here) it is concluded that ambient concentrations of all pollutants are underestimated possibly a factor 2 due to an at present incomplete set of loading data. Therefore, it may be expected that actual pollutant levels are affecting the quality of habitats more severe than can be concluded from the results of this study.

4.4.6 Analysis of the impact on recreation

For the indicated recreational areas and general functions, the following overall parameter indices were calculated:

Recreation	**Actual**	**20%rrf**	**Intermed**	**Pristine**
Oils	1.0	0.99	0.99	1.00
Copper	0.92	0.92	0.96	0.98
Zinc	0.66	0.67	0.77	0.78
BOD5	0.39	0.40	0.62	1.0
Nitrate	1.0	1.0	1.0	1.0
Ammonium	1.0	1.0	1.0	1.0
Oxygen	0.99	1.0	1.0	1.0
SuspSol	0.40	0.41	0.55	0.61
HSI	**0.39**	**0.40**	**0.55**	**0.61**
Beach length	390 km	400km	550 km	610km
(Optimum length estimation= 1000km)				

General functions	**Actual**	**20%rrf**	**Intermed**	**Pristine**
Oils	1.0	1.0	1.00	0.99
Copper	0.95	0.94	0.92	0.99
Zinc	0.77	0.78	0.65	0.84
BOD5	0.63	0.65	0.40	1.0
Nitrate	1.0	1.0	1.0	1.0
Ammonium	1.0	1.0	1.0	1.0
Oxygen	1.0	1.0	1.0	1.0
SuspSol	0.64	0.68	0.67	0.54
HSI	**0.63**	**0.65**	**0.40**	**0.54**
Area (km2)	31500	32500	20000	27500
(Optimum area estimated= 50000km2)				

In order to calculate indices per parameter, nationally accepted standards for sanitary hygiene were used. In addition, exceedance of the given limit for any parameter results in complete unsuitability for human use. In this case no linear interpolation method was used. This approach will lead to a conservative quantification of suitable beach length or area. Furthermore, any exceedance within the selected time-period (april-august) will lead to unsuitability for the complete period. From the results it is shown that for beach quality is limited by Suspended Solids and BOD5. For the general functions (covering the whole study area), BOD5 is the most limiting factor. Impacted beaches are located mostly within the neighbourhood of local outfalls. The changes between the available case are limited.

4.4.7 Discussion of results

Species selection and data collection

The results of this ecological impact assessment are based on the collection of both descriptive and quantitative data for the selected key-species. It was chosen to select as much as possible distribution data and biomass data for the actual situation. From the start of the project, a reduction of a larger group of key-species to the final selection has taken place in order to enable a timely conclusion of the data collection phase. Furthermore, the collection of toxicological data has been impossible to complete for all species, due to the lack of species specific data. Therefore, assumption of non-specific toxicity data that could be applied to a complete species group was necessary (zooplankton and fish species). In future these assumptions should be reconsidered if additional toxicity data are made available. When looking to distribution data, a rough distinction between wintering, feeding and spawning areas was made. It is assumed that no changes in distribution occur in future under different hydrodynamic regimes as identified in the four cases that are studied. In effect, this will probably not be the case. Furthermore, only one time-period is selected and applied for all habitats for all species. This is a further simplification of the real situation. For some species (such as *Acipenser*/Sturgeon) a part of its habitat is not included in the study area. This will mean that results derived for this species should be interpreted with care. Improvement of habitat within the study area not necessarily implies improvement of habitats outside of the study area.

Choice of parameters

The present selection of parameters within this study is based on the limited availability of parameters from the hydrodynamic and water quality modelling. In reality, many more parameters influence the suitability of habitats to species. For instance, it is well known that temperature ranges are of relevance to species. Furthermore, additional contaminants such as pesticides and PAH's will induce extra stress to species. For the latter substances, no data were available to justify their modelling. For other included contaminants loading data are incomplete, resulting in underestimation of ambient concentrations. At present levels, impact of oil is already seen. It is suggested therefore, to introduce a more complete set of loading data and realistic temperature modelling as a priority within future stages in this project.

Local outfalls and recreational areas

The impact of local outfalls to the quality of habitats seems to be limited due to the limited area of impact (1-10km2) in relation to large habitat areas (mostly > 1000km2). For recreational areas however, impact are more severe. These areas are mostly located near centres of population, that also contain the local outfalls. At present, given the extension of recreational areas, 61% of the beaches shows an exceedance of limits within the considered time period mostly caused by local outfalls. This impact should be studied in more detail, introducing detailed spatial information on beach length and recreational intensity.

Ecological impact of modelled cases

From the results it is concluded that significant impact of the four cases might be expected to the habitat quality for a number of species. Within the limitations and assumptions of the approach, this results in increased or decreased biomass or catch. Going from the actual situation to a less saline pristine situation, catch of fresh water species such as *Abramis*/Bream, *Rutilus*/Roach and *Stizostedion*/Pike-perch will increase up to 400% of the actual situation. Acipenser/Sturgeon will profit only slightly (60%). The intermediate case that was studied is not resulting in significant improvements for these species. On the other hand, for marine species *Clupeonella*/Kilka and *Scophtalmus*/Turbot, the freshening of the system leads to strong decrease of catch. Turbot seems to be sensitive to even small decreases in salinity. Its catch is reduced 50% for the intermediate case ("Intermed").

On the other hand, marine species profit if the river flow is further reduced (case "20%rrf"). Catch of turbot is even increased to 500% of the actual situation. For all other species this scenario results in slight positive or negative effects (approx. 20%). Judging from zoobenthos production and fish food consumption, food limitation will not occur in any case.

It should be noted, that the results indicate a potential biomass or catch, on the basis of modelled parameters exclusively. It is feasible that other non-modelled parameters will limit biomass in some cases. Furthermore, in any real situation, biomass will deviate from the calculated potential due to unpredictable meteorological, physical or biological impacts. The potential biomass as calculated in this study indicates a level that could be expected as an average over a longer time period.

Mnemiopsis leidyi

From the description of the present state of the ecosystem it is clear that *Mnemiopsis* is affecting the functioning of the ecosystem by its predation on zooplankton, including fish larvae. From literature it is reported that three main factors influence the occurrence of *Mnemiopsis*, (1) Temperature, (2) Food availability, (3) Predation (P. Kremer, 1994). The species seems to have a wide range of allowable salinity. In the study area impact on *Mnemiopsis* from temperature regime can be expected by the changes made in the hydrological boundary conditions. Sadly, the present model does not include realistic temperature modelling. On the other hand, no specific data on the relation of *Mnemiopsis* occurrence and ambient temperature are available. Due to the fact that *Mnemiopsis* is not a native species in the area, predators and diseases are not found. It is stated in the same literature source that only in an environment with high food availability, *Mnemiopsis* can outcompete other species. In more food limited circumstances, *Mnemiopsis* can not compete as efficiently.

In the present study, no major impact in any case is seen on the habitat suitability of *Mnemiopsis*. From literature it is suggested that temperature changes could have an effect on the occurrence of this species. It is suggested by the author that changes in spring temperature regime within the studied cases might negatively affect *Mnemiopsis* biomass. This could not be modelled at present. Comparison of actual other zooplankton species production with *Mnemiopsis* food consumption flux indicates that during years with *Mnemiopsis* blooming food limitation for fish may occur due to massive grazing of *Mnemiopsis* on zooplankton. From literature it is concluded that predation on fish larvae might directly impact the future fish stock .

4.4.8 Summary of results of the ecological evaluation

- The selected cases result in significant impacts on species biomass and fish catch within the limitations of the approach chosen in this study. Increase or decrease of catch can be 400% of the actual situation.

- Recreational areas are affected by pollution from local outfalls. In the present situation approx. 60% of the beaches exceeds at least once one limit in the period april-august. The approach indicates a worst case situation.

- Salinity and minimum oxygen concentration limit habitat suitability for most of the species. Ambient concentrations of studies toxicants are not a major impact. Total oil concentration generates the highest exceedance of toxicological thresholds. It is assumed that exclusively modelled parameters limit the habitat suitability. In the field, impacts of additional parameters might be expected.

- Mnemiopsis biomass is not impacted significantly by the formulated cases. It seems that environmental additional parameters are needed to describe changes in its habitat suitability. Ambient temperature is suggested as a likely parameter.

- Fish food consumption is not limited by biomass production of its prey species in any case. During years with Mnemiopsis blooms food limitation for fish is to be expected.

- Impacts on species biomass or catch that are generated in habitats outside of the study area could further limit or enhance the potential biomass presented as results of this study.

- The actual biomass of species in the study area will deviate at any given moment from the calculated potential biomass due to unpredictable meteorological, physical or biological impacts. The potential biomass as calculated in this study therefore indicates a level that could be expected as an average over a longer time period.

5 An illustration of integrated policy analysis

The separate calculation of the effects of different testcases is not the only application of a DSS. Its swift operation allows the comparison of measures for the development of an overall policy on water resources management. This chapter describes such a comparison, executed during the final workshop in Rostov-on-Don in April 1996.

The workshop was used to, once again, go through all the steps of (1) definition of test cases, (2) calculation of test cases and (3) comparison of test cases. The results of this procedure are reported here, together with the separate conclusions drawn during this workshop.

5.1 Definition of cases

Within the DSS framework a large number of cases can be defined. Any case will have its specific influence on the water quality of the Sea of Azov and subsequently on species living in the water system, expressed as habitat suitability , biomass or catch. A case consists of a certain combination of river flow and contaminant loading. In this paper four river flow options and four contaminant loading options are selected, thus defining sixteen cases. All sixteen cases were calculated. Of course any desired case can be defined by future users of the DSS, only limited by (information on) the available boundary conditions.

The following options with regard to river flow were considered:

- pristine conditions. This option assumes a natural river flow without regulation by reservoirs, resulting in high flow in spring and low flow in summer;
- actual river flow (1991). This option is based on present day water consumption in the Azov Sea river basin;
- 20% decreased river flow. This option considers a future situation in which nonretrievable water consumption by human user functions is increased resulting in an annual 20% less river flow into the Azov Sea;
- increased river flow. This options considers a future situation in which water availability for consumption in the summer is reduced, leading to 20% increased flow in the March-April and 20% decreased flow in the rest of the year. Total annual river flow is comparable to the actual situation.

With regard to contaminant loading the following options were selected:

- pristine conditions, concentrations of contaminants and nutrients are set at their natural backgrounds;
- actual situation (1991);
- fifty per cent reduction of anthropogenic loads. This options deals with a reduction of emissions in river basins and coastal areas;
- fifty percent increase of anthropogenic loads. This options represents economic or population growth without environmental measures.

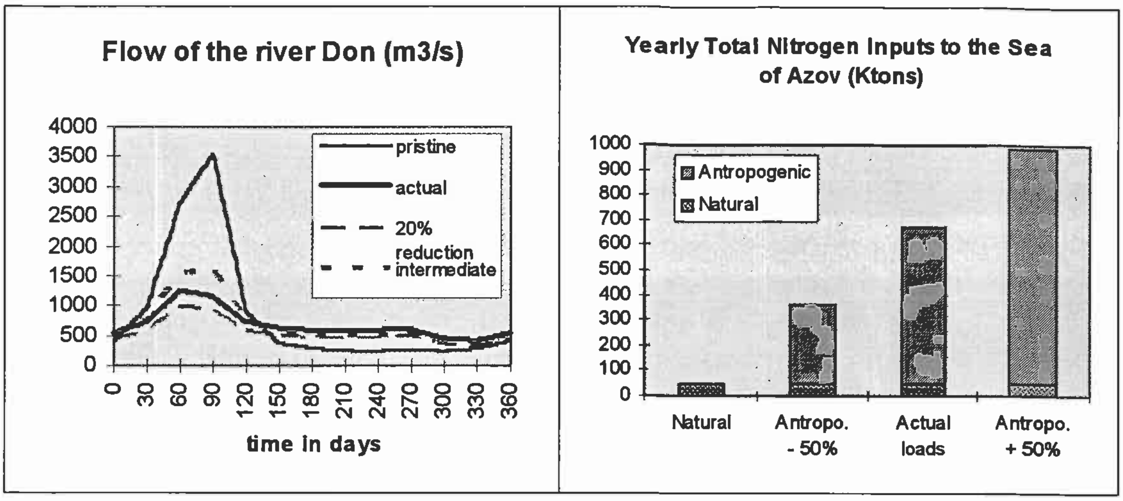


Figure 5.1 Flows and loads into the Sea of Azov

Case results can be evaluated and compared using effect parameters. Effect parameters are for instance: night time minimum oxygen concentration, copper concentration, salinity, chlorophyll and habitat suitability expressed as biomass or catch. The four contaminant loading options and the four river flow options can be structured as a matrix. Rows in this matrix (see figure 4) represent waste load analyses with a fixed river flow. Columns represent river flow analyses with a constant waste load. Each row or column can be presented as a graph, thus expressing the sensitivity of the Azov Sea water system to changes in contaminant loading or river flow (see figure 5).

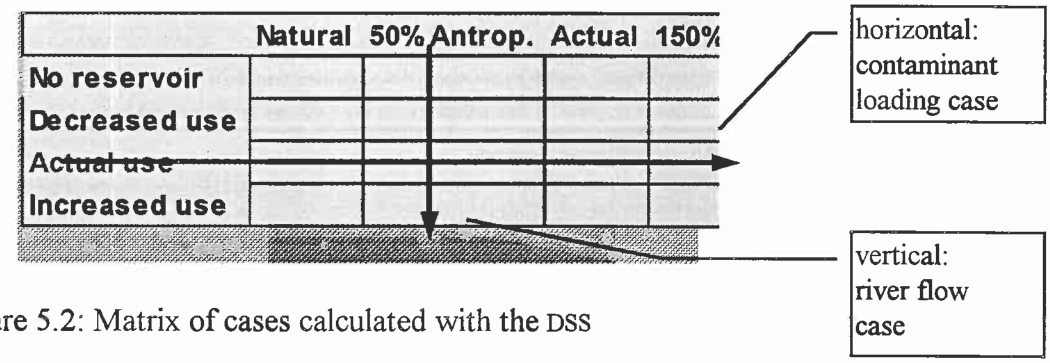


Figure 5.2: Matrix of cases calculated with the DSS

5.2 Results of cases

Results are presented for a selected set of effect parameters: Salinity, minimum night time oxygen, habitat suitability for Mullet, Sturgeon and Turbot and beach length complying standards.

Salinity

Salinity is selected because of its impact on habitat suitability for key species. As is shown in figures 5a and b , annual average salinity is not effected by contaminant loading but only by changes in river flow.

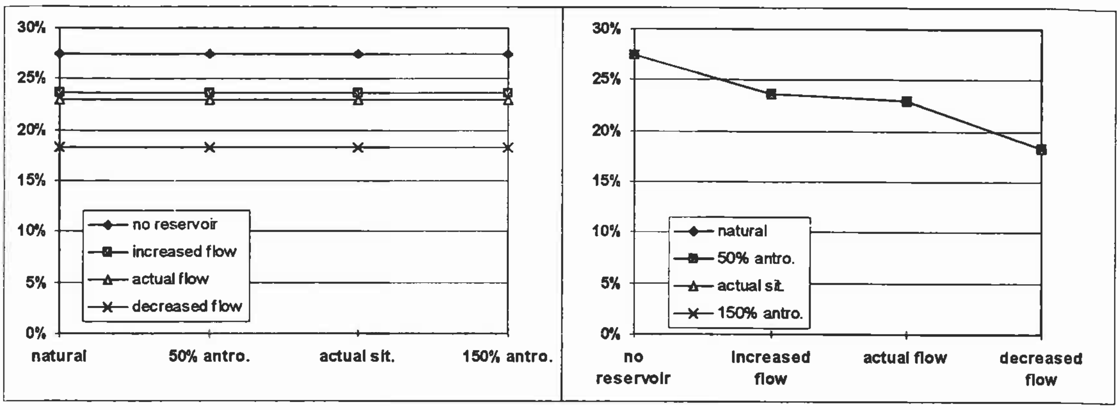


Figure 5.3a,b: %Area with salinities < 7mg/l for four contaminant loading and four river flow cases

Oxygen

Minimum night time concentration is selected as effect parameter due to the sensitivity of parameter to nutrient loading and because of its relevance to biota. Benthos and fish mortality can be observed with oxygen concentrations below 3 mg/l. In figures 6a and b it is shown that the area where oxygen concentration can fall below this threshold value is sensitive to nutrient loading.

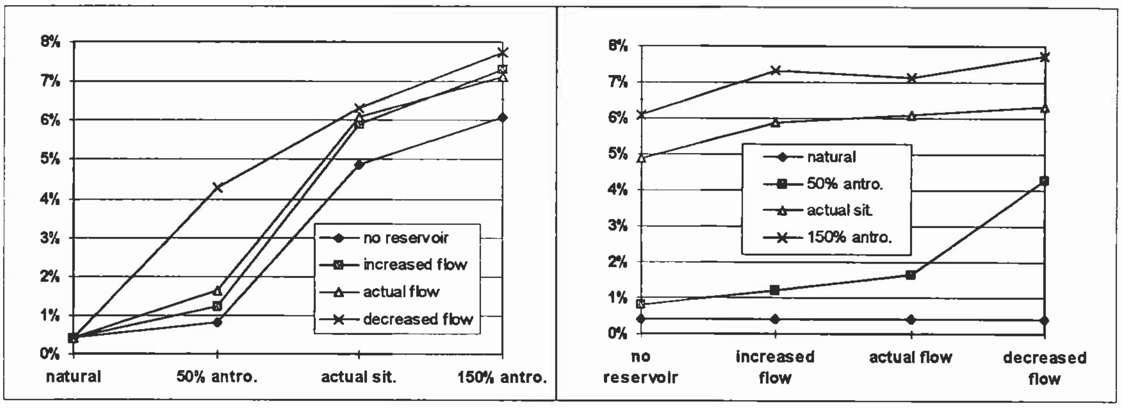


Figure 5.4a,b: %Area with night time oxygen < 3mg/l for four contaminant loading and four river flow cases

Habitat suitability

The location of spawning habitat for Mullet, feeding habitat for Sturgeon and wintering habitat for Turbot results in sensitivity of habitat suitability to changes in river flow and contaminant loading. Therefore this effect parameters can be seen as an integration of all environmental factors. In the figures 7a and b, the impact of flow and contaminant to spawning habitat suitability of Mullet is shown. Both salinity (river flow) and oxygen (nutrient loading) limit the suitability. It follows, that only a simultaneous reduction of limitation of both limiting factors will be effective (see Table 1). As can be seen from the table, wintering habitat suitability for Sturgeon is improved by increased river flow whereas feeding habitat suitability for Turbot is reduced under the same conditions. All species considered benefit from a reduced input of nutrients.

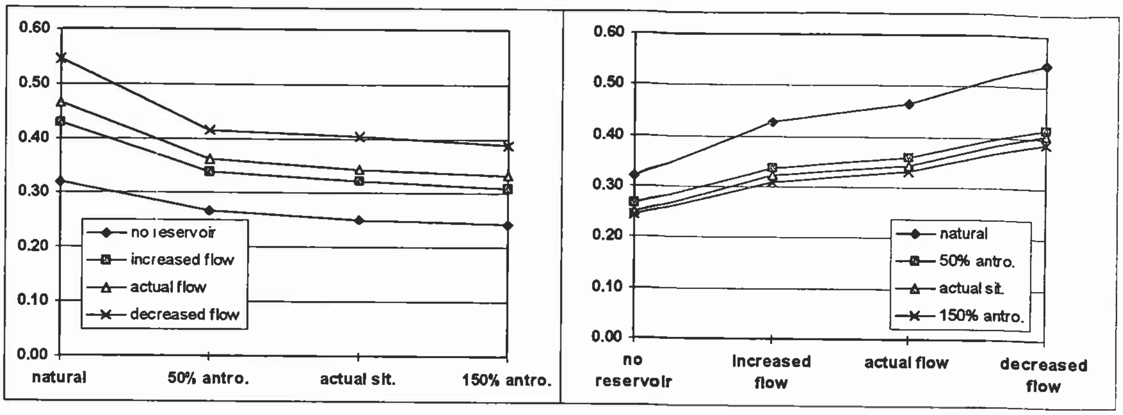


Figure 5.5a,b: %Area with habitat suitability for Clupeonella for four contaminant loading and four river flow cases

Table 5.1: Effect of cases on habitat suitability of three fish species (relative to actual situation)

Flow&Load case (actual=100%)	Turbot	Mullet	Sturgeon
no reservoir / natural load (reference)	1%	94%	128%
increased flow / 50% anthropogenic load	39%	99%	107%
actual river flow / actual load	**100%**	**100%**	**100%**
decreased flow / 150% anthropogenic load	361%	115%	76%

Beach length complying to standards

For gridcells adjoining beaches on the northern shores of the Azov Sea, water quality for available parameters was compared to the locally accepted sanitary hygiene standards. It can be concluded that BOD5 is the most limiting factor (standard 3 mg/l), albeit that total coliforms were not included in this study. It is assumed, that the sources of coliforms and BOD5 are identical. Moreover, coliforms degradation rates are higher then for BOD5, so BOD5 will be the limiting factor in most cases. If any of the sanitary hygiene standards is violated, suitability for recreation for this gridcell will be zero. In figure 8a and b it is shown that beach length complying to standards is most sensitive to contaminant loading.

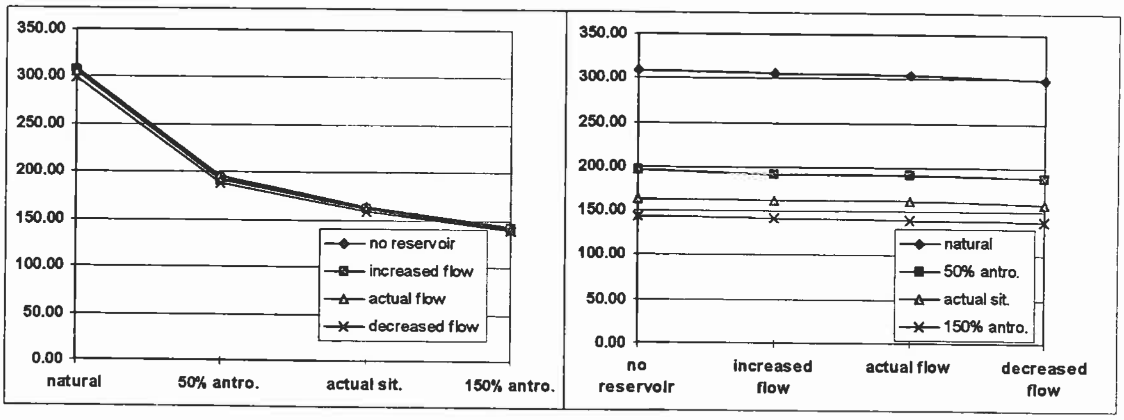


Figure 5.6a,b: Beach (km) complying to sanitary hygiene standards for four contaminant loading and four river flow cases

5.3 Conclusions and recommendations

From the results presented in this paper and from workshops some first conclusions relevant for decision making can be listed.

- A change in water management strategies will result in change of the abiotic and biotic quality of the Azov Sea water system;
  1. 20% increase in river flow in spring will lead to a 33% increase of the area with a salinity lower then 7 promilles, compared to the actual situation;
  2. a 50% decrease in contaminant loading will lead to a 75% decrease of the area with night time oxygen concentrations below 3 mg/l, relative to the actual situation;
  3. increased river flow will increase habitat suitability for Mullet and Sturgeon, but will decrease habitat suitability for Turbot;
  4. decrease in contaminant loading will increase habitat suitability for all key fish species due to improvement of oxygen conditions;
  5. beach length complying with sanitary standards is increased 25% due to a 50% reduction of the actual contaminant loading.
- Changes in water management should both address water quantity and water quality in order to maximise improvements;
- It should be noted that concentrations of micro-pollutants are underestimated in the present application due to lacking input data. Effects of contaminant loading options are now governed by nutrient availability. Therefore habitat suitability's might be overestimated
- Most of the environmental measures and policies which affect the Azov Sea address management issues upstream in the drainage basin.
- The structure of DSS has proven to allow users to investigate the relationships between causes and effects in relation to system functioning, acting as a stimulus for discussion and understanding of complexity of the Azov Sea water system.

From the experience with application of the DSS and on the basis of above conclusions the following recommendations are formulated:

- The quality of DSS results is presently limited by the quality and availability of loading data. Therefore the quality of available data should be checked and the data availability should be extended.
- Effect parameters such as beach length complying to standards and habitat suitability should be translated into economic parameters (for instance using beach length). In this way, cost benefit analysis will be feasible.
- It is suggested to distribute the DSS to all involved institutes and to provide training of experts within each institute to become DSS managers.
- A national DSS focal point will increase quality and acceptance of results thereby increasing the effectivity of DSS for policy making in relation to water quality and water quantity management. The focal point should ascertain a regular update with improved data. The focal point could be assigned to provide further training to local experts.
- The quality of decision making will be further improved when additional DSS's are developed for the Azov Sea drainage basin and Black Sea and the Black Sea region.

6 Project evaluation and recommendations

The management of water resources involves a wide range of aspects. In the Azov Sea project those aspects have been selected which, in an integrated approach, should lead to an improvement of the environmental decision making process. The integration should be supported by methods and instruments. The possibilities of integrating instruments have been illustrated with a decision support system, designed specifically for the Azov Sea. This system has been developed in an international project with expertise from outside the Azov Sea region. Careful evaluation of the concepts and the methods should lead to decisions on future actions: the development of a new system by regional institutes or the improvement and extension of the present system.

The concept of integrated water resources management and the application of supporting management instruments has only become accepted in the last decade. Implementation in operational environmental decision making in the Netherlands is still in progress. Adoption and implementation of the concept in operational environmental decision making in Russia or Ukraine will also take many years, especially in the present changing socio-economic situation. It was therefor to be expected that many problems would be encountered during the three year project period. Some of the problems directly involved the project, others may limit the implementation of the results or the effectiveness of environmental decisions which may be based on the methods.

Valuable observations could be made during the project. These have led to recommendations for future activities. These activities may be carried out locally, or in an international context such as the second phase of the Black Sea Environmental Protection Programme.

6.1 Recommendations

On the basis of the results presented and discussed in the underlying report a number of recommendations is made to enhance the knowledge on the functioning of the Sea of Azov and its response to changing hydrological and environmental conditions. In addition it is necessary to further enhance the capabilities of local organisations to exert large scale advanced environmental studies, in which integration of different disciplines should be the main issue.

- *Research on Response of the Sea of Azov to Extreme (Hydrological and Meteorological) Conditions.*
  Environmental conditions in the project area are strongly influenced by inflow from the Don and Kuban River and meteorological forcing. Extreme conditions such as extended periods of high or low river discharges and/or strong westerly or easterly winds may seriously affect the transport and fate of pollutants. Extended periods of calm weather may lead to increased primary productivity. Storms on the other hand may lead to enhanced remobilisation of suspended solids and pollutants from the sediment.

- Set Up of an Integrated Environmental Monitoring System for the Sea of Azov. The present study revealed a lack of monitoring data and knowledge on specific processes (such as atmospheric deposition, sediment-water exchange, competition between phytoplankton species, available inputs of pollutants from point-and non-pointsources).
  Environmental Monitoring of large scale areas as the Sea of Azov can only be carried out with restricted coverage in both time and space, given the high cost of surveys and analysis of water samples. Therefore the interpretation of the monitoring results in both space and time is difficult. In this respect the use of mathematical models can be very useful to interpret the monitoring results. The integrated use of the results from monitoring and modelling can result in a more complete view on the quality status of the water system, its behaviour and the trends. In addition, such an approach allows for a reduction in monitoring efforts if new gained knowledge on observed gradients and changes in time can be taken into account.

- *Analysis of Changes in the Don and Kuban River Loads as a Result of River Basin Developments*.
  It was concluded that little change in the overall pollution load to Sea of Azov can be made without a drastic reduction of pollution discharged to the main river systems. The important catchment of the Don and Kuban requires a detailed inventory of all pollution inputs.

- *Analysis of other impacting parameters*
  An integrated monitoring strategy (see above) should lead to a more complete understanding of other stress factors for the environment. Analysis of impacts can be easily included in the present system. One factor which may be analysed is that of the water temperature in the deltas, influencing the habitats of many spawning fish species.

- *Analysis of local effects*
  The present instrument is unable to analyse the effects of outfalls on a very local scale (kilometers). However, environmental measures are more easily taken on that scale than on a regional scale. Evaluation of the DSS should therefor indicate if further development is necessary

- *Integration with the drainage basin management*
  The present DSS has been explicitly limited to the Azov Sea itself. Many of the environmental measures which can improve the Azov Sea have to be taken on the rivers of its drainage basin. For a full evaluation of the impact of measures the drainage basin should be included into future management systems.

6.2 Implementation

The presented DSS should be seen as a demonstration of the possibilities of integrated management instruments. Careful evaluation of the present instrument and comparison with the needs at management level should indicate what future developments are necessary. In an international management situation like the Azov Sea this process is likely to take 5 to 10 years. Adoption and implementation of the integrated water management approach has already been supported through workshops (Delft and Odessa) and during many informal contacts. Support for further implementation should be based on a step by step approach, in which Russian and Ukrainian environmental managers and their advisors evaluate the importance and use of the approach in their management structure. The success of the concluding workshop is Rostov in April 1996 indicated that the present instrument will be an important tool in this process.

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main office
Rotterdamseweg 185
p.o. box 177
2600 MH Delft
The Netherlands

telephone	+31 15 2569353
telefax	+31 15 2619674

telex 38176 hydel-nl

location 'De Voorst'
Voorsterweg 28, Marknesse
p.o. box 152
8300 AD Emmeloord
The Netherlands

telephone	+31 527 242922
telefax	+31 527 243573