Cleaning Up the River Rhine

Intensive international efforts are reclaiming the most important river in Europe

by Karl-Geert Malle

VOLKER HINZ

In Köln, a town of monks and bones,
and pavements fanged with murderous stones
And rags, and hags, and hideous wenches;
I counted two and seventy stenches,
All well defined, and several stinks!
Ye Nymphs that reign o'er sewers and sinks,
The river Rhine, it is well known,
Doth wash your city of Cologne;
But tell me, Nymphs, what power divine,
Shall henceforth wash the river Rhine?

So wrote Samuel Taylor Coleridge in 1828, after a visit to the Rhine with William Wordsworth. Just how prophetic those lines were, Coleridge could hardly have guessed. In the 1960s and early 1970s, as central Europe resurged economically, organic and inorganic pollution in the Rhine reached levels high enough to decimate or wipe out dozens of fish species and other creatures that had existed in the river for many thousands of years. Most of the river became unsuitable for swimming or bathing, and the production of drinking water was threatened.

After the 1970s, however, international attempts to clean up the Rhine, including some dating to the 1950s, finally began reclaiming long stretches of the river. Today, although much remains to be done, the work is emerging as a success story in cooperation among nations for the sake of pollution control and as a model for the many other places where transborder flows of contaminants have strained relations.

Most important, the reclamation efforts are giving new life to one of the world's great rivers. Countless poets, prose writers and lyricists have praised (or lamented) this fabled waterway, which winds through or along five countries before emptying finally through a Dutch delta into the North Sea. From Alpine headwaters in east central Switzerland, the Rhine flows 1,320 kilometers north and west through rugged mountains, lovely Lake Constance in Switzerland, the Black Forest, broad Alsatian valleys and such cities as Strasbourg, Bonn, Düsseldorf and Rotterdam. Both the Volga and the Danube are mightier and longer, but neither can match the Rhine's relatively constant flow and utility as an artery into the heart of Europe.

The catchment area, within which precipitation collects and feeds the river, covers some 190,000 square kilometers and has a population of 50 million. More than eight million of these people get their drinking water from the river, and another 10 million from Lake Constance. All told, more than 20 percent of the average flow of the Rhine is diverted and used, either for human consumption or for industrial rinsing and cooling. In addition, 10 hydroelectric plants, built after World War I and clustered in French territory below Alsace, generate a total of 8.7 million megawatt-hours every year.

The river is navigable for 800 kilometers, from the North Sea to the waterfalls below Lake Constance. Each day more than 500 barges ply its waters, laden with gasoline and other petroleum-based fuels, salt, phosphate rock, coal, gravel, new automobiles and other cargo, which adds up to about 150 million tons a year. Overall, use of the Rhine has been estimated to be five times greater than that of the Mississippi, when measured in terms of gross national product and accounting for the two rivers' flow rates and catchment populations.

One of the main reasons for the Rhine's importance is its relatively reliable water supply. In winter and spring, the flow is fed by precipitation in the plains and uplands of the catchment area; in summer, melting snow from the Alps takes over. Constance and other Swiss lakes act as convenient reservoirs. The average flow rate between 1925 and 1992 was 2,350 cubic meters per second, and the ratio between the greatest yearly flow (3,170 cubic meters per second in 1966) and the lowest (1,510 in 1971) is 2.1—less extreme than for most other rivers.

Reclamation Begins

Before the end of World War II, hardly any large sewage treatment plants were situated on the Rhine. The odors so poignantly described by Coleridge were at one time confined to the major cities, whose sewage was released untreated into the river. After the war, however, as central Europe revived its economies, the pollution problem intensified to such an extent that it could no longer be ignored. In 1953 five nations—Switzerland, France, Luxembourg, Germany and the Netherlands—formed the International Commission for the Protection of the Rhine against Pollution, to coordinate multinational efforts and to monitor, at least, the levels of contaminants in the river.

The commission, known by the acronym IKSR, now monitors water quality at several fixed points, mostly at inter-

national borders. The most significant of these lies between Germany and the Netherlands, because this area is not far downstream from the heavily industrial German Ruhrgebiet. Named after the Ruhr, a small tributary of the Rhine, this region's coal, steel and chemical plants constitute one of the major sources of pollution. Moreover, after entering the Netherlands, the river passes through a fairly rural area, with no significant sources of pollution until it encounters the big Dutch harbors at Rotterdam and Amsterdam, some 150 kilometers from Germany and not far from the delta on the North Sea.

Another notable factor in this regard is the river's flow, which slows considerably in the Netherlands. After making its way from Switzerland through France and Germany within seven or eight days, the water remains for 70 or 80 days in the Netherlands because of the country's sophisticated system of dikes, canals and other water-management facilities (including two large artificial lakes, the IJsselmeer and the Haringvliet). Shortly after entering the Netherlands, the Rhine becomes a delta with three separate estuaries: the Waal, Lek and IJssel.

The IKSR issues an annual report with extensive analytical data, reviewed and confirmed by the countries within the commission. But its main business is proposing and implementing international projects to improve the river. The two most significant of these are the Convention on the Protection of the Rhine against Chemical Pollution and the Convention on the Protection of the Rhine against Chloride Pollution. Both were put into effect in 1976. Another convention, which would have addressed thermal pollution, was drafted but never ratified by all the member states. Although the river is being warmed gradually by natural trends and human activities, the degree of warming—1.8 degrees Celsius since 1925—is not considered onerous enough to merit extensive attention.

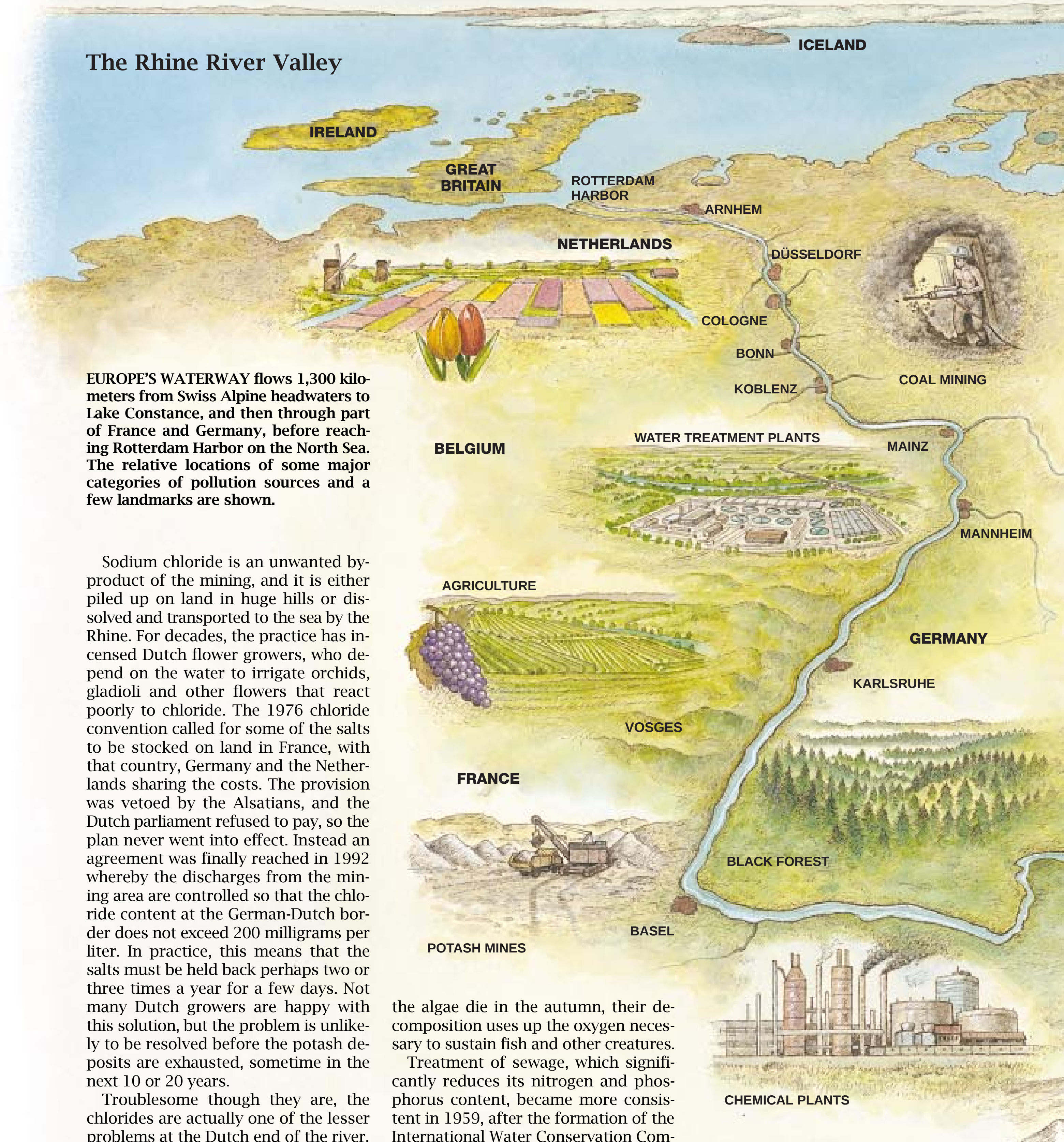
Inorganic Contaminants

Rivers typically contain far more inorganic salts than organic substances. Some of these salts are leached naturally out of the soil by rainwater and carried to the river. Through sewage, industrial activity and agriculture, however, humankind has significantly augmented the natural content. The concentration of salts—including anions such as chloride and carbonate, as well as cations such as sodium and calcium—was measured at 581 milligrams per liter at the German-Dutch border in 1992. There have been no striking changes in this level of concentration over the past two decades. Reducing the concentration of fairly dilute salts is extremely expensive, so the water is desalinated only when necessary—before being used for irrigation, for example.

Human activities have been especially productive of chloride ions. Based on the 1992 measurements, it is believed that they contribute some 318 kilograms of chloride to the river every second, as compared with the 15 to 75 kilograms per second from nature. The largest sources are the French potash mines in Alsace, which alone add 130 kilograms per second.

INDUSTRY AND FARMING have contributed significantly to the Rhine's pollution. A combination of tighter regulations, voluntary controls and subsidies for farmers who limit their use of certain chemicals has lately lessened impacts on the river.

The Rhine River Valley



EUROPE'S WATERWAY flows 1,300 kilometers from Swiss Alpine headwaters to Lake Constance, and then through part of France and Germany, before reaching Rotterdam Harbor on the North Sea. The relative locations of some major categories of pollution sources and a few landmarks are shown.

Sodium chloride is an unwanted byproduct of the mining, and it is either piled up on land in huge hills or dissolved and transported to the sea by the Rhine. For decades, the practice has incensed Dutch flower growers, who depend on the water to irrigate orchids, gladioli and other flowers that react poorly to chloride. The 1976 chloride convention called for some of the salts to be stocked on land in France, with that country, Germany and the Netherlands sharing the costs. The provision was vetoed by the Alsatians, and the Dutch parliament refused to pay, so the plan never went into effect. Instead an agreement was finally reached in 1992 whereby the discharges from the mining area are controlled so that the chloride content at the German-Dutch border does not exceed 200 milligrams per liter. In practice, this means that the salts must be held back perhaps two or three times a year for a few days. Not many Dutch growers are happy with this solution, but the problem is unlikely to be resolved before the potash deposits are exhausted, sometime in the next 10 or 20 years.

Troublesome though they are, the chlorides are actually one of the lesser problems at the Dutch end of the river. Nitrogen and phosphorus, which come mostly from sewage, boost algae growth to extreme levels and artificially stimulate the food chain—a process called eutrophication. The phenomenon is of concern mainly in the slow-moving Dutch waters, where the algae can become thick enough to hinder shipping and to clog pumps. In addition, when the algae die in the autumn, their decomposition uses up the oxygen necessary to sustain fish and other creatures.

Treatment of sewage, which significantly reduces its nitrogen and phosphorus content, became more consistent in 1959, after the formation of the International Water Conservation Commission for Lake Constance. Since the early 1970s, sewage treatment plants, along with the use of phosphate-free detergents, have steadily reduced the phosphorus in the river. In 1992 an average concentration of 0.21 milligram of phosphorus per liter was measured at the German-Dutch border, which, though an improvement over previous years, is still 10 times higher than the level in Lake Constance.

Nitrogen levels, however, have not fallen significantly, and the reasons are somewhat complicated. Nitrogen in the river has two main forms: ammonium and nitrate. Over the past 20 years, treatment has reduced the ammonium to about 0.27 milligram of nitrogen per

liter. Nitrate levels, on the other hand, have increased and were found in 1992 to be 3.8 milligrams of nitrogen per liter. Most of the nitrate is believed to come from fertilizers used to grow crops along the banks. Hopes that nitrate levels will not increase are pinned to various subsidy programs. For example, faced with a surplus of certain crops, the European Union gives subsidies to farmers who take land out of cultivation. Germany, meanwhile, subsidizes farmers who avoid using fertilizers in the bank zones of the river and who reduce the total use of fertilizers.

Another class of inorganic chemicals of great physiological significance are the heavy metals. In trace concentrations, some of these metals are essential to life. In higher concentrations, they can cause nervous system, growth and metabolic disorders. Mercury, cadmium, copper and some chromium come mainly from metal and chemical plants, which are easily identified and therefore controlled. Nickel, zinc and the rest of the chromium get into the river with the sewage effluent as a result of corrosion of pipes and equipment in homes and industrial plants and so are harder to restrict. Lead has been minimized through its removal from gasoline. The river's minute traces of gold do not endanger human health. (In the early 19th century untold numbers of prospectors panned for the metal along the banks of the upper Rhine, between the Swiss border and Worms in Germany.)

Overall, the amount of these metals in the Rhine has declined by more than 90 percent since the early 1970s. Sewage treatment plants have also helped by immobilizing large amounts in the sludge. In addition, programs have been instituted at industrial dischargers, by which the metals are selectively retained for reuse.

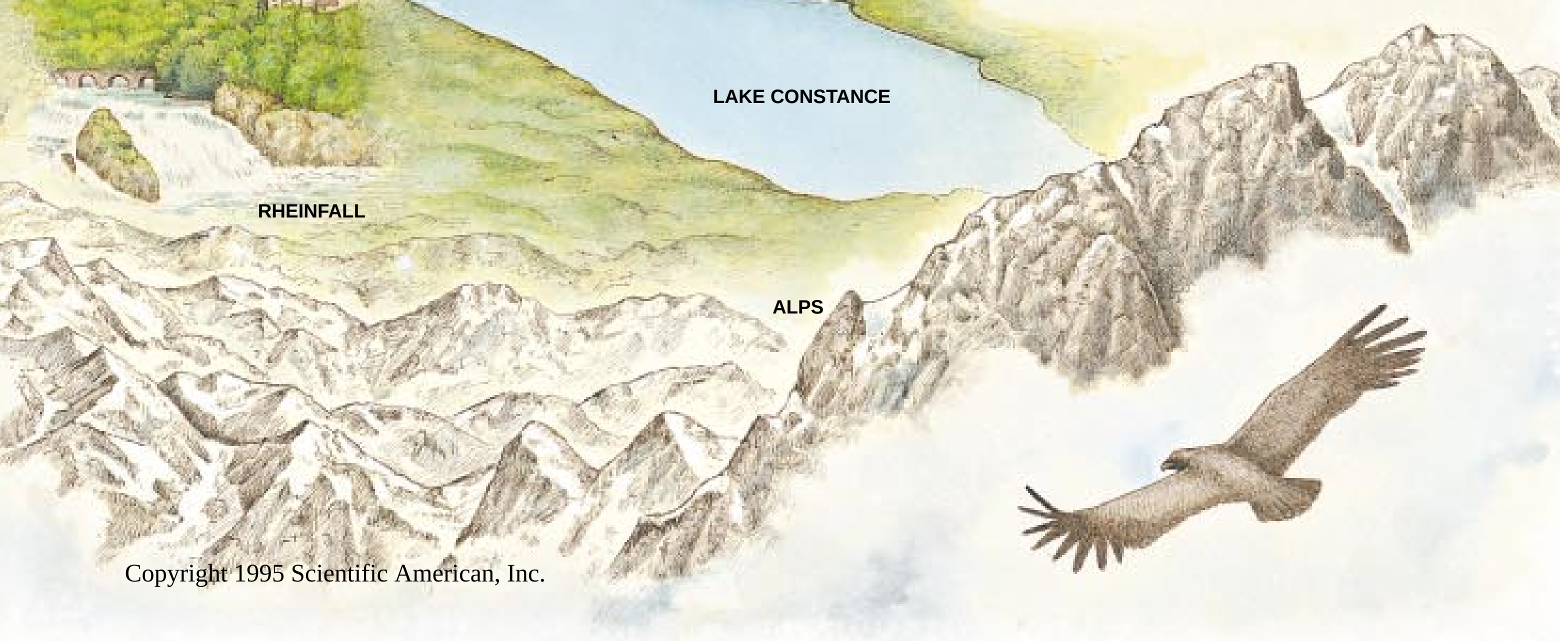
For the most part, the metal content in the Rhine's waters is no longer sufficient to harm people or marine life. But the sediments underneath certain parts of the riverbed and its tributaries are still quite metallic. Problems persist at the heavily industrial port of Rotterdam as well. Excavation there has dredged up metal-laden sediments, which have remained suspended in nearby estuaries. Protracted negotiations between the port authorities and some upstream metal and chemical industries have led to private-law contracts intended to reduce further the amount of metals that are released.

Organic Ogres

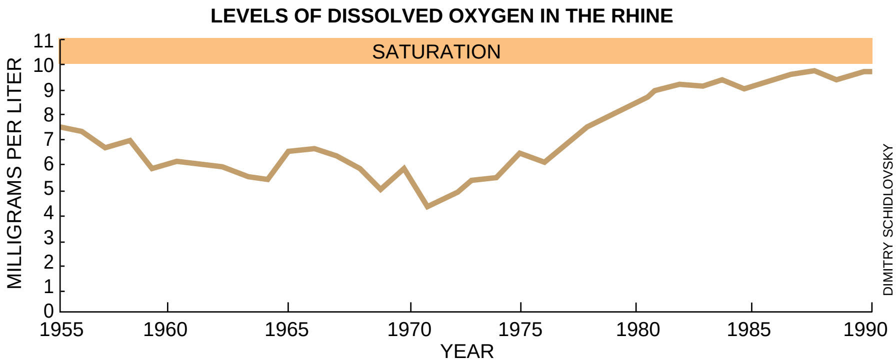
Whereas the monitoring and control of inorganic substances are useful in any river, water quality overall is generally much more sensitive to organic pollutants. Although such organics are usually no more than 1 percent of the pollution in a river, they tend to use up its dissolved oxygen, making the water unfit for sustaining life.

Between 1969 and 1976, organic pollution peaked in the Rhine, frequently sending dissolved oxygen levels below two milligrams per liter in some parts of the middle and lower river during the summer months. Such levels are not high enough to sustain many organisms. Since then, Germany alone has spent some $55 billion on sewage treatment plants, which retain about 90 percent of the organic pollutants. Dissolved oxygen has returned to healthier levels of about nine or 10 milligrams per liter (about 90 percent of the amount the water can physically contain in solution).

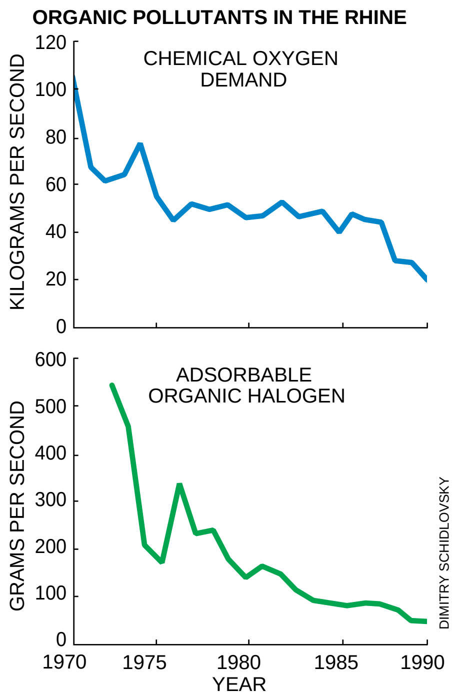
In comparison with the monitoring of inorganic pollutants, keeping tabs on organic substances is considerably more complex. Although inorganic chemicals may account for 99 percent of the pollution in a river, their number generally adds up to only several dozen. In contrast, organic constituents, of both natural and artificial origin, are more likely to number in the thousands. Isolating and analyzing each of them is not feasible, so researchers usually group them into various categories and employ different methods to track them.



ROBERTO OSTI



LIFE-SUSTAINING OXYGEN levels reached a nadir around the summer of 1970, when amounts in certain parts of the Rhine were too low to keep many creatures alive.



OXYGEN CONSUMPTION by organic pollutants, as well as the influx of such compounds containing halogens (mainly chlorine), has fallen dramatically since 1970.

One commonly used technique establishes the effects or characteristics of all organic substances in the water. Another determines the concentrations of groups of similar compounds. Together these techniques can give a useful estimate of the organic state of a body of water and can be supplemented by measurements of single organic substances as needed.

One of the most common measurements in the first category is the biological oxygen demand, typically within a five-day period (abbreviated BOD_5). Bacteria and nutrients are added to the water, and their consumption of oxygen is recorded, generally in milligrams per liter of water. Another good measurement is known as chemical oxygen demand (COD), in which concentrated sulfuric acid and chromium are used to establish the maximum possible oxygen consumption of the sample. In 1992 at the German-Dutch border, the BOD_5 was measured at an average of three milligrams per liter; the COD was 10 milligrams per liter.

Substances commonly grouped together fall into four broad categories: adsorbable organic halogens (AOX, which refers primarily to compounds that contain chlorine); detergents; hydrocarbons; and humic acids. Even as part of larger molecules, chlorine and other halogens are especially worrisome because of their toxicity and persistence. Chlorine compounds come from several sources, including cellulose factories, which bleach raw cellulose to whiten it for making paper. Most of these factories have been converted to low- or even no-chlorine bleaching processes. Chlorine has also entered the river in the form of insecticides, such as DDT (dichlorodiphenyltrichloroethane), HCH (hexachlorocyclohexane), HCB (hexachlorobenzene) and PCP (pentachlorophenol). Germany no longer produces or permits the use of these chemicals. DDT and HCB are similarly banned by other countries along the Rhine, and the use of HCH, PCP and other persistent chlorinated compounds is tightly restricted by these and other countries. Since the mid-1970s, such measures have helped reduce the levels of some organic chlorine compounds at the German-Dutch border by factors between 5 and 15.

Substitution of less persistent pollutants has also been effective in controlling surfactants, the active ingredients of detergents. Since 1964, Germany has permitted only detergents that are readily biodegradable. This restriction has been key in reducing anionic surfactants (the most common kind), as measured in the waters flowing by Düsseldorf, from 650 grams per second in 1964 to 80 grams per second in 1987. In 1992 all measurements for anionic surfactants at the German-Dutch border were below 0.05 milligram per liter.

Hydrocarbons are more readily biodegradable than the halogenated compounds. Petroleum products such as gasoline, kerosene and naphtha account for about 20 percent of all upstream traffic carried on the Rhine across the Dutch border. In addition, the bilges of the thousands of vessels that use the Rhine every year collect some 20,000 cubic meters of an oil-and-water admixture, most of which is collected and removed by special-purpose boats. Such measures are keeping hydrocarbon concentrations down to 0.01 milligram per liter at the Dutch border.

The fourth grouping of organic substances—the humic acids—are the short-term products of biodegradation, one of the most potent tools of reclaimers. Yet whether it is induced in a sewage treatment plant or takes place naturally in the river itself, biodegradation is a never-ending process. Only part of the organic substances consumed by bacteria is fully metabolized and respirated as carbon dioxide. The rest are only partly oxidized and thereby converted into humic acids. Although produced in sewage treatment plants, they have always been in the river. In 1973 humic acids were estimated to account for about 25 percent of the residual organic pollution of the Rhine. More recently, this fraction has increased, although the percentage is difficult to determine because of the lack of analytical methods. Humic acids are considered essentially harmless, however, because they are produced early on in the natural, gradual oxidation of organic material in any river.

A Seminal Accident

No matter how carefully certain pollutants are controlled, the Rhine, like any heavily trafficked waterway, remains vulnerable to the occasional accident. At one time, accidents went mostly unnoticed amid the high background level of pollution. Today's cleaner river, however, reacts more profoundly to such events, and a sensitive early-warning system has been put in place to alert authorities when accidents occur.

A few unfortunate episodes were pivotal in getting the monitoring system up and running. In one of the worst, on November 1, 1986, a Sandoz Ltd. warehouse full of pesticides caught fire near Basel. Water sprayed on the fire washed the chemicals into the river,

THOMAS MAYER *Das Fotoarchiv*

UNHEALTHFUL FROTH and even dead creatures were periodic appurtenances of the river Rhine as late as the 1980s.

JOCHEN TACK *Das Fotoarchiv*

Today the same region, seen in front of the Voerde power plant in the industrial Ruhr area of Germany, is much cleaner.

where one of them—disulfoton—proved especially toxic to eels. Many thousands were killed downstream, all the way to Karlsruhe.

The disaster triggered an effort of unprecedented scope to follow the Rhine's recovery and to assess the biological state of the river in general. During the project, biologists from a German government research institute used a diving bell to study fish, macroinvertebrates and other creatures systematically in the riverbed. To the surprise of many, the river's fauna completely recovered by October 1988, less than two years after the fire.

The survey documented 155 species of macroinvertebrates, which tend to cluster near the banks, between Basel and Düsseldorf. Some of the most common were freshwater sponges, leeches, zebra mussels, benthic amphipods, mayflies, caddis flies and worms, and chironomid larvae. Some species, such as the mayfly *Ephoron virgo* and the snail *Theodosus fluviatilis,* had been thought to be virtually extinct in the Rhine but were found in large quantities. Other once common species, such as the mussel *Spaericum solidum* or the stonefly *Euleuctea geniculata,* were present as individual specimens and are only now starting to reestablish themselves in greater numbers. Somewhat disconcertingly, however, an amphipod, *Corophium curvispinum,* a relatively recent arrival from the Caspian and Black seas, is proliferating extensively enough to drive out certain species of sponges and mollusks.

Some fish, too, are making a comeback. Of the 47 endemic species known to have inhabited the river, a recent survey found 40. About 75 percent of the individual fish identified were hardy, unspecialized creatures, including roach, bleak and bream. Researchers also spotted carp, perch, eel, pike, chub and dace. In addition, they tallied 15 species that had been introduced into the river, including pike-perch, rainbow trout and sunfish. In 1992, for the first time in decades, sexually mature salmon (*Salmo salar*) were caught in the Rhine. Released as hatchlings into tributaries of the river a year or more previously, they had survived a migration to the North Sea. Even sturgeon—believed extinct from the river for 40 years—have been seen occasionally.

A Model River

The river survey was not the only legacy of the 1986 warehouse fire in Basel. The states bordering the Rhine launched a joint Rhine Action Program, with four objectives: long-term safeguarding of the drinking water; decontamination of sediments; reestablishment of higher species of fish (salmon and so on); and protection of the North Sea.

As a first step, in 1989 the program compiled an inventory of all discharges of 30 different hazardous substances. By 1995 the rates of discharge for all had been reduced by 50 percent or more. In addition, improved safeguards prevent or limit discharges into the river after industrial accidents. In coming years, the construction of fish ladders to help creatures such as salmon get back to their upstream spawning grounds and the improvement of those grounds will begin to restore runs.

In 1991, at a conference on the waterworks in the Rhine's catchment area, the Dutch minister for transport and public works, Hanja Maij-Weggen, called for the experience acquired on the Rhine to be applied to the Meuse and Scheldt rivers. With the end of the cold war, international commissions have been set up to reclaim the Elbe, which flows from the Czech Republic and Poland through Germany to the North Sea, and the Oder, which forms part of the border between Poland and Germany. Even the Volga has benefited from lessons learned on the Rhine, which were passed on from German experts to their Russian counterparts in a recent series of meetings. For the Danube, reclamation will have to wait: work on the river has been suspended because of the war in the former Yugoslavia.

Amid sweeping changes in Europe it is fitting that the Rhine has become a tribute to the great things that can happen when countries cooperate.

The Author

KARL-GEERT MALLE recently retired from BASF in Ludwigshafen, Germany. After joining that company in 1960, he worked in inorganic research and in various production units before taking on the responsibility of monitoring all wastewater discharges. In 1984 he headed special tasks in environmental protection and was appointed a director. He is a member of a working committee of the German Commission for the Protection of the Rhine and of the Commission for the Evaluation of Water-Endangering Substances. He lectures on ecological chemistry at the Technical College in Mannheim.

Further Reading

HEAVY METAL POLLUTION IN THE RHINE BASIN. William M. Stigliani, Peter R. Jaffé and Stefan Anderberg in *Environmental Science and Technology,* Vol. 27, No. 5, pages 786–793; May 1993.

REHABILITATION OF THE RIVER RHINE. Edited by J.A. van de Kraats. Special Issue of *Water Science and Technology,* Vol. 29, Issue 3; 1994.