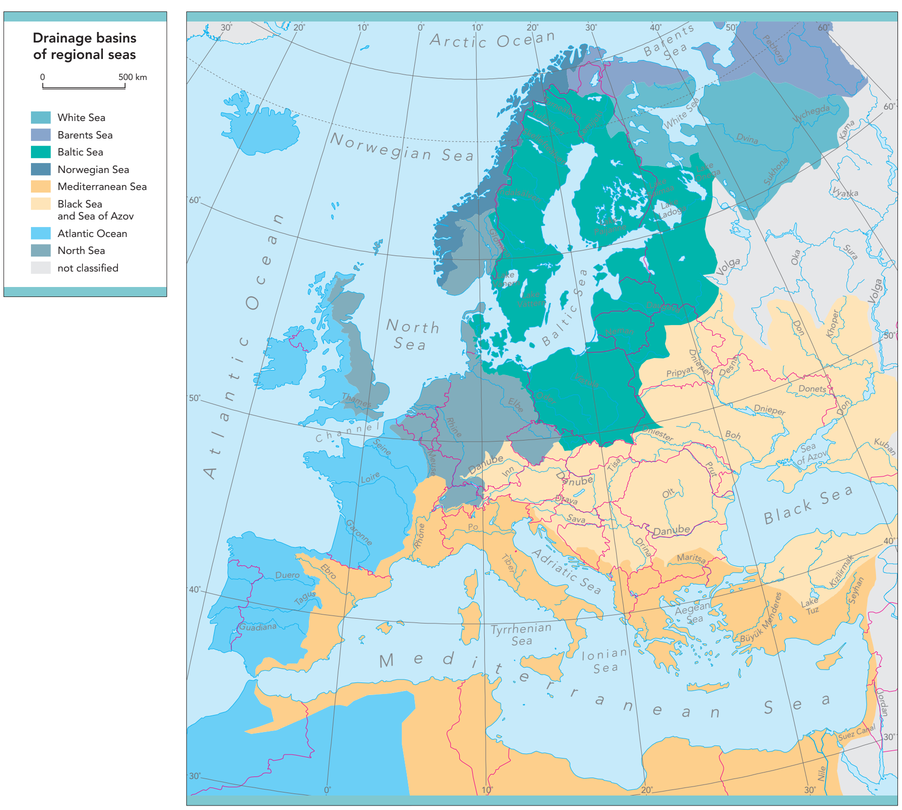
3. The seas of Europe

Nutrients are brought with freshwater from land via rivers, pipes and groundwater seepage to the coastal margin of the marine environment and via the atmosphere to the surface water of the seas. Figure 2 shows the catchment areas of the different European regional seas.

The sensitivity of an area to the nutrient load is to a large extent determined by the hydrography. The sensitivity increases with the residence time and the strength of the stratification of the water column. Over time and in space the nutrient-rich freshwater is mixed with marine water bodies by water exchange, tidal currents, local coastal currents and large-scale circulation currents. Stratified water columns can prevent mixing of oxygen-rich surface water with the bottom water for parts of the year or in certain areas permanently. Background levels in imported waters to coastal areas and upwelling phenomena also play a role, as also the high turbidity of the water in shallow tidal areas.

This report focuses on eutrophication in coastal areas. For that reason this chapter does not include a description of deep waters and deep-water current systems, except in cases where important upwelling takes place. A comprehensive description of water masses and current circulation patterns in the different seas can be found in OSPAR Commission QSR 2000, Region IV (2000), Helcom (1996) and EEA (1999c).

Figure 2. Catchment areas and drainage basins of regional seas



Source: EEA, 1999a.

3.1. Baltic Sea

The Baltic Sea is the largest brackish water area in the world and consists of several sub-basins separated by sills. The transition area (the Belt Sea and Kattegat) to the North Sea is narrow and shallow with a sill depth of 18 m. At irregular intervals, major inflows supply large volumes of highly saline and oxygen-rich water to the Baltic Sea. Only these inflows are able to renew the stagnant bottom water of the deep basins of the Baltic Proper. In the period 1983–92 no such inflows were recorded, and anoxic conditions prevailed in the deep basins. The latest important inflow of saline water from the Kattegat happened in 1993/94 (Helcom, 1996; Helcom, 1999). This inflow event was moderate in volume but the only important one since the major event in 1977. A new moderate inflow took place in December 1999.

The Baltic Sea is shallow (mean depth 52 m, maximum depth 459 m) with a water volume of 21 700 km^3 and a surface area of 415 000 km^2, including the transition area. The overall residence time is 25 to 35 years. The mean maximum ice coverage in winter is about 150 000 km^2. In general, ice covers the northern part for about four to six months, but sea ice also occurs in some winters also in the rest of the Baltic Sea area.

The drainage area is 1 745 136 km^2 (Figure 2). The mean net outflow from the Baltic Sea is 15 000 $m^3 s^{-1}$ (= 476 $km^3 y^{-1}$: run-off 436 km^3 + precipitation 224 km^3 — evaporation 184 km^3). The mean inflow of saltwater to the Baltic Proper, mostly intruding at intermediate depths and not renewing the deep water, is calculated to 471 $km^3 y^{-1}$, resulting in an overall mean outflow of 947 km^3. The in- and outflows have shown very large fluctuations from year to year in the past century.

A huge part of the Baltic Proper with water depth larger than 50 to 60 m and in the transition area larger than 20 m is strongly stratified all year round. In the summer a thermocline is established in about 20 m depth in the Baltic Proper. In the Gulf of Bothnia the stratification is weak and occurs only in summer. The salinity in the surface water is very low in the eastern and northern gulfs of the Baltic Sea (< 5 psu) gradually increasing to 8 psu at the entrance to the Belt Sea. Due to the low salinity the biodiversity is lower than both in more saline waters and in freshwaters, and many species live at the edge of their ability. Large-scale mixing of Baltic surface water and saline North Sea water takes place in the Belt Sea and Kattegat (Helcom, 1996).

3.2. Norwegian Sea

Central and northern Norway borders the Norwegian Sea as the only mainland. The Norwegian catchment area covers 168 000 km^2 of mainly mountainous areas with little anthropogenic input (Figure 2). Two surface current systems run more or less parallel north-east up the coastline. The Norwegian coastal current runs near shore. When it enters the Norwegian Sea from the south-west, it transports approximately 1 million $m^3 s^{-1}$ and has a salinity that generally exceeds 30 psu (OSPAR Commission QSR 2000, Region I, 2000). The water mass is a mixture of low saline Baltic water, North Sea water and Atlantic water mixed in the Kattegat and Skagerrak. The North Atlantic current has two branches each bringing warm and high saline water masses to the Norwegian Sea. Modified North Atlantic water enters the Norwegian Sea between Iceland and Faeroes and is somewhat colder and less saline than the main stream entering between Faeroes and Scotland. The total input of the North Atlantic current in the Norwegian Sea is 8 million $m^3 s^{-1}$ (OSPAR Commission QSR 2000, Region I, 2000; AMAP, 1998). In addition to the water masses transported by the two current systems near and offshore there are a number of different water masses found in fiords and other estuaries along the coastline. Wide ranges of water characteristics are found, depending on estuary type, residence time, freshwater input, mixing conditions, etc.

3.3. Greater North Sea

The Greater North Sea covers approximately 750 000 km^2 and has a volume of about 94 000 km^3. Without strict boundaries it is often divided into seven sub-areas: the southern North Sea, the central North Sea, the deeper northern North Sea, the Norwegian Trench, Skagerrak and finally the shallow Kattegat as a transition zone to the Baltic Sea and the Channel as a transition zone to the north-east Atlantic. The shallow southern North Sea includes the large Wadden Sea tidal area, the German Bight and the southern Bight.

The catchment area for rivers discharging to the North Sea is 850 000 km^2 (Figure 2). The total run-off of freshwater is on average 300 $km^3\ y^{-1}$; however there are large year-to-year differences in run-off (OSPAR Commission QSR 2000, Region II, 2000). The most important rivers are the Rhine, Weser, Meuse, Scheldt, Seine and Elbe draining central and northern Europe. The Thames and Humber rivers drain east England and Goeta drains large parts of western Sweden. However, the largest freshwater source to the North Sea is the Baltic Sea (476 $km^3\ y^{-1}$).

A branch of the North Atlantic current sweep into the northern North Sea transporting approximately 1 million $m^3\ s^{-1}$. Most of the Atlantic inflow circulates in the deeper part of the northern North Sea, the Norwegian Trench and Skagerrak, before it enters the Norwegian Sea. A small proportion of water enters the North Sea through the English Channel. The flushing time for the entire North Sea is estimated to be in the range of between 365 and 500 days (OSPAR Commission QSR 2000, Region II, 2000).

Tidal currents are the most energetic features in the North Sea. In the Channel and the shallow southern part of the North Sea it affects the whole water column preventing stratification all year around. Stratification occurs from spring to autumn in the central and northern North Sea, while the water column is well mixed during wintertime. Year round stratification persists in the Norwegian Trench, Skagerrak and the deep parts of Kattegat due to the strong outflow of less saline Baltic water. The same salinity induced stratification is found in seaward river mouths. In periods with westerly wind low saline water, carrying nutrients from the rivers in the southern North Sea, is carried up the Jutland west coast by the Jutland coastal current to the Skagerrak (OSPARCOM QSR, Region II, 2000).

3.4. Bay of Biscay, Iberian west coast and Gulf of Cadiz

The catchment area that drains into the western Atlantic Ocean is 700 000 km^2 (Figure 2), with an average annual run-off of 180 km^3. More than half of the run-off takes place in the Bay of Biscay. The four most important rivers responsible for more than half the loading are the Loire and Gironde that drain into the Bay of Biscay, and Miño and Douro that drain into the Atlantic at the Iberian west coast (OSPAR Commission QSR 2000, Region IV, 2000).

Most of the surface waters found in the area have an Atlantic origin. Deeper water masses may also be a mixture of Atlantic and Mediterranean water masses. A warm saline continental slope current runs northward along the Iberian west coast pass the Bay of Biscay before entering the Celtic Sea in the north. The current is most pronounced in late autumn, but is weak or non- existent in the surface from spring to autumn along the Iberian coast. Along the Cantabrian slope the current has maximum transport values in wintertime and northward of the Celtic slope it is most pronounced in late summer. The mean monthly transport in the upper 500 m of the water column is of the order of 1.5 million $m^3 s^{-1}$. Near shore in the Bay of Biscay a northward shelf residual circulation exists with less saline water driven by Coriolis forces. Seasonal variability in run-off and wind directions greatly affects this coastal current system. Small river run-offs and a narrow shelf make density stratification less persistent off the Iberian coast compared to the shelf in the Bay of Biscay (OSPAR Commission QSR 2000, Region IV, 2000).

Coastal upwelling is a dominant process in summertime off the Iberian west coast and in the south-western part of the Bay of Biscay. Upwelling takes place in rather narrow bands, so called filaments, along the coast (OSPAR Commission QSR 2000, Region IV, 2000).

3.5. Celtic Seas

This area includes the Celtic Sea located south of Ireland, Saint George's Channel, the Irish Sea and North Channel between Ireland, Wales, England and Scotland, and finally the shelf areas west of Ireland and Scotland. The total catchment area is shown in Figure 2.

During summer the North Atlantic water is found offshore Ireland and a band of less saline water is found around the island. In wintertime the Atlantic water mass is close to the West Coast of Ireland. On the Marlin shelf off Scotland there are three water masses. The main body is high saline Atlantic water. Then there is a water mass with slightly lower salinity coming from the Irish Sea and inshore of this lies coastal water with an even lower salinity due to run-off of freshwater.

Stratification, primarily due to surface heating, develops especially in the western part of the Irish Sea, in the Celtic Sea and in the Marlin shelf area during late spring and summer. Inshore the thermal stratification is weaker. In the Minch and Sea of the Hebrides stratification does not take place even in summer leading to development of fronts. Strong western wind and strong tide in the Bristol Channel and in the eastern part of the Irish Sea ensure intense vertical mixing (OSPAR Commission QSR 2000, Region III, 2000).

The continental slope current, also described for the Biscay area, follows the slope edge to the south-west of Ireland. On average there is a northward water movement through the Irish Sea and 30 000 to 100 000 $m^3 s^{-1}$ are transported through the North Channel, but transport fluctuations are huge due to wind conditions. On the Marlin shelf west of Scotland the water masses continue the same overall residual northerly direction, but the flow direction and transport are strongly dependent on the wind regime in the area (OSPAR Commission QSR 2000, Region III, 2000).

Based on transport models and radionuclide distributions it is estimated that the flushing time is 150 to 300 days in the Bristol Channel, one to two years in the Irish Sea and four and half to six months in the Marlin shelf area. Storm events are known to change those rates considerably (OSPAR Commission QSR 2000, Region III, 2000).

In addition to the water masses in the open areas there are a number of different waters found in fiords and other estuaries along the west coast of Scotland and the Scottish islands. Wide ranges of water characteristics are found, depending on estuary type, residence time, freshwater input, mixing conditions, etc. (OSPAR Commission QSR 2000, Region III, 2000).

3.6. Mediterranean Sea

Data on the total size of the Mediterranean catchment area were not found. The Nile has the largest catchment area of all rivers entering the Mediterranean Sea with 335 000 km^2 (Figure 2). However, because of the construction of the Aswan dam an average of only 5 km^3 water is discharged into the sea per year. Other important rivers are all located in the northern part of the Mediterranean. With a few exceptions all river systems discharging into the Mediterranean Sea are small. The Rhone, Ebro and Po have catchment areas extending to 96 000, 84 000 and 69 000 km^2. The discharge of freshwater from the 50 main rivers is about 255 $km^3 y^{-1}$. Net inflow from the Black Sea amounts to 163 km^3 per year.

Evaporation exceeds precipitation and freshwater load. As a result there is a net inflow of 1 700 km^3 water from the Atlantic Ocean per year and the overall effect is a very high salinity in the Mediterranean Sea. The actual annual inflow of Atlantic water is much higher. Chou and Wollast (1997) estimate that 53 000 km^3 pass the Strait of Gibraltar as a surface current. This inflow is compensated by export of high saline water from the Mediterranean Sea at the bottom. The export is estimated at 50 500 km^3, giving a net water transport that is 800 km^3 higher per year than the figure given in the Mediterranean assessment report (EEA, 1999c).

The Mediterranean is divided into two basins separated by the Sicilian Channel about 150 km wide and with a maximum water depth of 400 m. The water depth averages 1 500 m and shelf areas are narrow and separated from the deeper parts by steep continental shelf breaks.

The inflow current of Atlantic water continues as a surface current from west to east of the Mediterranean Sea. On its way east in the central part of the sea, this current drives a number of gyres effecting the coastal areas (EEA, 1999c). The inflow of Atlantic water keeps the surface salinity at between 36.2 psu in the western part and 38.6 psu in the eastern part. The intermediate water found only in the eastern basin has salinity between 38.4 and 39.1 psu. The deep-water salinity in the two basins ranges from 38.4 in the west to 38.7 in the east (EEA, 1999c). Deep-water formation takes place in wintertime each year in a few isolated areas in both basins predisposed to convection overturning.

Coastal sea level variations are generally limited to tens of centimetres. Tidal amplitudes are small in the Mediterranean.