water

World Health Organization
Regional Office for Europe

EUROPEAN COMMISSION

Eutrophication and health

40

preface

Eutrophication and health

Algal blooms, “red tides”, “green tides”, fish kills, inedible shellfish, blue algae and public health threats. What is the common link ?

The answer is, EUTROPHICATION: a complex process which occurs both in fresh and marine waters, where excessive development of certain types of algae disturbs the aquatic ecosystems and becomes a threat for animal and human health. The primary cause of eutrophication is an excessive concentration of plant nutrients originating from agriculture or sewage treatment.

The purpose of this booklet is to describe in a simple way the causes of eutrophication, the environmental effects, the associated nuisances and health risk as well as the preventive and mitigating measures.

It is hoped that the booklet, which represents a collaborative effort between the European Commission and the WHO, will contribute to a better understanding of the problem of eutrophication and a more effective control of nutrient enrichment in our lakes, rivers ans seas.

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A great deal of additional information on the European Union is available on the Internet.
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Local authorities - this publication is meant for you

WHO's Regional Office for Europe is regularly approached to provide technical or practical advice on a large number of questions related to health and the environment.

Experts and many other partners have together drawn up a series of documents which will help you solve your environment and health problems.

The recommendations are ranked by priorities, so that strategies can be developed which are appropriate to the local context.

⚕⚕⚕ marks the recommendations that must be put into effect in order to ensure a safe and clean environment. All local authorities have a duty to tackle these tasks immediately.

⚕⚕ identifies the recommendations that will yield marked improvements in people's health and should be regarded as priority actions.

⚕ marks the recommendations that will, if they are implemented, substantially improve the local environment. Everyone's quality of life will benefit from these.

The unranked recommendations are designed to help you draw up strategies at local level and will not, in general, have a direct effect on health.

This pamphlet has been written to enable local authorities to take fully informed decisions. The annexes contain practical information which will help technical personnel and those in charge of public relations in their daily work.

Titles already published or in preparation are listed on the inside back cover.

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Algal bloom in sea-water

The word "Trophi" in Greek means food or nutrient, whereas the words "oligo", "meso", "eu" and "hyper" stand respectively for rare, moderate, abundant and excessive. Therefore, the words oligotrophic, mesotrophic, eutrophic and hypertrophic have been used by biologists to describe the various nutritional statuses of a marine or fresh water environment. These words are used to describe the potentially available quantitative biomass.

Eutrophic waters, or waters where one can find "abundant" food (nutrients) will favour "greedy" and quickly developing plants and algae. Long living (and slow growing) flora species, which cannot resist competition, although important for biodiversity (including as habitat for a varied fauna), generally develop in oligo or mesotrophic waters. Therefore in terms of biodiversity and ecological quality eutrophic waters are often of little interest. "Hypertrophic" waters have so much food available that they almost die of indigestion!

The word "eutrophication" is also now being used in a perspective of preserving the ecological quality of waters, e.g. in the Directives of the European Union and various international treaties. "Eutrophication is an accelerated growth of algae on higher forms of plant life caused by the enrichment of water by nutrients, especially compounds of nitrogen and/or phosphorus and inducing an undesirable disturbance to the balance of organisms present in the water and to the quality of the water concerned".

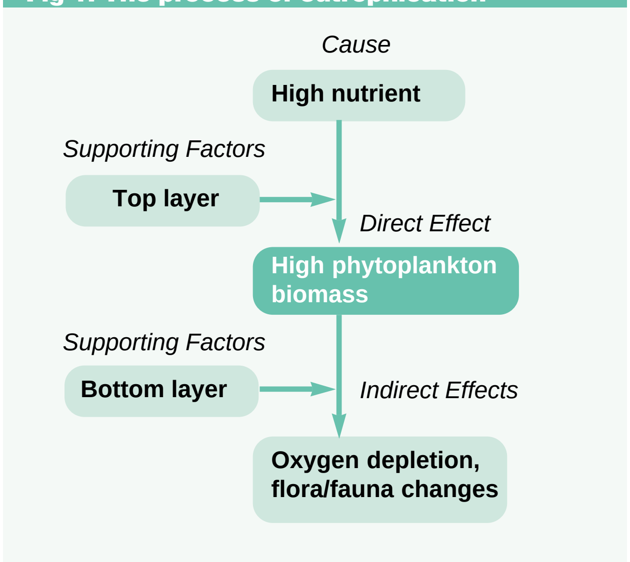
Thus, today "eutrophication" is more of a status than a trend and the term describes the qualitative conditions of an aquatic environment that has been disrupted, more than its quantitative (biomass) productivity. It is this definition that is adopted in this document.

Typical scenario leading to eutrophication

The mechanisms that lead to eutrophication, i.e. to this new status of the aquatic environment, are complex and interlinked. Figure 1 describes the process of eutrophication.

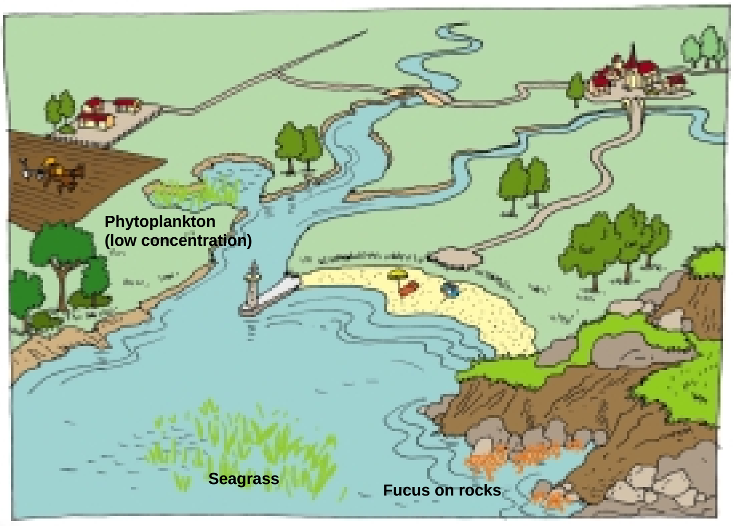
The main cause of eutrophication[1] is the large input of nutrients to a water body and the main effect is the imbalance in the food web that results in high levels of phytoplankton[2] biomass in stratified water bodies. This can lead to algal blooms[3]. The direct consequence is an excess of oxygen consumption near the bottom of the water body. The additional factors supporting this

Fig 1. The process of eutrophication

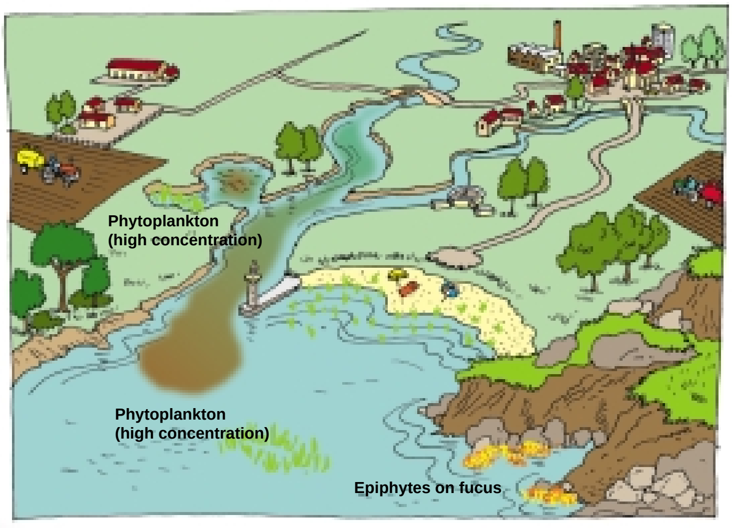


1 Druon J.N., the eutrophication risk index, internal document for DG ENV.
2 Phytoplankton: microalgae, with a silicon skeleton (diatom) or not, mobile (dinoflagelates) or not, in suspension in fresh or marine waters. They can be green, brown or even red.
3 Blooms: characterized by the explosive growth of algae or cyanobacteria, usually observed in eutrophic waters. They are generally dominated by a single or few species. The blooms can be seen by the naked eye when the density reaches several millions of cells per litre of water.

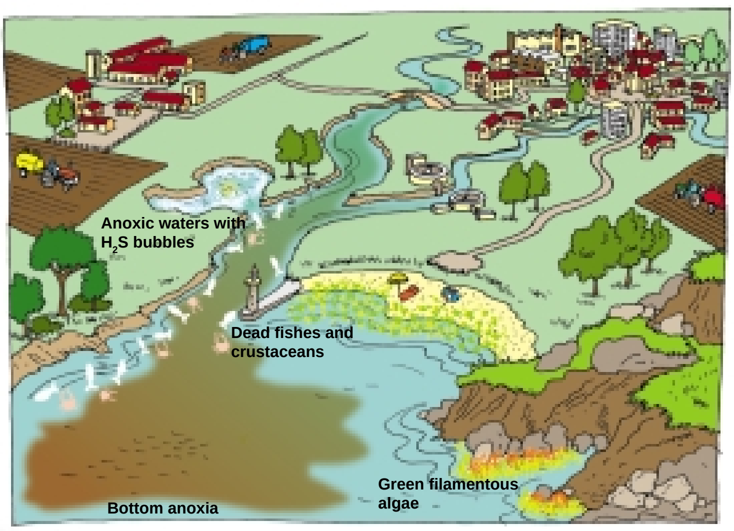
Fig 2 Ecosystem disruption



Pristine situation



Start of eutrophication



Extreme eutrophication

process can be divided into two categories depending on whether they are linked to the nutrient dispersion and the phytoplankton growth, or to the oxygen cycle near the bottom of the water body (for example, containment, light and water movements). Various effects can be observed depending upon the severity of the eutrophication.
The various steps of the ecosystem disruption are described in Figure 2.

In addition to carbon, oxygen and hydrogen that plants can find directly from water, and carbon dioxide in the atmosphere, two major nutrients are necessary for the development of aquatic life: Nitrogen (N) and phosphorus (P). A third one, silica (Si), is necessary for the development of diatoms. During eutrophication, the concentration of nutrients in the water changes. In some cases one out of the three nutrients may be totally bound to the aquatic life and will not be available for further growth of algae. This nutrient is then called the limiting factor.

The ratio of nitrogen to phosphorus compounds in a water body is an important factor determining which of the two elements will be the limiting factor, and consequently which one has to be controlled in order to reduce a bloom (Table 1).

Generally, phosphorus tends to be the limiting factor for phytoplankton in fresh waters. Large marine areas frequently have nitrogen as the limiting nutrient, especially in summer. Intermediate areas such as river plumes are often phosphorus-limited during spring,

Table 1: Nitrogen/Phosphorus ratios *(expressed in weight)* **for various limiting conditions in freshwater and estuarine/coastal water**

	N-limiting (Ratio N/P)	**Intermediate** (Ratio N/P)	**P-limiting** (Ratio N/P)
Freshwater	≤ 4.5	4.5-6	≥ 6
Estuarine/ coastal water[4]	≤ 5	5-10	≥ 10

4 The literature dealing with the marine environment usually uses the atom for atom ratio. With such a method these figures would range between 12 and 24.

but may turn to silica or nitrogen limitation in summer. When phosphorus is the limiting factor, a phosphate concentration of 0.01 mg l^{-1} is enough to support plankton and concentrations from 0.03 to 0.1 mg l^{-1} or higher will be likely to promote blooms.

In coastal areas, the growth and proliferation of diatoms is promoted by the presence of silica. When the silica concentration is low diatoms cannot develop. Then other opportunistic toxic algal species, which are no longer submitted to competition, can grow and form blooms. Species from the genus *Phaeocystis* and several dinoflagellates *(Prorocentrum, Dinophysis, Gymnodynium)* are known to proliferate under such conditions.

Causes of eutrophication and supporting factors

The enrichment of water by nutrients can be of natural origin but it is often dramatically increased by human activities. This occurs almost everywhere in the world. There are three main sources of anthropic[5] nutrient input: runoff, erosion and leaching from fertilized agricultural areas, and sewage from cities and industrial wastewater. Atmospheric deposition of nitrogen (from animal breeding and combustion gases) can also be important.

According to the European Environment Agency, "the main source of nitrogen pollutants is run-off from agricultural land, whereas most phosphorus pollution

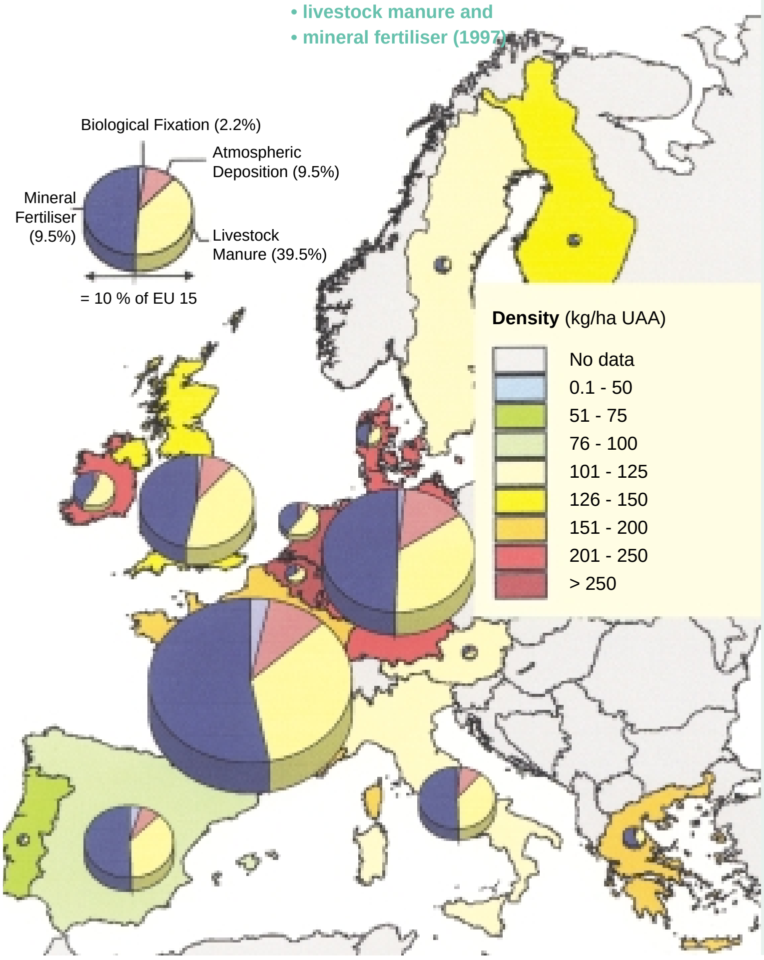
5 Anthropic: of human origin

CASE STUDY

Mapping N from agriculture - European Commission

Based on DG ENV / Eurostat / ERM / AB-DLO / JRC CIS

Total N pressure from
- **atmospheric deposition**
- **biological fixation**
- **livestock manure and**
- **mineral fertiliser (1997)**



Nitrates

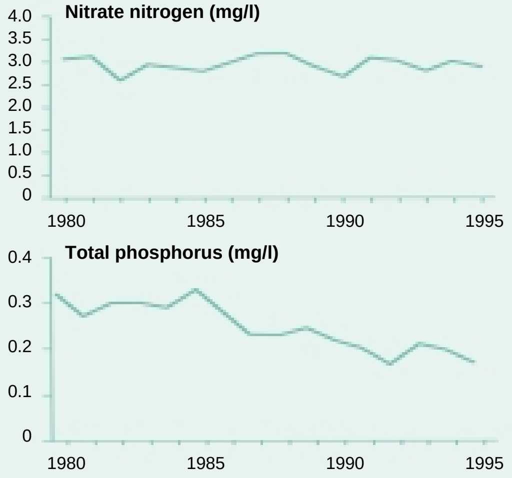
From the year 1950 until 2000 the use of mineral nitrogen in fertilizers for agriculture in the 15 EU member states has been increased tenfold, from 1 to 9-10 million tons. At the same time the amount of nitrogen released by animal husbandry rose to nine million tons. The nitrogen pressure on the environment currently reaches 18 millions tons[6] solely from agriculture.

Agricultural practices have led to a reduction of permanent grassland, and other "buffer" areas such as ditches, hedges and wetlands a situation which favours erosion, run-off and quick drainage of nutrient to the water bodies.

Country	Biological Fixation %	Atmospheric Deposition %	Livestock Manure %	Mineral Fertiliser %	Total 1000 t
Austria	3.4	19.1	45.4	32.1	349.4
Belgium	0.8	9.5	56.9	32.9	480.9
Denmark	3.4	8.2	40.5	47.9	596.3
Finland	2.3	3.7	29.9	64.1	272.9
France	3.0	9.6	34.4	52.9	4760.1
Germany	1.5	13.7	35.5	49.3	3627.3
Greece	1.2	4.8	37.3	56.7	541.4
Ireland	0.3	4.7	53.9	41.1	960.4
Italy	1.3	9.5	38.5	50.7	1805.9
Luxembourg	0.5	9.5	39.6	50.4	35.7
Netherlands	0.3	7.7	52.5	39.6	935.0
Portugal	3.1	4.6	50.6	41.7	270.3
Spain	4.3	7.3	37.6	50.7	2047.9
Sweden	3.4	3.8	37.8	55.0	373.9
United Kingdom	1.6	9.3	42.4	46.8	2674.3
EU 15	**2.2**	**9.5**	**39.5**	**48.9**	**19731.7**

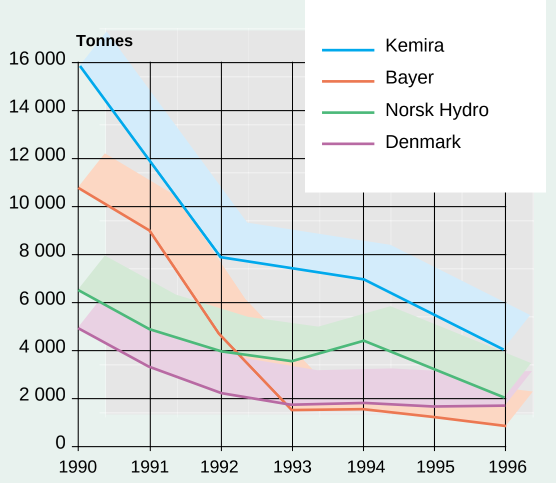
6 Source: European commission report. Implementation of the nitrates directive, COM (2002) 407

Fig. 2: Nitrogen and phosphorus in major EU rivers



Source: EEA-ETC / IW based on country returns under EC Exchange of Information Decision (77/795/EEC)

Fig. 3: Phosphorus emissions from some large industries



Note: Total loading from Denmark added for comparison
Source: wwwhomepages of the companies; Windolf, 1996.

comes from households and industry, including phosphorus-based detergents. The rapid increase in industrial production and in in-house consumption during the 20th century has resulted in greater volumes of nutrient-rich wastewater. Although there has been recently a better management of nitrogen and phosphorus in agricultural practices, saturation of soils with phosphorus can be noted in some areas where spreading of excessive manure from animal husbandry occurs. Nutrient removal in sewage treatment plants and promotion of phosphorus-free detergents are vital to minimize the impact of nitrogen and phosphorus pollution on Europe's water bodies"[7].

Since 1980, nitrate concentrations in major EU rivers have generally remained constant. There is no evidence that reduced application of nitrogen fertilizers to agricultural land has resulted in lower nitrate concentrations in rivers. Indeed, concentrations in some regions in Europe, such as Brittany, or Poitou in France, and Catalunya in Spain, are still increasing. More detailed information on nitrates are to be found in the companion pamphlet in this series "nitrate and health" and in the E.C. report mentioned in (6).

Phosphorus concentrations have shown a decline in major EU rivers (figure 2) mainly due to improved wastewater treatment and less phosphorus in household detergents. Phosphorus release from industry has also fallen sharply (Figure 3) whereas phosphorus from agriculture, despite a reduction in the consumption of phosphate fertilizers in the EU, remains an important source of phosphorus pollution.

Unfortunately, due to the main role of nitrogen in the eutrophication process in summer in the coastal zone, the reduction in the discharge of phosphorus from rivers into the sea has not been visible, except in very specific sites. In most cases the phosphorus released by the sediments into the open sea is sufficient to allow eutrophication to occur, although external inputs have sharply decreased. In fact, only the Dutch coast has benefited from the improvement of the water of

Slurry spreading

7 http://reports.eea.eu.int/signals-2000/en/page014.html

the Rhine, everywhere else the situation is stable or has worsened.

Some activities can lead to an increase in adverse eutrophication and, although they are very specific, they should be noted:

- **Aquaculture development:** Expansion of aquaculture contributes to eutrophication by the discharge of unused animal food and excreta of fish into the water;
- **The transportation** of exotic species: Mainly via the ballasts of big ships, toxic algae, cyanobacteria and nuisance weeds can be carried from endemic areas to uncontaminated ones. In these new environments they may find a favourable habitat for their diffusion and overgrowth, stimulated by nutrients availability;
- **Reservoirs in arid lands:** The construction of large reservoirs to store and manage water has been taking place all over the world. These dams are built in order to allow the collection of drainage waters through huge hydrographic basins. Erosion leads to the enrichment of the waters of these reservoirs by nutrients such as phosphorus and nitrogen.

Factors supporting the development of eutrophication

Besides nutrient inputs, the first condition supporting eutrophication development is purely physical - it is the containment (time of renewal) of the water. The containment of water can be physical, such as in a lake or even in a slow river that works as a batch (upstream waters do not mix with downstream waters), or it can be dynamic.

The notion of dynamic containment is mostly relevant for marine areas. Geological features such as the shape of the bottom of the sea, the shape of the shores, physical conditions such as streams, or large turbulent areas, and tidal movements, allow some large marine areas to be really “contained”, exhibiting very little water renewal. This is known as dynamic containment.

Eel grass bed in June 1987

Eel grass covered with green filamentous algae in June 1988

In other cases, due to tidal effects, and/or streams, some areas that would seem to be prone to containment see their waters regularly renewed and are not contained at all and are therefore very unlikely to become eutrophic.

Other physical factors influence eutrophication of water bodies. Thermal stratification of stagnant water bodies (such as lakes and reservoirs), temperature and light influence the development of aquatic algae. Increased light and temperature conditions during spring and summer explain why eutrophication is a phenomenon that occurs mainly during these seasons. Eutrophication itself affects the penetration of light through the water body because of the shadow effect coming from the development of algae and other living organisms and this reduces photosynthesis[8] in deep water layers, and aquatic grass and weeds bottom development.

8 Photosynthesis: the process in which the energy of sunlight is used by organisms, especially green plants to synthesize carbohydrates from carbon dioxide and water.

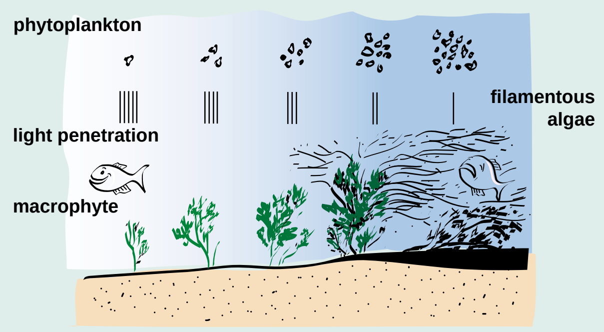
Main consequences of eutrophication

The major consequence of eutrophication concerns the **availability of oxygen**. Plants, through photosynthesis, produce oxygen in daylight. On the contrary, in darkness all animals and plants, as well as aerobic microorganisms and decomposing dead organisms, respire and consume oxygen. These two competitive processes are dependent on the development of the biomass. In the case of severe biomass accumulation, the process of oxidation of the organic matter that has formed into sediment at the bottom of the water body will consume all the available oxygen. Even the oxygen contained in sulphates (SO_4^{2-}) will be used by some specific bacteria. This will lead to the release of sulphur (S^{2-}) that will immediately capture the free oxygen still present in the upper layers. Thus, the water body will loose all its oxygen and all life will disappear. This is when the very specific smell of rotten eggs, originating mainly from sulphur, will appear.
In parallel with these changes in oxygen concentration other changes in the water environment occur:

Effects of nutrient enrichment on biodiversity

Under normal conditions, i.e. outside eutrophication periods, macrophytes at the bottom of the water body develop normally, the amount of phytoplankton is such that light can penetrate down to the bottom and fish and shellfish can live and reproduce. If the amount of nutrient increases, mainly short-living macrophytes will grow much faster and larger and new species will develop that will compete with those originally present. In some cases phytoplankton will also multiply. This development of macrophytes, including free-floating algae, and phytoplankton will prevent a large proportion of the light from reaching the bottom.
The first signs of the reduction of oxygen concentration will become visible. Should the situation become extreme, oxygen concentrations will reach levels that make aquatic life impossible. Only those species that require very little oxygen will survive in these conditions. The amount of organic sediment will increase, as will the demand in oxygen. The final step will be the end of all aerobic life.

Fig. 4: Development of plant life in coastal waters with increased level of nutrients[10]

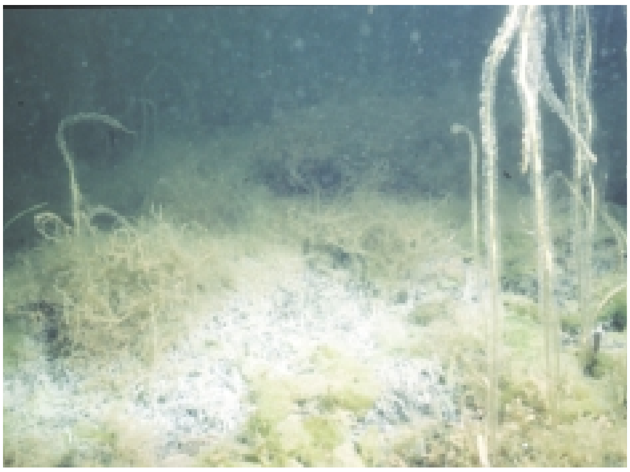


10 Funen City Council, Eutrophication of coastal waters, published by Funen City Council, Denmark, 1991

- **Changes in algal population:** During eutrophication, macroalgae, phytoplankton (diatoms, dinoflagellates, chlorophytes) and cyanobacteria[9], which depend upon nutrients, light, temperature and water movement, will experience excessive growth. From a public health point of view, the fact that some of these organisms can release toxins into the water or be toxic themselves is important.

- **Changes in zooplankton[11],** fish and shellfish population: Where eutrophication occurs, this part of the ecosystem is the first to demonstrate changes. Being most sensitive to oxygen availability, these species

9 Cyanobacteria: also called cyanophyte or blue/green algae, are organisms capable of plant-type photosynthesis and have close relationship with both bacteria and algae.
11 Zooplankton: community of animals with or without limited active locomotion, suspended in a water body.



Growth of white sulfure bacteria on black (anoxic) sediments between colonies of common mussels

Localised occurence of white sulfur bacteria and oxygen depletion in the sea bed following heavy oxygen demand during the decomposition of a mat of filamentous algae

may die from oxygen limitation or from changes in the chemical composition of the water such as the excessive alkalinity that occurs during intense photosynthesis[12]. Ammonia toxicity in fish for example is much higher in alkaline waters.

Effects of eutrophication

The effects of eutrophication on the environment may, have deleterious consequences for the health of exposed animal and human populations, through various pathways. Specific health risks appear when fresh water, extracted from eutrophic areas, is used for the production of drinking water. Severe impacts can also occur during animal watering in eutrophic waters.

Macroalgae, phytoplankton and cyanobacteria blooms

Algae display varying degrees of complexity depending on the organization of their cells. Macroalgae, phytoplankton and cyanobacteria may colonize marine, brackish or fresh waters wherever conditions of light, temperature and nutrients are favourable.

Cyanobacteria have been largely studied in fresh water systems, due to their ability to proliferate, to form massive surface scums, and to produce toxins that have been implicated in animal or human poisoning. Some species of algae may also contain toxins, but incidents where fresh water algae are at the origin of cases of human or animal illness have very seldom been reported.

Coloured toxic tides caused by algal overgrowth have been known to exist for many centuries. In fact the Bible (Exodus, 7: 20-24) states “all the water of the Nile river became red as blood and fish which were in the river died. And the river was poisoned and the Egyptians could not drink its waters”.

Algal blooms were observed in 1638 by fishermen in north west of Iceland. Fjords were reported to be stained blood red and during the night produced a kind of phosphorescence. The fishermen thought that the colours could be due to the blood of fighting whales or to some marine insects or plants (Olafsson and Palmsson, 1772). The first scientific report of domestic animals dying from poisoning as a consequence of drinking water that was affected by a blue/green algae bloom was in 1878 in lake Alexandrina, Australia.

In coastal and estuarine systems, however, where conditions are less favourable to the proliferation of cyanobacteria, which need oligo-elements such as iron, toxic algae such as dinoflagellates have been observed and have been at the origin of health troubles. There is growing evidence that nutrients, especially nitrogen, favour the duration and frequency of such toxic “blooms”, and concentrations of toxin in the cells.

Health effects linked to toxins of cyanobacteria in fresh waters

Some cyanobacteria have the capacity to produce toxins dangerous to human beings. Toxins can be found either free in the water where the bloom occurs or bound to the algal or cyanobacterial cell. When the cells are young (during the growth phase), 70 to 90% of the toxins are cell bound, whereas when the cells

12 During intense photosynthesis, living organisms will catch all the CO_2 that is available, including CO_2 coming from carbonates in the waters. As a consequence, alkalinity of the water will increase during daytime, and acidity during the night.

Tab 2. Target organs of the cyanotoxins and species of cyanobacteria involved *(Chorus and Bartram, 1999)*		
Toxin group	**Primary target organ in mammals**	**Cyanobacterial genera**
Cyclic peptides		
Microcystins	Liver	Microcystis, Anabaena, Oscillatoria, Nostoc, Hapalosiphon, Anabaenopsis
Nodularin	Liver	Nodularia
Alkaloids		
Anatoxin-a	Nerve synapse	Anabaena, Oscillatoria, Aphanizomenon
Anatoxin-a(S)	Nerve synapse	Anabaena
Aplysiatoxins	Skin	Lyngbia, Schizothrix, Oscillatoria
Cylindrospermopsins	Liver	Cylindrospermopsis, Aphanizomenon, Umezakia
Lyngbyatoxin-a	Skin, gastrointestinal tract	Lyngbia
Saxitoxins	Nerve axons	Anabaena, Aphanizomenon, Lyngbia,
		Cylindrospermopsis
Lipopolysaccharides		
	Potential irritant, affects any exposed tissue	All

are ageing, free toxins can reach 70% of the total. It is difficult to remove free toxins in the water by the normal processes used in treating water for drinking purposes. It is usually much easier to remove cyanobacterial cells than free toxins (see technical annex).

The resistance and persistence of toxins in the environment depend on the nature of the compound. Investigations have shown the ability of certain toxins to withstand physico-chemical and biological constraints, especially high temperatures (up to 300°C). Generally, the cumulative effects of these constraints cause toxin degradation in the natural environment after one to three weeks. In dark natural waters toxins can possibly persist for several months or even years.

To date there are more than 50 identified species of cyanobacteriae able to produce toxins. In Europe, the most frequently observed genera in fresh waters during blooms are *Microcystis, Anabaena, Aphanizomenon, Oscillatoria, Nodularia* and *Nostoc.*

Numerous experiments have been carried out to characterise the effects induced by toxins released by cyanobacteria, also called cyanotoxins, particularly in fresh waters. People may be exposed to toxins through the consumption of contaminated drinking water, direct contact with fresh water or the inhalation of aerosols. Toxins induce damage in animals and humans by acting at the molecular level and consequently affecting cells, tissues and organs (Table 3). The nervous, digestive, respiratory and cutaneous systems may be affected. Secondary effects can be observed in numerous organs. Age or physiological conditions of the affected individual may determine the severity of the symptoms. A variety of symptoms, depending on the toxins implicated, are observed such as fatigue, headache, diarrhoea, vomiting, sore throat, fever and skin irritations.

Cyanotoxins can be classified into three groups:

• Hepatotoxins.

These are the most frequently observed cyanotoxins. Experiments using mice indicate that they cause liver injury and can lead to death from liver haemorrhage and cardiac failure within a few hours of exposure at acute doses. Chronic exposure induces liver injury and promotes the growth of tumours.

Questions remain concerning the effects of repeated exposures to low levels of toxins. Animal experiments have shown liver injury from repeated oral exposure to microcystins, the most frequently observed cyanotoxins. It is thought that the high prevalence[13] of liver cancer observed in some areas of China could be due to the presence of microcystins in water supplies.

• Neurotoxins.

These are generally less common and act on the nervous system. In mice and aquatic birds, they cause rapid death by respiratory arrest, sometimes occurring in a few minutes.

• Dermatotoxins.

These induce irritant and allergenic responses in tissues by simple contact.

The global toxicity of a cyanobacterial proliferation is not constant in time or space, making it difficult to assess the health threat although some acute poisonings have led to death (Tables 3 and 4).

The release of cyanotoxins in water has been at the origin of several outbreaks affecting animal or human health (Case studies p. f12). About 75% of cyanobacterial blooms are accompanied by toxin production. The presence of cyanobacterial toxins after potabilization treatment represents a health threat for patients undergoing renal dialysis treatment.

Table 3. Cases of toxic cyanobacterial blooms reported in drinking waters
(Chorus and Bartram, 1999, Draft AFSSA, 2001[14])

Location and date of Cyanobacterial bloom	Species	Symptoms	Consequences
Drinking water			
USA, 1931	Microcystis	Gastro-enteritis	No data
USA, 1976	Schizotrix, Plectonema, Phormidium, Lyngbia	Gastro-enteritis	62% of the population fed by the network became ill
Australia, 1979	Cylindrospermopsis raciborskii	Hepatitis	141 hospitalizations
Australia, 1981	Microcystis	Gastro-enteritis Liver injury	No data
Brazil, 1988	Anabaena, microcystis	Gastro-enteritis	2000 people affected 88 deaths
Sweden, 1994	Planktothrix agardhii	Gastro-enteritis	121 people affected
Brazil, 1996	Aphanizomenon, Oscillatoria, Spirula	Hepatitis	166 people affected 60 deaths

Table 4. Cases of toxic cyanobacterial blooms reported in recreational waters
(Chorus and Bartram, 1999, Draft AFSSA, 2001)

Recreational water			
Canada, 1959	Microcystis Anabaena circinalis	Gastro-enteritis, headaches, nausea, muscular pains	30 people affected
UK, 1989	Microcystis	Gastro-enteritis, vomiting, sore throats	20 people affected 2 hospitalizations

13 Prevalence: The number of instances of a given disease or other condition in a given population at a designated time (Last, 1988).
14 Coquet Sandrine, Évaluation des risques lies à la présence de cyanobactéries dans les eaux destinées à la consommation humaine, rapport AFSSA, Paris, 2001

Release of cyanotoxins in water has been at the origine of outbreaks affecting animal health

C A S E S T U D Y

Fatalities after the consumption of drinking water contaminated by cyano toxins

In 1988 in Brazil 2000 cases of gastroenteritis, with 88 deaths were reported in an area supplied with drinking water from a dam contaminated by cyanobacteria (Anabaena and Microcystis). Cases were observed even in patients who boiled their water before drinking and were only observed in the areas supplied with drinking water from the dam, pointing to the origin as being a toxin produced by algae.

Algal toxins in marine waters

Algal toxins are observed in marine ecosystems where they can accumulate in shellfish and more generally in seafood, reaching dangerous levels for human and animal health.

Around 40 algal species able of producing toxins harmful to human or marine life have been identified in european coastal areas. Among these microalgae, Dinophysis, Alexandrium, Gymnodinium, Pseudo-nitzschia are frequently observed and represent a risk for seafood consumers.

The various effects are:

- **Diarrhoeic shellfish poisoning (DSP).** Intoxication leads to gastrointestinal symptoms (for example diarrhoea, vomiting and abdominal pain). Species frequently implicated are from the genus Dinophysis and Prorocentrum. Carriers are filtering shellfish such as oysters, mussels[15], cockles and clams. No fatality has been observed.

- **Paralytic shellfish poisoning (PSP).** Intoxication leads to muscular paralysis, difficulty in breathing, shock and in extreme cases death by respiratory arrest. Species frequently implicated are from the

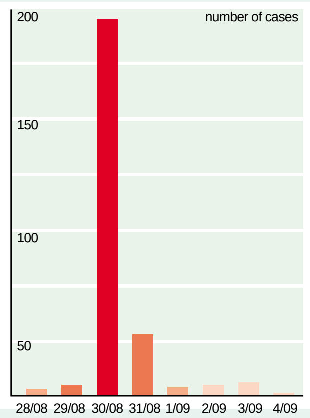
15 A mussel can filter up to 30-40 litters of water per day.

C A S E S T U D Y

A typical outbreak[16]

During summer 1988, around Fécamp, Seine-Maritime, France, the public health authorities were warned by the local hospital that an unusual number of patients had been admitted with vomiting and diarrhoea. After a short investigation with the local pharmacists on duty that weekend it appeared that there were additional cases that did not go to the hospital.

More than 200 people were affected. Thanks to the existing network of pharmacists the outbreak was well monitored, as shown in the graph below.



The epidemiological survey showed that the origin of this outbreak was the ingestion of mussels collected by tourists and local residents during the spring tides. The mussels had filtered a large amount of dinophysis (a toxic phytoplankton).

As a consequence, it was decided to expand the monitoring system (Réseau de surveillance du phytoplancton et des phycotoxines: REPHY; see p. f19) set up by the IFREMER, which was previously dedicated to commercial shellfish growing, to this area of France, in parallel with the existing "Diamoule" pharmacists network, coordinated by the public health authority (DDASS).*

**Institut français de recherche pour l'exploitation de la mer*

16 Coquillages et santé publique, du risque à la prévention, Lesne Jean et al, édition de l'ENSP, 1991

Table 5 Cases of intoxications due to seafood consumption *(MAP Technical Reports, 1996)*

Intoxication	Country	Date	Consequences
PSP	Philippine	1983	300 cases 21 deaths
	United Kingdom	1968	78 cases
	Spain	1976	63 cases
	France	1976	33 cases
	Italy	1976	38 cases
	Swiss	1976	23 cases
	Germany	1976	19 cases
DSP	Japan	1976-1982	1300 cases
	France	1984-1986	4000 cases
	Scandinavia	1984	300-400 cases
VSP	Japan	1889	81 cases
			51 deaths
	Japan	1941	6 cases
			5 deaths
	Norway	1979	70 cases
ASP	Canada	1987	153 cases
			3 deaths
NSP	Florida	1977 (?)	ND

genus Alexandrium and Gymnodinium. Carriers can be oysters, mussels, crustacean and fish. Fatality rate is estimated at close to 10% of people intoxicated.

- **Amnesic shellfish poisoning (ASP).** Intoxication leads to mental confusion and loss of memory, disorientation and sometimes coma. Species frequently implicated are diatoms from the genus Nitzschia. Carriers are filtering shellfish, such as mussels. Fatalities have been observed in elderly people.

C A S E S T U D Y

Severe health effects due to recreational exposure to water contaminated by toxic blue algae *(Chorus and Bartram, 1999)*

Ten out of twenty army recruits in the United Kingdom (1989) showed symptoms indicating intoxication (vomiting, diarrhoea, central abdominal pain and sore throats) after training in water with a dense bloom of Microcystis spp. Two of them developed severe pneumonia and needed hospitalisation and intensive care.

C A S E S T U D Y

A newly discovered side effect of eutrophication of sea waters[17]

The presence of bacteria potentially harmful to human health such as Escherichia coli, Salmonella spp *or* Vibrio Cholerae *can represent a threat to people bathing in water. Under normal conditions, these bacteria do not survive very long in seawater. The major reasons for this are the relative poverty of nutrients in seawaters, the exposure of bacteria to UV rays which have a bactericidal effect, and, finally, the osmolarity[18] of sea water which is much higher than that of bacteria.*

During blooms, the conditions are reversed, food becomes abundant, light is diminished and it has been recently established that some algae may even release chemicals that produce osmo-protection for the bacteria.

As a consequence, during blooms, if bacteria already pollute the seawater, the situation may deteriorate due to the new conditions allowing them to survive and perhaps multiply.

- **Neurotoxic shellfish poisoning (NSP).** Intoxication leads to muscular paralysis, state of shock and sometimes death. Species frequently implicated are from the genus Gymnodinium. Carriers are oysters, clams and crustaceans. Human fatalities have been observed. They have been at the origin of ecological catastrophes with the death of huge numbers of fish and other aquatic life.

- **Venerupin shellfish poisoning (VSP).** Intoxication leads to gastrointestinal, nervous, haemorrhagic, hepatic symptoms and in extreme cases delirium and hepatic coma. Species frequently implicated are from the genus Prorocentrum. Carriers are oysters and clams. A high fatality rate has generally been observed among intoxicated populations.

17 M.Ghoul et al, Marine Macroalgae as a source of Osmoprotection for Escherichia coli, in Microb Ecol, 1995, vol 30, pp 171.181
18 Osmolarity: a chemical characterisitc of water mainly linked to its concentration in dissolved salts

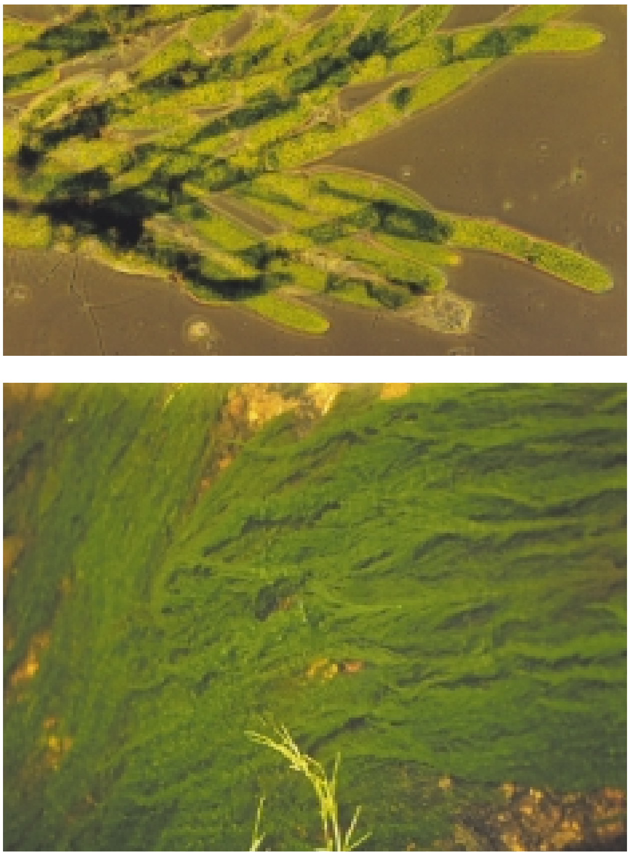
Microphytes blooms

There are some possible individual effects of microalgal blooms in seawater that may have large economic consequences. Blooms of blue/green algae, diatoms and Prymensiophytes can produce mucus forming “blankets” floating on the surface (“marine-snow” as observed in 1999 in the Euboikos Gulf, Greece). The same occurs almost each year, in spring, with phaeocystis along belgian coasts (thick white foam).

Massive amounts of gelatinous aggregations were noted floating on the Aegean Sea in 1982 and 1983. Almost similar events are described p. f15.

Macrophytes[19] mass developments

Macroalgal proliferations, also called green tides, are repeatedly observed in the marine environment. Such proliferation's are directly related to the nitrogen enrichment of waters and often occur in bays and estuarine systems. The opportunistic species implicated are frequently from the genus Ulva (Ulva armoricana, Ulva rotundata, Ulva rigida), Monostroma



Fresh growth of Cladophora. At high magnification, the alga is clearly seen to be branching

(Monostroma obscurum), Enteromorpha (Enteromorpha intestinalis, Enteromorpha linza, Enteromorpha clathrata, Elodea Myrisphyllus in fresh waters) and to a lesser extent Chaetomorpha and Cladophora. The main periods for the massive developments of macroalgae are spring and summer. The proliferation of these short-living macroalgae can compete with, and be detrimental to, autochtonous long-living (e.g. Fucus) species, much more interesting for biodiversity. In coastal areas their accumulation on beaches can reach thousands of tons and induce numerous nuisances including odour, making it impossible to use the beaches. In the Brittany region of France, it has been estimated that more than 50 000 tons of macroalgae are deposited on the beaches every year, requiring costly mechanical removal.

The effects of these macrophyte blooms on public health, including well-being and safety, are mostly linked to the recreational use of the water bodies, unpleasant aspect and decomposition odours. Recreational activities sometimes become impossible or dangerous, and in all cases unpleasant in areas affected by macrophyte blooms. Rare cases of allergies linked with macrophytes have been described.

C A S E S T U D Y

Trends in the Black Sea

Over the last 30 years the environmental quality of the Black Sea has deteriorated due to the eutrophication of the water, resulting in alarming algal overgrowth. Following the break up of the ecosystem between the 1970s and the 1980s, fish deaths were estimated at five million tons between 1973 and 1990, representing US$ 2 billion at market cost. A further consequence is that tourists have stopped visiting the coasts of the Black Sea leading to losses for the tourist industry. A study performed in the framework of the Black Sea Environmental Programme estimated in 1995 that the annual economic loss due to tourist disaffection in this region was close to US$ 360 million for a 10% decrease in the environmental quality.

The collapse of the economy in Central and Eastern Europe, and large Danube water protection programmes have led to a decrease in nutrients discharge and a decrease in the eutrophication (Roger Aertgaerts: personal communication).

19 Macrophyte: literally meaning a large plant as opposed to the single celled phytoplankton, includes seaweeds and flowering plants such as sea grass.

Finally, the consequences of these macrophyte blooms due to eutrophication can be seen on fishing activities. For instance some filamentous and mat-forming green algae such as Cladophora, have increased their coverage in many Baltic sites. Some of them are alleged to produce compounds toxic to herring' eggs. In addition, they induce fishnets clogging resulting in breakage and loss.

CASE STUDY

Aesthetic effects

Some algae, particularly of the taxa "Phaeocystis", produce a mucus, which when disturbed produce a foam. These algae are more prone to develop when there is little competition. It seems that in areas such as the south-east coast of the North sea, where all the silica has been captured by diatoms in estuarine regions, the residual nitrogen is used by Phaeocystis to bloom. They produce large amount of mucus which, if the weather is windy, will in turn be transformed into large amounts of foam covering extensive areas of beach and lake shores. Besides the impact on the landscape and the nuisance it represents for tourists, this foam is suspected of disturbing flat fish larvae development.

This phenomenon is frequently observed at the Belgian and Dutch coasts, and appears from time to time in Germany.

Foam originating from Phaeocystis bloom (May 1988, "Côte d'Opale", France)

Mechanical removal of macroalgae (July 1985, Lannion Bay)

In fresh waters, similar macrophytes, but also proliferating aquatic plants (for example Renunculus and Myriophyllum) can also strongly disturb the ecosystem, navigation and recreational use of rivers and lakes.

Effect of eutrophication on drinking water

In some specific cases, local authorities must rely on eutrophic waters for producing drinking water. There are two major risks for health in using such waters:

1. Risks linked to the presence of organic matter: Treating raw water with high levels of organic matter is always technically difficult. It can lead to the creation of carcinogenic by-products (Trihalomethanes (THMs), other chlorinated components or ozonides) as a result of their reaction with disinfectants. If the water is eutrophic, then on the top of the organic matter that would be present under normal circumstances, there will also be the organic matter produced by the cyanobacteriae (toxins and intracellular materials). An apparent association between bladder cancer and THMs has been demonstrated in one epidemiological study[20]. However, as chlorinated water contains a large number of by-products it is not possible from such epidemiological studies to conclude

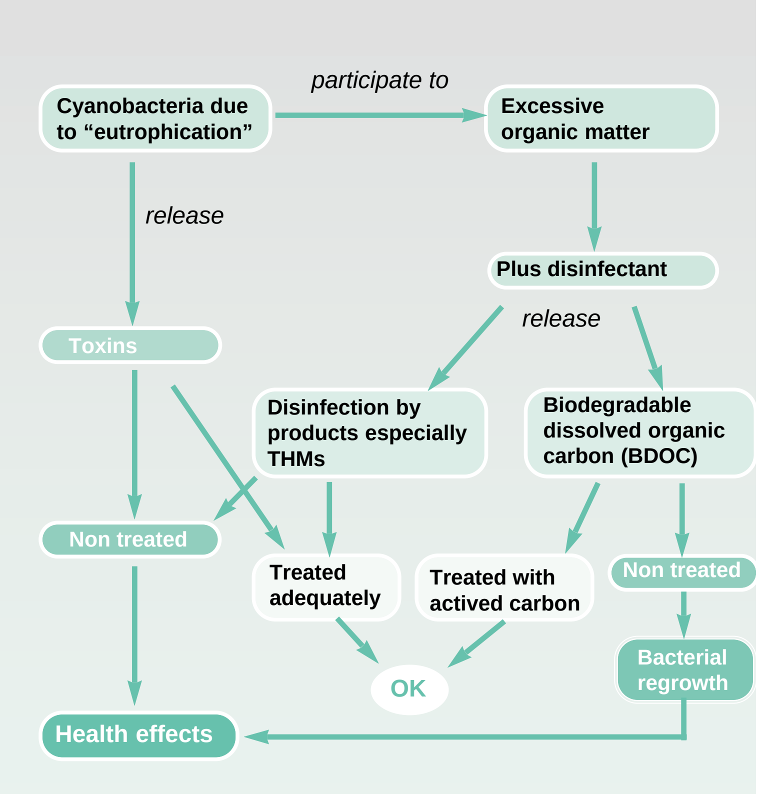
20 US EPA. Preliminary assessment of suspected carcinogens in drinking water. Report to Congress. Washington, DC, 1975.

that specific THMs are human carcinogens. The World Health Organization (WHO) propose guideline values for THMs in drinking water that range between 25 to 100 mg/l depending upon the compounds. However, and this point is the most important, WHO also points out “compliance with THM guideline values must not, under any circumstances, be at the expense of microbiological standards.”

For similar reasons, the EU directive 75/440 EEC has set guideline values for the organic matter content of raw surface waters used for drinking water production (30 mg/l for COD[21] and 7 mg/l for BOD_5[22]). These values are often exceeded during blooms.

2. Risks linked to the presence of specific cyanobacteria in fresh waters: When eutrophication leads to the development of cyanobacteria that are potentially toxic, the elimination of these toxins is complex.

Fig. 5: Possible health effects of chlorination of water with organic matter



21 COD: chemical oxygen demand
22 BOD: biochemical oxygen demand after 5 days

When faced with eutrophication of the water reservoir the best option, where possible, is to rely on an alternative resource for the water production. If it is not possible, then some changes can be made to the existing treatment chain, but there is no guarantee that the end product will be totally safe. Information of the receiving population is necessary. Distribution of bottled water to the population at risk can be an option to consider. More detailed information on the changes that can be made to the treatment process and on the resistance of toxins to various disinfectants can be found in the technical annex.

Monitoring of eutrophication

Monitoring is useful if it is performed for a purpose. The main reasons for monitoring a water body for eutrophication are:

- To prevent the occurence of eutrophication;
- Early warning purposes. Public health authorities need to know when eutrophication is likely to start in order to allow them to implement preventive actions;
- To know the level of development of the process, and have a precise picture of the quality of the water. This is mostly relevant for water companies, which have to deal with eutrophic waters;
- Research.

The reality is that monitoring systems are often multi-purpose.

Monitoring and management of cyanobacterial growth in fresh waters for public health purposes

Chorus and Bartram (1999) have proposed the following monitoring and management scheme to water treatment plant operators and managers as an alert level framework. It provides a graduated response to the onset and progress of a cyanobacteria bloom. This tool initially comes from Australia. Three response levels are defined:

- **Vigilance Level** is defined by the detection of one

Ulva Armoricana

colony, or five filaments, of a cyanobacterium in a 1 ml water sample. When the Vigilance Level is exceeded, it is recommended that the affected water body is sampled more frequently - at least once a week, so that potentially rapid changes in cyanobacteria biomass can be monitored.

- **Alert Level** 1 is initiated when 2,000 cyanobacterial cells per ml or 0.2 mm^3/l biovolume[23] or 1 µg/l chlorophyll-a[24] are detected. Alert Level 1 condition requires an assessment to be made of the total toxin concentration in the raw water. A consultation should be held with the health authorities for on-going assessment of the status of the bloom and of the suitability of treated water for human consumption. Monitoring should be conducted at least once per week. It may also be appropriate at this time to issue advisory notices to the public through the media or other means. Government departments or interested authorities or those with legal responsibilities should also be contacted, as should organizations that treat or care for members of the public with special needs.

- **Alert Level 2** is initiated when 100,000 cells per ml or 10-mm^3/l biovolume or 50 µg/l chlorophyll-a are detected, with the presence of toxins confirmed by chemical or bioassay techniques. This density of cells corresponds to an established, toxic bloom with high biomass and possibly also localized scums. In this situation there is a need for effective water treatment systems and an assessment of the performance of the system. Hydro-physical measures to reduce cyanobacteria growth may still be attempted.

If efficient water treatments are not available (see technical annex), a contingency water supply plan should be activated. In extreme situations, safe drinking water should be supplied to consumers in tanks and bottles. Media releases and contact with consumers should be undertaken via mail of leaflets informing that water may present danger for human consumption but is still suitable for the purposes of washing, laundry and toilet flushing.

National water quality monitoring programs

Few national water quality monitoring programmes include parameters which indicate eutrophication or a risk of algal or cyanobacterial overgrowth. In Europe, North America, Japan and Australia, local monitoring plans which check the occurrence of toxic species in areas where shellfish or fish are consumed, are implemented. This is based on sampling at strategic points and analysis of phytoplankton and/or shellfish. The frequency of sampling generally depends on the sea-

23 Biovolume: ratio of the volume of cells to the volume of water.
24 Chlorophyll-a: the green pigment found in most plants, responsible for light absorption to provide energy for photosynthesis.

Table 6: Frequency of monitoring of water bodies for phytoplankton and shellfish programs in EEC Member States

Country	Frequency of monitoring for Phytoplankton	Frequency of monitoring shellfish areas
Belgium	---	Weekly
France	Twice a month from Sept to April Once a week from May to August Once a week during alerts	Only during alert: Same as phytoplankton
Germany	Continuous	Weekly
Ireland	Once a month from Nov to April Twice a month in May Once a week from June to Sept	Beginning of June and mid-July
Italy	---	Weekly
Portugal	Once a month from Dec to April Twice a month from May to Nov Once a week during alerts	Systematic over 30 stations
Spain	Once a month from Dec to March Twice a month from April to June Once a week from July to Nov	Only during an alert Same as phytoplankton
The Netherlands	Weekly (Wadden Sea)	In the disgorging facilities
United Kingdom	---	Mussel sampling on the East coast

son. Table 6 summarizes the monitoring systems in some EU Member States. They only allow the monitoring of toxic blooms, which are only a part of the eutrophication consequences.

Technologies such as satellite imaging can be used to monitor large water bodies. The same technique can be applied to monitor the extent of high chlorophyll-a concentrations reflecting the phytoplankton biomass of the upper layers of the eutrophic area.

Possible parameters used for monitoring purposes

According to the definition of eutrophication, it is clear that formulae such as “an increase of x grams of bottom macrophytes per square meter” or “y micrograms chlorophyll-a per litre” are not suitable to define a threshold, which, when exceeded, will describe eutrophication. Such unique parameter does not exist.

Moreover, in order to define the magnitude of eutrophication, two measurements are required: That of the system in its reference conditions, and in its current or predicted future condition. As baseline data for a site is the exception rather than the rule, this makes it difficult to test eutrophication using a case-by-case approach.

Nevertheless, as the first signs of adverse eutrophication is a decrease in the oxygen concentration in the lower layers of the water body of stagnant waters, and an increase in pH due to photosynthesis (CO_2 depletion), these parameters, together with direct microscopic observations, are likely to be the only ones that can help forecast the likelihood of the start of such a process as long as a model integrating physical conditions, nutrient inputs and biological effects has not been locally validated.

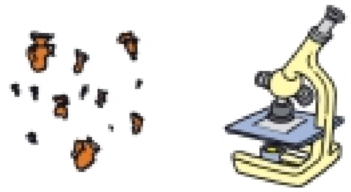
C A S E   S T U D Y

REPHY (Réseau de surveillance du phytoplancton et des phycotoxins)

The French Research Institute for Exploitation of the Sea (IFREMER) has created a phytoplankton and phycotoxins monitoring network (known as REPHY). It is limited to the coastline of continental France. Its objectives are to improve the knowledge of the spatio-temporal distribution of various phytoplankton species and to protect the consumers.

IFREMER undertakes regular sampling of seawater in order to identify both in quantitative and qualitative terms the presence of various species of phytoplankton and to monitor the toxicity of the water. This monitoring network has been in place since 1984 and has led to the identification of hundreds of episodes of toxic blooms. Only 12 of the 43 monitoring sites, representative of the whole continental French coastline, have never been affected. When toxicological tests (on mice) are positive, the information is provided to local authorities. They have the power to forbid recreational collection and professional sale of all filtering shellfish originating from the areas designated as contaminated. The three species that have a potential to lead to toxic episodes for human that have been identified so far along French coasts are Dinophysis, Alexandrium minutum and Pseudo-Nitzschia.

1st alert level



Count of Dinophysis cells in sea water. Threshold 300 per liter

2nd level - Mice test

3 mice are injected extracts of mussel's liver. Should the three mice die within 5 hours, shellfish collection is immediately prohibited.

3rd level - «Réseau Diamoule»

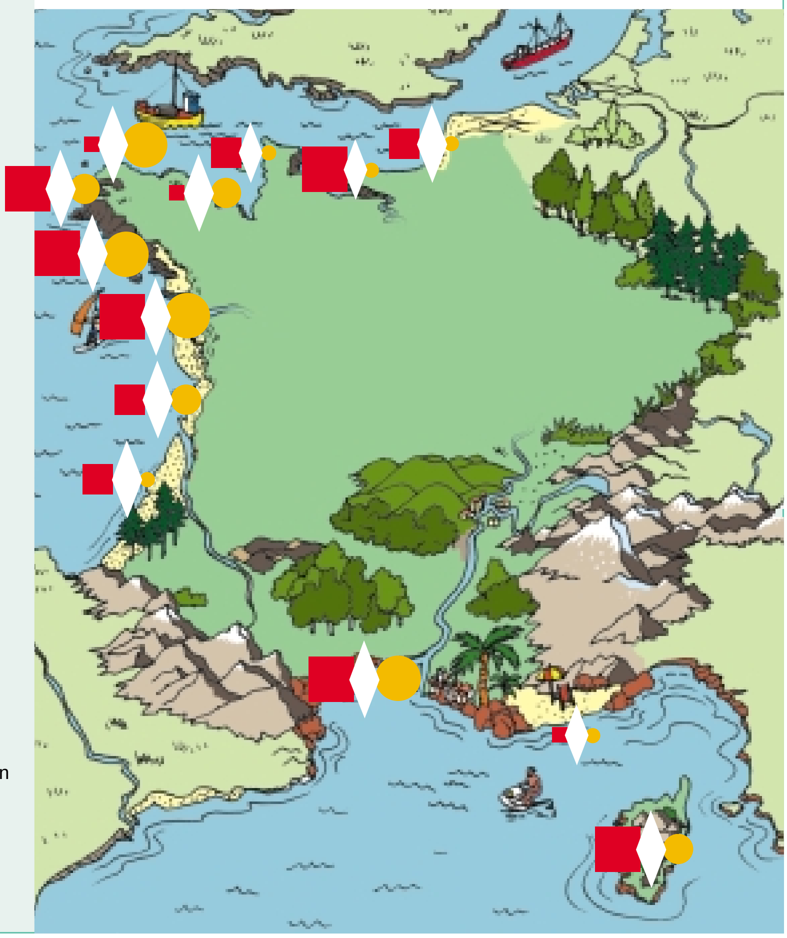
(From J. Duchemin)

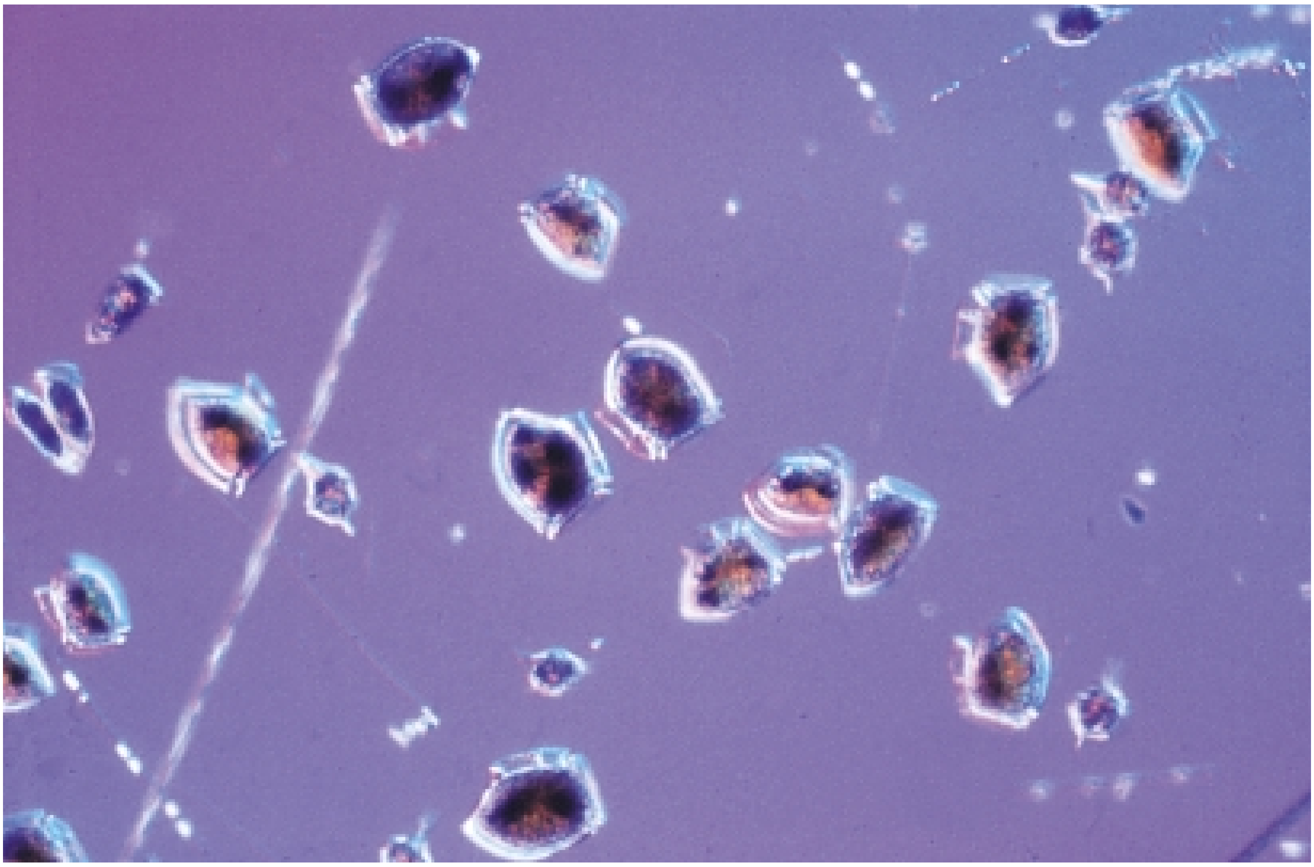
Medical doctors and pharmacists established along the sea shore are taking careful notice of any case of diarrhoea. All cases that would occur within 12 hours after consumption of mussels must be reported to public health autorities.

Maximum cell-counts cells per liter 1992 - 2001

The three main potentially toxic genus in France. The maximum cell count includes toxic and non toxic species of these genus

Dinophysis	Pseudo-nitzschia	Alexandrium
> 10 000	> 1 million	> 1 million
1 000 to 10 000	10 000 to 1 million	10 000 to 1 million
< 1 000	< 10 000	< 10 000





The potentially toxic dinoflagellate Dinophysis norvegica

Table 7. Parameters relevant to eutrophication monitoring

Parameter	Relevance to monitoring eutophication	Cost per analysis* (Euros)
Nitrogen and phosphorus	Indicators of eutrophication and potential bloom occurrence. Reflect the balance between a large number of physical and biological processes. Information is needed on both inorganic and dissolved organic forms of N and P.	60
Silicon (Si)	Indicator of freshwater dispersion and of potential for diatoms blooms. Si deficiency in coastal waters can favor dinoflagellates blooms.	10
Suspended solids	Relevant indicator for drinking water production.	15
Dissolved oxygen	Essential information with regard to eutrophication effects. It is the key indicator to detect the beginning of an eutrophication process	5
Bacteria	Microbial processes happen within the cycle of aquatic life and are relevant in the assessment of eutrophication and nutrients budgets.	10
Algal or cyanobacterial biomass	Increased algal or cyanobacterial biomass is a characteristic of eutrophication. Information is also useful for assessing the effects of eutrophication on the ecosystem. Biomass can be determined directly by microscopic counts or indirectly by measurement of pigments such as chlorophyll a. Others measures are available such as the determination of the amount of suspended particulate organic matter or the automated analysis of number and size of particles. It is a useful indicator for managers.	Variable
Development of short living species of macrophytes	Relevant indicator of a potential disturbance of the recreational ue of the waters and of a disbalance of the aquatic ecosystem.	Variable, depends upon the observation mode

** Costs are indicative*

Prevention[25,26]

The causes that drive eutrophication are multiple and the mechanisms involved are complex. Several elements should be considered in order to assess the possible actions aimed at counteracting nutrient enrichment of water supplies. The use of computerised models now allows a better understanding of the role of each factor, and forecasting the efficiency of various curative and preventive measures. The best way to avoid eutrophication is to try to disrupt those mechanisms that are under human control; this clearly means to reduce the input of nutrients into the water basins. Such a control unfortunately does not have a linear effect on the eutrophication intensity. Integrated management should comprise:

- **Identification of all nutrient sources.** Such information can be acquired by studies of the catchment area of the water supply. Knowledge of industrial activities, discharge practices and localization, as well as agricultural practices (fertilizer contribution/plant use and localization of crops) is necessary in order to plan and implement actions aiming at limiting the nutrient enrichment of water. The identification of sewage discharge points, agricultural practices, the nature of the soil, the vegetation, and the interaction between the soil and the water can be of great help in knowing which areas should be targeted.

- **Knowledge of the hydrodynamics** of the water body, particularly the way nutrients are transported, and of the vulnerability of the aquifer, will allow determination of the ways by which the water is enriched with nutrients.

Anthropogenic nutrient point sources such as non-treated industrial and domestic wastewater discharge can be minimized by systematic use of wastewater treatments. In sensitive aeras, industries and local authorities should control the level of nutrients in the treated wastewater by the use of specific denitrification or phosphorus removal treatments.

Diffuse anthropogenic nutrient sources can be controlled by soil conservation techniques and fertilizer restrictions. Knowledge of the agronomic balance (ratio of fertilizer contribution to plant use) is very relevant to optimize the fertilization practice and to limit the loss of nutrients. Diffuse nutrient losses will be reduced by implementation at farm level of good practices such as:

- Fertilization balance, for nitrogen and phosphorus, e.g. adequation of nutrients supply to the needs of the crop with reasonable expected yields, taking into account soil and atmospheric N supply.
- Regular soil nutrients analysis, fertilization plans and registers at plot level.
- Sufficient manure storage capacities, for spreading of manure at appropriate periods.
- Green cover of soils during winter, use of “catch-crops” in crop rotations.
- Unfertilized grass buffer strips (or broad hedges) along watercourses and ditches.
- Promotion of permanent grassland, rather than temporary forage crops.
- Prevention of erosion of sloping soils.
- Precise irrigation management (e.g. drip irrigation, fertilisation, soil moisture control).

In coastal areas, improvement in the dispersion of nutrients, either through the multiplication of discharge points or through the changing of their localization, can help to avoid localized high levels of nutrients.

Reuse and recycling, in aquaculture and agriculture, of waters rich in nutrients can be optimized in order to avoid discharge into the water body and direct consumption of the nutrients by the local flora and fauna.

25 see also “Nitrates” Directive 91/676/EEC-Annexes II and III
26 see also the Urban Wastewater Treatment Directive -91/271/EEC

Recommendation 1

Should eutrophic water be the only source available for the production of drinking water, all necessary preventive measures should be taken, among which the most important are:

- To limit to the maximum extent possible the amount of organic matters present in the water before final chlorination;
- To ensure that there is free chlorine available at the distribution point. Chlorination itself can ensure the destruction of most of the toxins released by fresh water blue/green algae blooms and is necessary for bacteriological safety.

Recommendation 2

Although all water receiving bodies do not have the same susceptibility to become eutrophic, all possible efforts should be made in order to reduce the discharge of nutrients such as phosphorus and nitrogen into the environment.

This can be achieved though various policies, two of which are particularly important:

- Reduction in the use of chemicals based on nitrogen and phosphorus (for example fertilizers, or P-builders in washing powders);
- Advanced treatments of wastewaters before their discharge into the environment.

Recommendation 3

In the marine environment, it is possible, with a reasonable level of certainty, to forecast the occurrence of algal blooms, and in some cases to predict the occurrence of toxic algae associated with the process of eutrophication.

All measures should be taken by local authorities in order to make such monitoring mechanisms available which allow implementation of the necessary protective measures to be taken in good time. As a consequence public health will be protected more efficiently than if waiting until a crisis occurs.

water

Eutrophication and health

TECHNICAL ANNEX

Table of contents

Measurements of toxins

Analytical methods capable of detecting algal toxins require specific laboratory experience and trained staff. They belong to two major classes:

(a) Those that detect whether toxins are present or not in a water sample. These are based on biological, enzymatical, or immunological methods.

(b) Those allowing the identification and quantification of toxins present in a water sample. These are more complex, usually based on physico-chemical methods, and used on purified water samples.

Physico-chemical methods are very sensitive and can be highly specific (i.e. able to selectively detect one toxin). However, they are not always conclusive about the global toxicity of the event. On the other hand, biological methods are less specific but allow the assessment of the global toxicity of the event. The specificity, duration and indicative costs of the major methods are presented in Table 8.

Whichever method is used the water sample should be kept in dark and cold conditions and the analysis should be performed as soon as possible after sampling to avoid the possible degradation of some toxins.

Table 8: Detection of toxins *(After Chorus and Bartram, 1999; AFSSA, 2001)*

Method	**Toxins**	**Cost** *Cap*	*Con*	*Pers*	**Response time**[27]	**Remark**
Biological						
Mouse	Global toxicity, hepatotoxins, neurotoxins	H	H	H	h-d[28]	Limited sensitivity and specificity
Artemia	Global toxicity	L	L	H	h-d	Limited sensitivity and specificity
Daphnia	Global toxicity	L	L	H	/	No correlation with human sensitivity
Bacteriological						
Microtox	Global toxicity	H	H	L	mn[29]	No specific, contested method
Enzymatical						
Phosphatase	Hepatotoxins	M	M	L	h	High sensitivity
Acetylcholinesterase	Anatoxins (a)	M	M	L	/	Good sensitivity
Immunological						
Elisa Monoclonal Polyclonal	Microcystins, Nodularin, saxitoxin	M	H	L	/	Highly sensitive
Physico-chemical						
HPLC/UV /MS /fluorescence LC/MS	All toxins	H/VH	M	L/M	Var	Variable sensitivities and specificities available Identification and quantification of toxins
GC/MS /ECD						Detection of very low concentrations
NMR						Analysis of numerous samples
MECK						Research application

Cap = Capital, Con = Consumable, P = Personnel, VH = Very High, H = High, M = Medium, L = Low.
HPLC = High Performance Liquid Chromatography, UV = Ultra-Violet, MS = Mass Spectrometry, LC = Liquid Chromatography, GC = Gas Chromatography, ECD = Electron Capture Detection, MECK = Miscellar Electrokinetic Chromatography.

27 Response-time : time needed for the laboratory to provide the result
28 h-d : hours or days
29 mn : minutes

Treatment of water bodies affected by blooms

When a bloom affects a water body, preventative measures can be taken either to limit its spread over unaffected areas or to treat the contaminated areas.

When the regulations of countries permit it, algicides can be used if no other solutions are available or efficient. Several algicides such as copper sulphate, chlorine and citrate copper are capable of killing algal and cyanobacterial cells. This will result in the release of their intracellular charge, including the undesirable toxin. This approach is radical and should be undertaken with caution. Algicide treatment of water bodies may result in adverse taste and odour of the affected water. Moreover, some of the algicides have undesirable environmental impacts which can lead to the selection of resistant species of algae or cyanobacteria. The efficiency of the algicide depends on the features of the water and especially the quality of the contact made between the product and the target. Examples of algicides include:

• Copper sulphate
This has been frequently used due to its efficiency and low cost. Copper, which is not biodegradable, can accumulate in sediments and could in turn affect phytoplankton, macro-invertebrates or even fish directly or indirectly by depleting the available oxygen.

• Copper chelates such as copper citrate
These can be used in hard and alkaline waters, where copper sulphate is less efficient.

• Oxidants such as chlorine or potassium permanganate.

In many countries the use of algicides is prohibited or strictly limited. Where they are permitted care should be taken not to allow the use of the water supply for drinking water production, for animal watering or as a recreational site during the treatment and until the toxins are degraded. This can take several weeks. Algicides should be applied when the cell density is low to avoid a massive release of toxins, which generally appears between three and 24 hours after the treatment.

If the bloom is well established, algicides could be the last option. These should only be used if the reservoir can be disconnected for several days.

Reservoirs which frequently receive water from lakes have their intake system equipped with a possibility of a catchment at different depths, allowing an intake from uncontaminated areas of the water column.

The case of intermediate artificial reservoirs

Reservoirs that collect water coming from a large area can accumulate high levels of nutrients which may lead to a bloom. Pre-reservoirs that temporarily store the water can reduce total phosphorous input by 50 to 65%. The removal of the sediment from these "pre-reservoirs" has to be done regularly in order to prevent the phosphorus being re-released, although not too often in order to allow the assimilation of the phosphorus by the biomass in the prestorage zone. When nutrients come from a single major inflow, phosphorous removal through chemical processes can be very effective.

Another way of controlling the proliferation of algae and/or cyanobacteria in sufficiently deep reservoirs is by physical means such as limiting the penetration of light or mechanically destratifying the water column.

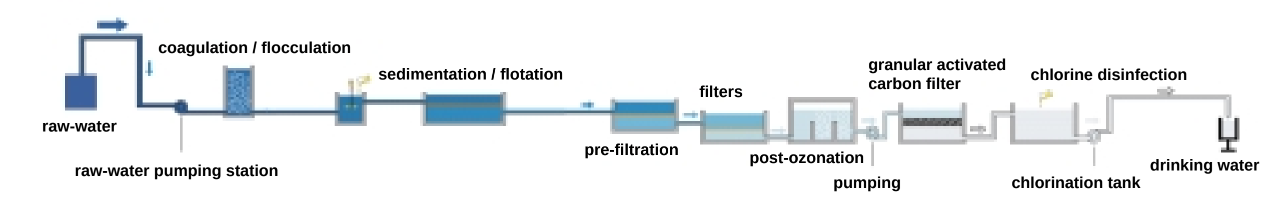
Treatment of eutrophic water for producing drinking water

The presence of large numbers of algal or cyanobacterial cells in raw water used for drinking water production creates four major problems:

- The mass of cells can disrupt the hydraulics of the water treatment process (resulting in clogging of filters and bulking of sludge)
- The cells and their by-products can degrade the aesthetic quality of the water, causing abnormal colour, taste and odour or, worse, produce harmful by-products
- In some cases, toxins may be released into the water, creating a health concern
- An indirect effect may be the release of an increased amount of biodegradable organic matter in the treated water that will in turn support the growth of undesirable bacterial populations. It is referred to in the literature as Biodegradable Dissolved Organic Carbon.

In addition to the treatment of such waters there is a need for the use of higher doses of reagents, which impact on the cost of the treatment.

A "typical" drinking water treatment chain able to head water with high coods of organic matters



Source: Michel Plumer, SAGEP, 2002

Conventional drinking water treatment, when carried out effectively (screening-prefiltration, coagulation-clarification, filtration), allows a good removal of algae and cyanobacteria.
Unfortunately, such a treatment is much less efficient to remove free toxins.

- **Screening-prefiltration:** Water treatment plants usually use screens to remove debris from the water. Screens have almost no effects on the removal of cyanobacterial cells, only the finest screens are able to retain the larger species.

- **Coagulation-clarification:** The aim of the coagulation process is through the use of chemicals (the so-called coagulants) to bring very fine particles to agglomerate with the coagulant in the form of larger particle called "floc". In turn, the floc is then removed during the clarification step (by sedimentation, flotation or filtration). The efficiency of such treatment depends on numerous factors including the dose, the nature of the coagulant and the water quality. This process is a good way to remove cells without bursting them. It is relatively inefficient at removing free toxins. Flotation is more efficient at removing cells than sedimentation because the flocs formed have a density very close to 1.

- **Filtration:** The major mechanisms that occur during filtration lead to the physical retention of particles, including large amounts of microorganisms and algae. Different types of materials can be used for this purpose, e.g. sand or anthracite coal. Depending upon the filtration rate the techniques are called rapid sand filtration, rapid mixed bed filtration, slow sand filtration etc. These techniques, depending upon their design and operation, lead to a medium to high rate of algal and cyanobacterial removal. Nevertheless filtration is not an efficient process for removing dissolved chemicals, in particular algal toxins.

The second mechanism which occurs during slow sand filtration is the biodegradation of some of the organic matter. It has a very limited effect on toxin removal.

Other water treatments can be considered in addition to the conventional ones:

- Activated carbon adsorption is an additional treatment, frequently used to remove dissolved organic matter. It can be used as a continuous or discontinuous treatment. Granular activated carbon (GAC) and particularly "biological" GAC is very effective in the retention and biodegradation of algal toxins. Powdered activated carbon (PAC) is added to the water at the beginning of the treatment chain. PAC, which can be added during the relevant periods i.e. algal blooms in the water, is more flexible in its use. Regular absorption tests in the laboratory are recommended to best adapt the doses to the amount of organic matter and to the specific toxins to be removed.

- Oxidation is used for several reasons in drinking water treatment: For disinfection purposes, in order to improve the coagulation/flocculation, or to control the colour and the odour of the water. Frequently used products are chlorine, ozone, chloramines, chlorine dioxide and potassium perman-ganate. Strong oxidants such as ozone (used after clarification) and free chlorine (used after filtration) can, to a large extent, remove free toxins[30]. Ozonation used at low doses in the pretreatment step can improve the efficiency of flocculation.

- Providing there is an efficient pretreatment of the raw water, membrane processes such as microfiltration, ultrafiltration or

30 Duguet J.P., Efficacité des traitements de potabilisation des eaux destinées à la consommation humaine vis à vis des toxines algales, in Techniques et sciences municipales, 9, pp75-83, Sept 2001

nanofiltration are very effective for removing the few algal and cyanobacterial cells left after the pretreatment. Reverse osmosis and nanofiltration removes all the existing toxins. Ultrafiltration, associated with PAC, is efficient for toxin removal.

When treating waters that contain potentially toxic cyanobacterial cells it is important to ensure that at the end of the treatment process there is free chlorine available for a sufficiently long time period. If insufficient doses of chlorine are used there will be an absence of free chlorine, and the toxins, in particular mycotoxins, will not be oxidized. The "CT" factor (concentration x time) is extremely useful in this respect. A rule of the thumb is that a CT[31] of 45 $mg.min.l^{-1}$, for free chlorine, is efficient to reduce the microcystin-LR level by a factor of ten. For example, a water containing 20 $\mu g.l^{-1}$ of microcystin-LR exposed to a free chlorine concentration of 0.5 $mg.l^{-1}$ during three hours (180 min) will be left with less than 0.2 $\mu g.l^{-1}$ of toxins (0.5*180=90, divided by a CT of 45 equals 2, i.e. a reduction of one in 10^2 or a division of the concentration by 100).

Disinfection with chlorine should be added to the treatment, with the necessary "CT", depending upon the toxin concentration in the raw water. It is not sufficient to rely exclusively on the efficiency of a treatment with activated carbon.

Prechlorination, as a preoxidation step, should be avoided in order to limit the production of THMs. If, for practical reasons, this cannot occur, then a high enough dose of chlorine should be applied. The presence of free chlorine will help minimizing the possible release of toxins from cyanobacteria. The toxins that are left after this treatment stage will have to be removed, if necessary, at a further stage (see graphic p. f26).

31 Duguet J.P. Is really algal toxins a health problem in disinfected waters? AIDIS/IWA International Seminar, Santa Fe, Argentina, Oct 2000.

Crisis management

In the event of algal blooms, short-term action such as those described below should be undertaken:

Public information

In areas at risk from toxic algal phytoplankton or cyanobacterial blooms, it is important that information is provided by local authorities to the general public. The written press, radio, television and internet are all helpful supports that need to be associated with. At the same time temporary warning signs should be posted along the water bodies affected by the bloom or adjacent land. At an early stage, the health officer and local medical personnel need to be provided with information on health issues associated with the bloom, including how to diagnose and treat affected individuals.

It is of good practice to inform people about:

- The risks of bathing or sporting activities in abnormally coloured or turbid waters;

- The anaphylactic phenomena, which may be experienced by allergic bathers or people walking along shores of a water body, affected by blooms. This may happen due to the ability of many algae to produce and release not only toxins but also allergizing compounds;

- The health risk connected to collecting and eating fish and shellfish during a bloom event;

The need to discourage domestic animals from drinking or bathing in fresh water affected by blooms and from grazing along the shore where scum has accumulated and dried.

Drinking water

- Contaminated water supplies should not be used for drinking water production during an alert or during a bloom event.
- If no alternative water supply is available, immediate action should be taken in order to check the quality of the water and especially to find out if it is affected (or likely to be affected) by a toxic bloom. If it is the case, the water should be treated accordingly to ensure it remains safe.

- If suitable water treatment processes are not available, specific measures should be taken such as preventing the consumption of the drinking water from the contaminated distribution network. Bottled or tanked water should be distributed as an alternative drinking source.

Adjacent water bodies

During a bloom event, in addition to the information measures, protection of the uncontaminated areas should remain a priority.

Bibliography, further reading and useful websites

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The WHO websites:

Headquaters:
http://www.who.int/water_sanitation_health/index.html

Regional office for Europe:
http://www.euro.who.int

The European Commission website
http://europa.eu.int

The European Environment Agency website
http://www.eea.eu.int

Eutrophication and health
(Local authorities, health and environment briefing pamphlet series; 40)
1.Eutrophication 2.Risk factors 3.Public health 4.Water pollution - prevention and control 5. Food contamination - prevention and control 6.Water supply 7.Water purification 8.Environmental monitoring 9.Local government 10.Europe

European Commission
Eutrophication and health
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Air
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- Transport and air
- Air pollution from wastes and solvents
- Energy and air
- Monitoring of air quality
- Asthma, respiratory allergies and the environment
- Air pollution and global effects
- Smog warning

Water
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- Lead and water
- Nitrates
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- Treatments II
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- Biological treatment of organic waste
- Recycling
- Waste minimisation
- Hazardous waste

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- Tools for town planning
- Travelling in cities
- Green cities, blue cities
- Urban networks
- City governance
- Urban health and socio-cultural aspects
- The city of the future
- Urban indicators
- Neighbourhood facilities
- Contaminated land
- Walking and cycling in the city

Noise
- Noise and health
- Acoustic measurement
- Noise and music
- Noise in schools
- Noise and traffic
- Noise and leisure
- Noise insulation
- How to face a complaint
- Local authorities as noise producer
- A healthy soundscape

Accidents
- Local policy for accident prevention
- Child accident prevention
- Accidents and the elderly
- Home safety
- Road safety
- Fire safety
- Water safety
- Play and leisure
- Playground safety

Housing
- Housing and health
- Sick building syndrome
- Asbestos and housing
- Kitchen and health
- Energy and housing
- Moulds and moisture

Radiation
- Radon
- Ultraviolet rays
- Before, during and after radiation emergencies
- Electromagnetic fields
- Radioactive wastes

Toxicology
- Lead and health
- Allergies and the environment
- Carbon monoxide poisoning
- Pesticides and health
- Mercury and health
- Asbestos and health
- Adverse reactions to food

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14

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