the blue pages

the IWSA information source on drinking water issues

SUMMARY

Water resource contamination has become a very real problem in the past few years, particularly in industrialised countries where the survey of water quality frequently indicates rising nitrate concentrations. This evolution has entailed numerous public interrogations and in this context, two issues must be considered:

- **a public health issue**, as nitrate concentrations in water resources frequently exceed the 10 mg N/l limit defined in most countries as one of the drinking water quality standards. Even if nitrate is not directly toxic for humans, this limit is kept on the basis of the precautionary principle. At present its adherence compels water suppliers to take specific treatment measures.

- **an environmental issue** as water contamination with nitrate may lead to alga blooms in the resource. These modifications of the ecosystem may persist and create activities that impact upon the water resource.

The agricultural intensification, the increase of chemical fertiliser use and organic manure production are considered as the main causes of nitrate contamination. Other anthropogenic nitrogen sources stemming from industrial and urban wastes have to be taken into account.
The first step of nitrate contamination management is the identification of nitrate sources and the understanding of the mechanisms responsible for the pollution. This information is hard to obtain because nitrate is involved in a cycle which includes both natural biochemical processes and anthropogenic activities and depends on the environment's natural conditions. Moreover, nitrate sources may vary with both time and space.

Nitrate concentration in the water resource also depends on transport mechanisms. Nitrate transport with runoff has a rapid effect on surface water quality, which leads to seasonal peaks of concentration. Alternatively, nitrate transport with slow leaching generally has a lag time effect on groundwater quality. Because of this delay, the improvement of groundwater quality may require quite a long time.
In facing the global increase of water contamination with nitrate, water suppliers have to develop two approaches in parallel.
A *curative approach* which treats the existing pollution but remains a short-term solution. Current available processes are specific as nitrate is not removed by conventional treatment techniques.
A *preventive approach* which should improve water quality in the long-term. At present, this approach is considered a necessity for a sustainable development and use of the resources. Three policy options have been developed to promote it, which are based upon persuasion, economic incentives and regulation. Preventive measures tackle the pollution up-stream of the water treatment plant: at its source (reduction of nitrogen loads from all anthropogenic activities) and during nitrogen transport from the soils to the water (reduction of the risks of agricultural nitrogen losses thanks to better land management).
The preventive action plans currently implemented demonstrate the need for good co-operation between all the stakeholders affected by this environmental problem and the need for the development of methodological tools to (a) elaborate relevant diagnosis of the contamination, (b) define preventive measures in a more global approach, and (c) evaluate the efficiency of the action plan.

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INTRODUCTION

The increasing nitrate concentrations in water resources and the increase in public questions concerning the nitrate risks have led to the current well-known "nitrate problem". Over the last 25 years, this problem has turned into a regional one in most industrialised countries. Modern agriculture is considered as a major contributor to this situation. However, at present, the "nitrate issue" is not merely a question of relationships between farmers, fertiliser manufacturers and drinking water suppliers: it is an environmental problem which also concerns scientists, politicians and the public.

The "nitrate issue" is complex as nitrate is included in a cycle within which natural biochemical processes as well as anthropogenic (agricultural, industrial and urban) activities occur. Furthermore, it involves the three compartments of the environment: soil. air and water. Thus, the simple word "nitrate" encompasses not only a chemical complexity (nitrate, nitrite, N-nitroseous compounds) but also biochemical, toxicological and epidemiological aspects.

At present, the required nitrate level necessary to supply a high quality drinking water is only just met because of high concentrations in the water resource. For technical and financial reasons, water suppliers have to implement curative as well as preventative strategies. the latter involving all the factors within the nitrogen cycle.

Sound scientific knowledge on nitrate exists, but public debate does not always reflect these insights. The following exists: even though nitrate is basically a vital element for plant growth and all forms of life in some way, it is considered today as a dangerous substance. This scientific knowledge needs to be known and nitrate management strategies must be defined on the basis of this knowledge.

This paper will focus on the aspects of the "nitrate issue" directly linked with water supply but also on all those aspects which need to be taken into account into a global management approach.

I - CHARACTERISTICS AND ORIGIN OF NITRATES

A - GENERAL INSPECTION

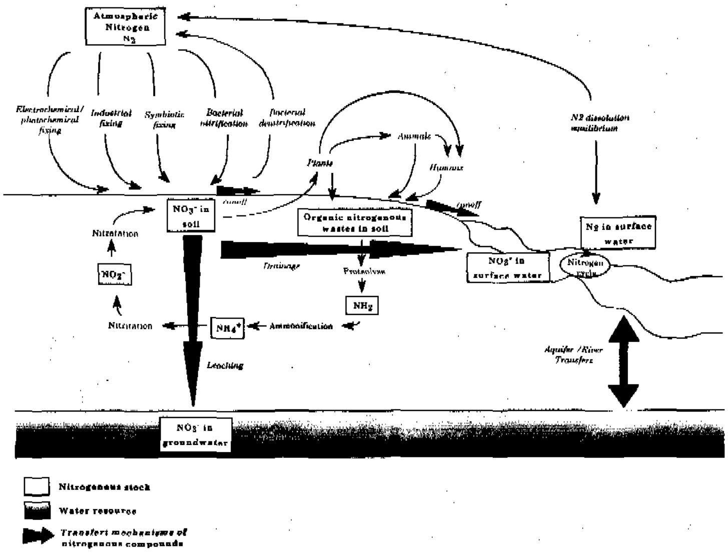
Nitrate (NO_3^-) is the stable ionic form of combined nitrogen and oxygen in aerobic environments. It is this nitrogenous form which is taken up by plants during their growth, for the synthesis of nitrogenous organic compounds and it is highly soluble in water, it is transported almost everywhere in solution. Furthermore, as nitrate is largely unreactive it may be stored in the environment (soil and water in particular).

Nitrate is mainly used for fertilisers, the production of explosives and glass making, and can be used as an oxidising agent.

B - NITROGEN CYCLE

The nitrogen cycle is the perpetual way a nitrogen atom goes from one living organism to another, infiltrating though either soil, air or water (see scheme below).

SCHEME OF THE NITROGEN CYCLE



Organic wastes from origins in soil contain nitrogen in protein form. Their first transformation step is protein degradation (proteolysis and ammonification of molecules) into ammonia nitrogen, by micro-organisms.
The second step is the nitrification (2 phases) performed by autotrophic bacteria:
1 - NH_4^+ is oxidised into NO_2^- by *Nitrosomonas,*
2 - NO_2^- is oxidised into nitrate (nitration) by *Nitrobacter.*

Protein biosynthesis, after nitrate uptake by plants. follows the reverse way. The plant proteins are the starting point of all animal and human proteins.
The nitrogen cycle also involves an atmospheric nitrogen pool as:

- some denitrifying bacteria in soil transform nitrate to nitrous oxide (N_2O) and nitrogen gas (N_2) is then released into the atmosphere.
- alternatively, several phenomena allow atmospheric nitrogen fixation:
- natural phenomena which are specific bacteria (Azotobacter and Rhizobium) and storms (during which released energy stimulates nitrogen and oxygen bindings under nitrite and nitrate forms);
- anthropogenic mechanisms, which fix nitrogen thanks to industrial means.

C - ANTHROPOGENIC NITROGEN SOURCES

Three main anthropogenic nitrogenous sources need to be considered, agriculture, waster water and domestic waste, as they spread nitrate heterogeneously in the environment:

1. Agriculture is the main human source of nitrate in the environment. This nitrate originates from synthetic fertilisers (inorganic nitrogen) and animal manure (organic nitrogen), spread on large surfaces. The increase in water resources, as indicated by environmental statistics and information collected by the Organisation for Economic Co-operation and Development (Annex 1).

2. Waste water from domestic and industrial sources (food factories, fertilisers and explosives producers, tannery, distillery, abattoir, sugar refinery) is the second main source of nitrogen discharge in receiving waters. These sources are mainly concentrated in heavily urbanised catchments (Annex 2).
3. Urban areas and more generally any source of organic waste (domestic wastes) may also lead to a significant discharge of nitrogen into the environment.

II - WATER RESOURCES CONTAMINATION WITH NITRATES

PREAMBLE

Evaluation of nitrate concentrations in water may be achieved thanks to several analytical methods, which are mainly based on colour measurement.

A - CONTAMINATION CHARACTERISTICS

Due to the characteristics of its sources, the water resource pollution with nitrate may be:

- accidental: such pollution is unforseeable, lasts a short time and originates in a point source of nitrogen (mostly of industrial or agricultural nature such as sewer break, accidental discharge of fertilisers),

- punctual and chronicle: this pollution occurs regularly, coming from the same area and often with rain events (leaching of domestic wastes, discharge of sewage effluent, industrial wastes...)
- diffused: this pollution originates from nitrate applied on a large land area for intensive agriculture. In that case, because of its solubility and stability in water, nitrate not taken up by plants is stored in soil and pollutes surface waters and groundwaters due to draining and leaching mechanisms. The partition of transported nitrate between groundwater and surface water depends on the dominant flow direction in soil being either horizontal or vertical. This direction is mainly influenced by soil porosity, the existence of a drainage system, land use, hydrology, hillslope and agricultural practices.

B - GENERAL PATTERN OF ANNUAL NITRATE VARIATIONS IN WATER RESOURCE

1 - SURFACE WATERS

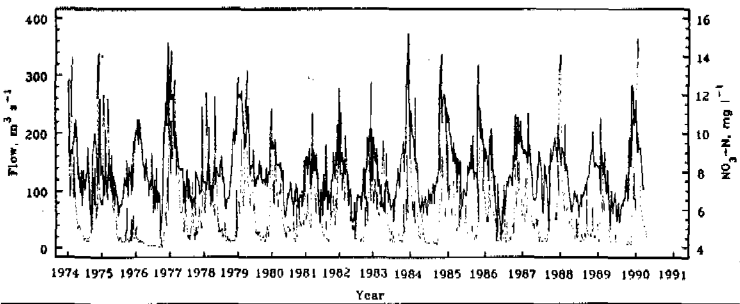
Nitrate in surface waters originates either from agricultural loads of nitrogen or urban (industrial and domestic) discharges. Contamination characteristics depend on relative importance of these two nitrogen sources at geographical scale. In the case of the surface water, seasonal variations of nitrate concentrations are observable, reflecting the instream nitrogen cycle. The occurrence of nitrification and denitrification in water depends mostly on temperature, pH and oxygen concentration.

Seasonal concentrations in the river also depend on the variations of agricultural nitrogen loads to the river (linked with nitrogen cycle in soil). The peak of nitrate concentrations often occur in winter with higher concentrations in wetter winters particularly in agricultural catchments. This high-concentration season coincides with the period when nitrates from arable post-harvest land becomes available. During that period, plant uptake of nitrogen is zero and degradation of nitrogenous organic compounds is high. For surface water, part of this nitrate pool drains to the river.

Later in winter, levels tend to decrease as nitrate is absorbed by plants. During the summer months, when the water temperature exceeds 15 to 20ºC, nitrate levels in river waters can meaningfully decrease, due to bacterial denitrification.

[* PICT is empty or cannot be processed. I In-line Graphic *]

Nitrate concentrations and flows in the River Thames between 1974 and 1991



Two types of nitrate contamination are to be considered:

- low level concentrations in main stream sustained by low-nitrate water pools (located in mountains, for example) which allow the dilution phenomenon;
- higher levels in lower-flow streams. In these cases, seasonal nitrate peaks are important particularly if the stream is located in an agricultural area and the catchment is small (less chance of dilution).

2 - GROUNDWATERS

Nitrate in groundwater comes mainly from agriculture that engenders stains of product geographically spread out. The appraisal of agricultural nitrate contamination needs specific survey programmes. Annual nitrate variations in groundwater depend on the depth of the aquifer, the type of soil, the geology of the catchment and in particular on the unconfined/confined characteristics of the aquifer (this explains the great spatial heterogeneity of contamination).

Unconfined groundwater is directly and rapidly recharged by percolation of water through the land surface. The seasonal characteristic of the contamination is similar to that of surface water (highest concentrations in autumn and early winter). Indeed, another part of the nitrate pool in soil, available in autumn, is transferred with leaching to groundwater, but because of the slowness of percolation mechanisms, the unsaturated zone often acts as a buffer and the magnitude of concentration variations is less important.

Confined groundwater is commonly a source of low-nitrate water as nitrate loads in the resource can only take place locally where the aquifer is recharged. Today, the major concern is that significant pollution recently noted in the unconfined section of certain aquifer may migrate into the confined strata.

D - PRESENT STATE APPRAISAL OF WATER RESOURCE CONTAMINATION

Recent reports by the OECD have commented upon significant increases in nitrate pollution over the last 30 years in water resources, indicating that:

- nitrate is the most commonly identified pollutant in groundwaters
- for either surface or ground waters, the nitrate problem is most serious in Western Europe - significant increases have been observed in the Netherlands, Belgium, France, Italy and Sweden[4] and North America and less serious in Asia, Africa and South Africa.

The main phenomena explaining this situation are post-war changes in farming practices (intensification of agriculture and fertiliser use, changes in landscape and land use) and multiplication of high-concentration point sources of nitrogen (concentration of industrial and domestic discharges).
The OECD overview of the state of contamination has to be carefully considered. Due to the pronounced lack and the strong heterogeneity of monitoring data for nitrate in water resources, only data from main water resources are usually taken into account. The importance of the problem may be underestimated.
For surface water in particular, sustained by large volumes of low-nitrate water from headwaters, important contamination of tributaries in the middle or lower parts of the catchment may easily be overlooked, if they are not specifically sampled, because of dilution of their nitrate loads by the main river channel.

E - LONG TERM TRENDS OF CONTAMINATION

Due to slow percolation through the unsaturated zone:

1. Groundwaters in Europe and USA which have shown a steady rise in nitrates may remain contaminated for decades, even if there is a substantial reduction in the nitrate loading of the surface;
2. Aquifers, which have not yet shown the expected nitrates increase from the increased use of nitrogen fertiliser or manure, are endangered today because of this nitrate accumulation in the soil column, potentially leachable.

In main river channels, often supplied with shallow groundwaters, particularly during periods of low flows, a background contamination may be observed during the whole year, giving evidence of the nitrate transfers from contaminated groundwater to the river. The delay of nitrate removal from groundwater may induce a similar delay in the removal of the background contamination of such rivers. Meanwhile, specific agricultural or urban measures aiming at reducing nitrogen discharge to the rivers should lead in the middle term to the reduction of the magnitude of the nitrate peaks in surface waters. This effect should be particularly important in small river basins.

III - NITRATE: RISKS AND ISSUES

A - PUBLIC HEALTH

When considering human exposure to nitrates the exogenous sources of the product are water and food. Most of the nitrogenous contributions come from vegetables (approximately 80% of ingested nitrates) whereas drinking water usually represents between 10% and 20%.

Nitrate concentrations in vegetables, in mg NO_3^- / kg of fresh weight

Vegetable	Extreme Values	Average
Artichoke	16-26	21
Aubergine	79-350	215
Beetroot	780-2310	1900
Carrot	22-885	154
Celeriac	85-3490	870
Cabbage	90-645	380
French bean	36-609	265
Lettuce	224-2720	1180
Potato	26-462	152
Radish	1430-2600	1510
Spinach	1141-2600	1870
Tomato	2-52	26
Turnip	2030-3721	2870

1 - RISK OF METHÆMOGLOBINÆMIA

Methæmoglobinæmia results from the oxidation of haemoglobin by nitrite. Methæmoglobin cannot transport oxygen in the blood and thereby leads to cyanosis and total asphyxia of the organism in some cases. Nitrite is formed by bacterial reduction of nitrate in the body (in the mouth, stomach and the lower part of the intestine). In average only about 5% of the ingested nitrate is transformed to nitrite in the human body.

The normal level of methæmoglobin in blood is less than 2% for adults and 3% for infants. As the enzymatic reductor system ensuring this equilibrium is only 50% efficient in infants, they are more sensitive to methæmoglobinæmia. Other groups such as pregnant women or people deficient in glucose-6-phosphate dehydrogenase or methæmoglobin reductase are also at risk to methæmoglobin formation.

There are also cases of methæmoglobinæmia without any exogenous source of nitrates or nitrites that are due to endogenous formation of nitrites. Thus, the correlation between the amount of ingested nitrate and the risks of methæmoglobinæmia is not direct.

Nitrate in itself is not toxic, only the nitrite directly ingested or in situ built from nitrate cause methæmoglobinæmia in humans. Nitrate needs other factors to be present to cause methæmoglobinæmia.

2 - CARCINOGENICITY

A carcinogenic risk has been first considered as:

- ingested nitrate can be reduced to nitrites in the human body,
- nitrites may react with amines to form N-nitroso compounds,
- N-nitroso compounds have been found to have a carcinogenic effect on animals. However, the quantities produced by the human body are far smaller than those proven to cause cancer in animals.

This led the WHO's experts as well as the Human Food Scientific Committee (of the European Commission) to recognise that *"there is no clinical or epidemiological proof to admit the responsibility of alimentary nitrates in risks of cancer in humans".*

Restrictive measures are kept towards this product as a precaution principle.

B - ENVIRONMENT : EUTROPHICATION OF FRESH AND COASTAL WATERS

Eutrophication is the result of enrichment of surface water by nutrient (primarily nitrogen and phosphorous). Consequences of this failure are:

- for the environment: the change in the freshwater and marine ecosystem (increase of the algal production resulting in the decrease of the oxygen concentration and the increase of organic matter leading to a general asphyxia in the resource);
- for drinking water supply: filter clogging, water colouring (development of phytoplankton giving a green or red colour), taste or odour, and in some case release of toxins.

Control of eutrophication depends on which nutrient is growth limiting: although phosphorous is commonly held to be the limiting nutrient, nitrogen may become limiting, depending on the characteristics of the catchment (land use, flushing rate of the water body, water depth, quantities of nutrients stored in sediments).

IV - GUIDELINES AND REGULATIONS ON NITRATE CONSUMPTION

A - TOLERABLE DAILY INTAKE FOR HUMANS

The first nitrate legislation was issued in 1962[9], when the Joint Expert Committee of Food Additives representing the World Health Organisation (WHO) and the Food and Agriculture Organisation, defined for nitrate a "Tolerable Daily Intake" (TDI) of 3.65 mg NO_3^-/kg. For a given product, the TDI is the quantity of product a human can ingest during his whole life without any effect. This value was defined by applying a risk coefficient of 100 to the TDI for rates (365 mg NO_3^-/kg) evaluated on the basis of a long term study. This value was then admitted by the Scientific Committee of Human Food of the European Communities Commission in 1990.

At present, some experts criticise the basis of the experiment and the considerations which have led to the definition of this TDI.

For preventing against methæmoglobinæmia in infants, a nitrite-TDI of 0.4 mg/kg B. W./day was also defined considering a body weight of 5kg, a daily intake of water of 0.75l and an allocation to water of 100%.

B - DRINKING WATER LIMITS

In 1962, on the basis of the risk of methæmoglobinæmia, the United States Public Health Service fixed a limit of 10 mg N/l (44.3 mg NO_3^- /l) in water, then used by the WHO (International) as a Guideline Value in 1971. This value applies for any human being, including pregnant women and infants below the age of 3 months. This value is based on the fact that about 5% of ingested nitrate is reduced to nitrite (the toxic agent) and derived from the nitrite-TDI.

The USEPA in 1977 and the Health and Welfare (Canada) in 1978 adopted this value as their maximum admissible concentration (MAC). In 1980, the EC Directive on Drinking Water 80/778 laid down 62 parameters relating to water quality provided for human consumption and defined 2 categories of standards that are required for nitrate: a MAC of 50mg NO_3^- /l and a "guide" level of 25mg NO_3^- /l (the latter is not an obligation). However, in some European countries, specific legislation exists. For example, in France, the regulation is as follows:

- consumption of a 50-100 mg NO_3^-/l water is tolerated except for pregnant women and infants under 6 months;
- consumption of a over-100 mg $NO_3^{-/l}$ water is forbidden.

At present, nitrate concentration in drinking water is regulated in many countries and based for the most part on the WHO guidelines.
Although the human health impacts of nitrate no longer appear to be acute, at least in the Western world, the precautionary principle prevails and no proposal has been made in any country for re-adjusting the standards.

V - POLLUTION MANAGEMENT

A - GENERAL APPROACH

In the short term, facing the global increase of water resource pollution with nitrate and achieving the nitrate MAC in drinking water causes several policy implementation problems. Two possible strategies have been developed to manage nitrate concentrations in potable waters.

- short term - curative engineering solutions, which aim at controlling existing contamination and solving it;
- long term - preventive measures, which tackle the problem at source and aim at anticipating the pollution or managing it. These kinds of measures are more admitted as necessary for ecological (nitrate is a long term pollutant), technical and financial (realistic means available to remove nitrate from water) reasons.

Depending on water catchment characteristics, comparisons between preventive and treatment scenarios may lead to similar costs. However, the environmental effects are incomparable as the time scale as well as the scale for the preserved or restored water resource are different.

B - CURRENT STATUS OF CLEAN-UP TECHNOLOGIES FOR NITRATE REMOVAL FROM WATER

In the context of the 1980s, important effects were devoted to adapt known denitrification concepts to the low concentration ranges of interest for the treatment of drinking water. The main challenge was the cost reduction. Since that date, specific treatment processes in the water plant or upstream (in situ denitrification of groundwater, wetlands and storages) have been applied in a limited number of cases as a last resort and for tackling temporary nitrate peaks in water supplies. Indeed, in most cases and for economical reasons, the engineering solutions firstly studied are blending of waters from different sources, connecting to approved water supply, relocation of wells within the confined section of an aquifer or use of surface water. However, current evaluations show that in numerous cases, achieving the drinking water standards may soon be no longer possible without specific technologies for nitrate removal.
Existing industrial processes are specific as nitrate is not removed by conventional water treatment techniques. Most of them are recent and have treatment capacities between 25 and 300 m^3/hour. Two types of processes[13] exist:

1 - PHYSICAL PROCESSES

These processes do not reduce nitrate pollution but concentrate it in eluates, which need to be managed in discharge channel (disposal is commonly directed into a waste water treatment plant). These processes only displace the problem and do not solve it in a definite way.

Ion exchange resins

This is the physical process that is most commonly used for treatment of nitrate-contaminated water. Water is passed through ion-exchange resin beds, which absorb anions, including nitrate, in exchange of other anions (commonly chloride). When the absorption capacity is exhausted, the resin is regenerated with sodium chloride solution.

The main advantage of this process is its low-capital-cost. But there are also some drawbacks:

1. For resins which are not nitrate selective, carbonates and sulphates may also be absorbed. This phenomenon reduces the efficiency of nitrate removal. It also leads to a saline waste water flow which is unsuitable for disposal on agricultural land.
2. Water needs to contain low levels for suspended solids (less than 1 mg/l), organic matter, iron and other oxidising agents, before being passed through the resins.

Membrane Processes

- Reverse osmosis: A hydraulic pressure, exerted on one side of a semi-permeable membrane, forces water across the membrane, leaving salts, including nitrate, behind. The relative volume of treated water and concentrated waste water produced is governed by the differential pressure across the membrane.
- Electrodialysis: The membrane allows ions to pass through it but not water. The driving force is an electrical current which carries ions through the membrane. With stacks of alternate anion and cation permeable membranes, it is possible to produce a treated and a concentrated stream. In the case of reverse electrodialysis, the current is reversed on a regular basis to prevent problems of calcium scale formation.

These membrane processes have not yet been applied that much at an industrial scale, because of their prohibitive capital and running costs (due to power consumption). For both processes, the concentrate flow varies from 5 to 20% of the throughput. Nitrate-selective membranes are now available. They improve the proportion of nitrate removed relative to other ions and make the process more cost-effective.

A new process that combines membranes bioreactor (MBR) technology and powered activated carbon (PAC) has been developed at industrial scale at Douchy in France. This process known as BIOCRISTAL® denitrifies, removes natural organic matter (NOM) and pesticides and disinfects. Denitrification is carried out by heterotrophic bacteria using ethanol as a carbon source. PAC added to the bioreactor adsorbs pesticides and a fraction of NOM. The membrane keeps the solids and high-molecular-weight compounds in the bioreactor by separating them from the treated water. Ultrafiltration removes protozoa, bacteria and viruses, thus achieving disinfection. Chlorine is added to the ultrafiltrated water to maintain quality in the distribution system.

2 - BIOLOGICAL PROCESSES

In-water plant biological treatment process

Specific bacterial species, concentrated in biological reactors, use nitrate as an electron acceptor in their respiration process. These electrons come from a food/energy source.
A wide range of biological denitrification processes have been developed, which vary in the type of food/energy source and the nature of the support bed:

- Processes using heterotrophic bacteria whose energy/carbon sources are organic compounds (methanol, ethanol, acetic acid). This biological treatment is the most common;
- Processes using autotrophic bacteria which obtain energy from inorganic chemical oxidation (hydrogen) and carbon from CO_2/bicarbonate. These bacteria have very slow denitrification kinetics. The required contact times are high and the percolation rates achieved are low (0.5 to 1 m/'h). Such techniques are therefore difficult to apply at an industrial scale.
- Processes using support beds of gravel, plastic media or fluidised sand.

A denitrification process is usually composed of two reactors:

- an anoxic reactor where denitrification reactions occur;
- an aerobic reactor for water reoxygenation, elimination of suspended solids issued from the anoxic reactor, ammonia (issued from raw water), nitrite traces (appearing when anoxic filters restart after a long interruption) and potential excess of ethanol.

These processes offer the advantage of eliminating nitrite in water and producing no waste to be treated. But there is also a drawback: in the denitrification process, the amount of food/energy source entering the water supply system has to be carefully controlled, in order to prevent any problem of bacterial growth in the distribution pipework.
Compared with the ion-exchange resin process, the biological denitrification process has approximately the same running cost but twice the capital cost.

In-situ biological denitrification techniques

These techniques rely on the denitrification potential of some aquifers, wetlands or storage offering anaerobic characteristics. They were mainly developed in the USA, for water plant using groundwater resource. Their principle is as follows:
Denitrification is initiated by the injection of a carbon source, within the aquifer, at strategic points around an abstraction well. This technique offers potential advantages with regard to capital costs because plant equipment requirements are minimal. However, its application is likely to be limited to relatively homogenous aquifers. The area of land required may be substantial, depending on the aquifer properties and the denitrification level required. The risks associated with failure of *in-situ* techniques are much greater than those for treatment plant (risk of aquifer blockage or acidification by sulphate and ferrous ions leading to borehole abandonment).
Denitrification is currently viewed as a key process in nitrate control. But the value of denitrification in nitrate control at the catchment scale depends on the nature of the gaseous end-product: while nitrogen (N_2) is acceptable, nitrous oxide (N_2O) is regarded as a serious atmospheric pollutant (the ratio N_2/N_2O produced through denitrification is largely determined by soil factors).

C - PREVENTION AND MANAGEMENT OF NITROGEN SOURCES

Although agricultural intensification is considered as the major source of nitrogen enrichment, a preventive approach of water contamination with nitrate has to tackle all nitrogen sources simultaneously - agricultural, industrial and domestic.
Management of nitrogen in receiving waters is also a question of getting the right scale of investigation and interpretation. A preventive approach involves a whole water catchment. It is indeed a topographical and hydrological unit which allows the evaluation of the efficiency of integrated measures.

1 - TECHNICAL PRACTICES TO REDUCE NITRATE LOSSES TO WATER RESOURCE

Many technical measures are currently available whose objective is both:
- to reduce nitrogen loads from anthropogenic activities
- to reduce the risks of water resource contamination with agricultural nitrogen in particular, once it is in soil.

Management of agricultural nitrate

Three types of agricultural measures may prevent nitrate in drinking water while retaining benefits associated with its on-going use[8].

A. Management of crop systems
The following four management systems minimise nitrate losses if they are suitably adapted to local conditions:

- nitrogenous fertilisation management (timing and rate of fertiliser application);
- definition of technical practices adapted to plot potential (timing of establishment and sequence of successive crops, drills direction with regard to the slope);
- use of nitrate-trap-crops and maintenance of crop cover during the critical autumn period;
- better use of animal manure (timing and methods of application, use as a valuable source of nutrients for crop growth rather than waste) and of grassland;
- use of green N-fertilisers (leguminosæ such as clover, lucerne, lupin...) which release slowly inorganic nitrogen when they decay in soil and reduce in the same way risks of nitrate seeping into the surrounding groundwater.

B. Landscape Modifications

- agriculture extensification (set-aside and fallowing of lands, reduction of intrants) in order to reduce nitrates pool in soil;
- valorisation of natural denitrifying areas (wetlands...);
- reduction of water and nitrate transports thanks to planting of grass-strips, hedges, trees.

C. Best management of animal manure before application on fields[8]:

- optimisation of livestock diet in order to reduce slurry quantities and the nitrogen volume it contains;
- changing the stalling, improving the manure collection and storage in order to minimise risks of accidental nitrogen discharge in the environment;
- installation of curative treatment of animal manure, if the quantities produced are superior to those the agricultural surfaces can receive.

Reduction of nitrogen wastewater disposal

For urbanised areas, waste water management necessarily involves specific treatment plants. In these areas, measures to reduce nitrate loads are the improvement of the waste water collection and the efficiency of nitrogen treatment in waste water treatment plants.
In rural areas, where habitat is widespread, collective treatment of waste water cannot often be applied for technical and financial reasons. There, individual or semi-collective treatments have to be implemented.

2 - PRACTICAL IMPLEMENTATION OF THESE MEASURES

To be implemented at the water catchment scale, nitrate management requires a logical step-by-step approach:
1 - Diagnosis of the water resource contamination. To be relevant, this diagnosis has to be based on both an appropriate sampling campaign (frequency and location of the samples) and a study of the water catchment. The latter has to focus on environmental characteristics (soils nature, climate, hydrology, geology, land use, topography...) and human activities (agricultural, industrial, urban, others...) in the water catchment and their interactions.
2 - Identification of the main sources of nitrogen and pathways of nitrogen losses and contamination risks.
3 - Identification of the potential measures needed to reduce nitrogen losses and contamination risks.
4 - Feasibility study of the identified measures (from an economical, technical and sociological point of view) and selection of the most appropriate ones.

This approach has been implemented first on water catchment aimed at drinking water production but is now extended to others whose issue is more largely environmental.

Three policy options are used to implement nitrate management[1]. The first two mainly concern the management of agricultural nitrogen:

- persuasion, education and applied research: such measures mainly aim at informing farming populations about the external effects of nitrogen fertilisation on water and food quality. The more the population is concerned with overall social welfare and ecology, the greater effect persuasion will have.
- economic incentives: financially supported by governments, they offer the advantage of being compatible with the free-market economy. An example of such policy is the European agri-environmental programme inviting less intensive farming methods with reduced levels of fertiliser application (A3).
- regulatory and compulsory measures: although they require high effort of measurement and control, they are currently the policy most used to implement nitrate management.

3 - CATEGORIES OF REGULATIONS FOR NITRATE MANAGEMENT

In Western countries, the growing concern about contamination of drinking water, risks for human health and environment, has led to the multiplication of regulatory measures aiming at managing the nitrate issue either at the water resource or the nitrogen source scale.

a - Regulations of the nitrogen sources

-from point sources (for industries, wastewater plants and animal husbandry systems): these measures, specified for European countries in a Directive on wastewater treatment[17], aim at controlling nitrogen loads and limiting risks of accidental losses by strengthening permitted discharge standards and constraints on production systems;
- from diffused sources: it is, for example, the EC Nitrate Directive, concerning the protection of waters against pollution caused by nitrates from agricultural sources. This directive aims at deeply modifying agricultural practices and animal manure management in order for them to integrate environmental concerns. It compels Member States to designate nitrate sensitive areas (i.e. lands which drain directly or indirectly resources intended for drinking water and which already contain or would contain - if protective actions were not taken - nitrate concentrations above 50 mg / NO_3^- / l). Within these areas, preventative programmes have to be implemented, which prescribe farmers to respect a Code of Good Agricultural Practice (control of timing, amount and location of fertiliser applications, definition of quotas for nitrogen loads on fields). Formation and information programmes have also to be defined in order to promote the voluntary implementation of this Code of Good Agricultural Practice out of the sensitive areas. Finally survey programmes are defined in order to evaluate the efficiency of measures taken.
[Problem concerning the implementation of these measures, which are financially penalising for farmers.]

b - Regulation on the water intake (drinking water objective)

This kind of regulation concerns the definition of protection zones around water intakes[1]. For example, in France, this regulation takes place within a specific law on water which aims at managing the resource taking all activities interfering with it into account. In these areas, human activities are controlled in order to limit risks of accidental contamination. Practically, some industrial, urban and agricultural activities may be either forbidden or restricted (prohibition of certain highly nitrogen-intensive crops, prescription of certain agricultural practices and upper limits on the nitrogen input per hectare) as they present a significant risk to the resource.

4 - FUTURE DEVELOPMENTS AND FUTURE NEEDS

An increasing number of nitrate management programmes are currently implemented in western countries. It is too early to evaluate their success. At least they are beginning in the recognition of catchment planning as a solution to the nitrate issue, as attested by the increasing interest of regulation on this subject.

The current needs for the management of water contamination with nitrate concern:

1. The comprehension and evaluation of nitrogen transport mechanisms

   Models are helpful tools for the comprehension of this complex phenomena and there is a need to develop new models, which tackle the pollution at catchment level and in particular operational models considering the whole water cycle.

2. The diagnosis methods

   To make a relevant diagnosis, methods currently employed require the collection of numerous environmental data, a study in the field and involve the necessary participation of an expert. In order to reduce cost and time needed to make this diagnosis, there is a need for tools and methods which could give a preliminary diagnosis and assist the expert analysis.

3. The implementation of prevention programmes

   A stock of the programmes already implemented should be taken, from a technical, economical and sociological point of view, in order to prevent difficulties of implementation and evaluate time and costs needs.

4. The survey of contamination

   Facing the heterogeneity of monitoring data, guidelines for water contamination surveys should be defined in order to improve the relevance of the contamination appraisal and the comparisons between the state of different areas. Some tools could also be developed to manage and exchange data bases, information necessary for the control of nitrate.

5. The evaluation of preventive actions, the control of nitrogen losses and transport

   For all these points, specific and representative indicators have to be defined. As reduction of nitrogen concentration cannot be expected for several years, these indicators should be used to convince environmental actors of the efficiency of such programmes to enable them to carry on with the implementation of better practices.

6. The definition of efficient communication strategies particularly towards the public whose questions and reactions attest its lack of information on the subject.

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