In the shadow of climate change: reactive nitrogen and water

The world's governments are embroiled in a fierce controversy on how to respond to climate change, but in the wake of this debate, is action wanting on other serious global environmental issues? **JAMIE PITTOCK** argues that the increase in reactive nitrogen in the environment is being overlooked, and outlines the roles that the water sector can play in addressing this looming threat.

Last year a bevy of the world's scientists, led by Johan Rockström, published an assessment in Nature (452(7184): 202-205) suggesting that a 'safe operating space for humanity' involves remaining within nine planetary boundaries – environmental thresholds. Among other environmental attributes, thresholds are proposed for biodiversity loss, greenhouse gas emissions, an overly optimistic view of water extraction, and an as yet undefined level of chemical pollutants. Two other proposed thresholds involve the addition of nitrogen and phosphorus. The authors explain: 'Modern agriculture is a major cause of environmental pollution, including large-scale nitrogen- and phosphorus-induced environmental change. At the planetary scale, the additional amounts of nitrogen and phosphorus activated by humans are now so large that they significantly perturb the global cycles of these two important elements.'

Reactive nitrogen in the Earth's environment has increased by a factor of ten over the last 150 years and now exceeds production from natural sources. The manufacture of fertilizer for crop production and the cultivation of leguminous plants convert around 120 million tonnes of nitrogen gas from the atmosphere per year into reactive forms: more than the combined effects from all Earth's terrestrial processes. A smaller portion of nitrogen pollutions originates from combustion of fossil fuels. Much of this anthropogenic nitrogen ends up changing terrestrial systems, polluting waterways, aquifers and seas, and adding a number of gases to the atmosphere. The 20-25% of excess nitrogen carried by rivers to the sea contributes to the formation of more than 400 dead zones in marine environments. The authors propose as 'a first guess' setting a planetary boundary for human modification of the nitrogen cycle to 'contain the flow of new reactive nitrogen to 25% of its current value, or about 35 million tonnes of nitrogen per year'. In other words, the proposed threshold for safe levels of nitrogen is already being considerably exceeded.

Writing in response, Dr William H Schlesinger, President of the Cary Institute of Ecosystem Studies, USA, criticises the proposal: 'This threshold for nitrogen seems arbitrary and might just as easily have been set at 10 percent or 50 percent,' but he explained to *Water21* that 'too much nitrogen in the environment leads to losses of nitrate to surface and groundwater, to the release of nitric oxide to the atmosphere (where it is a precursor to the formation of ozone) and to the release of nitrous oxide to the atmosphere, where it is a greenhouse gas and a destroyer of stratospheric ozone'.

Patrick Mulholland, a Senior Scientist at the Oak Ridge National Laboratory, USA, elaborates: 'Humans have doubled the input of nitrogen cycling in the environment. Although nitrogen is an important plant nutrient that increases crop productivity, when it runs off from agricultural lands or urban areas or is deposited from the atmosphere in rainfall and enters streams, rivers, lakes and eventually the oceans it can cause many harmful effects – including acidification of headwater streams, excessive and sometimes toxic algal blooms in lakes and estuaries, and large "dead zones" (areas devoid or with very low oxygen levels) in many lakes, estuaries, and the coastal oceans. These harmful effects of excessive nitrogen in the environment appear to be on the increase worldwide.'

Concerning water resources and human health, Dr Rob Collins, a water expert at the European Environment Agency, explains: 'Excessive levels of nitrogen released to water bodies are a primary cause of eutrophication, characterised by the growth of nuisance algal blooms and an associated loss in aquatic life. Moreover, some algae produce toxins that pose a threat to public health via freshwater and marine recreation. In addition, the presence of excessive levels of nitrogen in sources used for drinking water requires treatment, imposing significant capital and operating costs. Major health impacts of high nitrogen

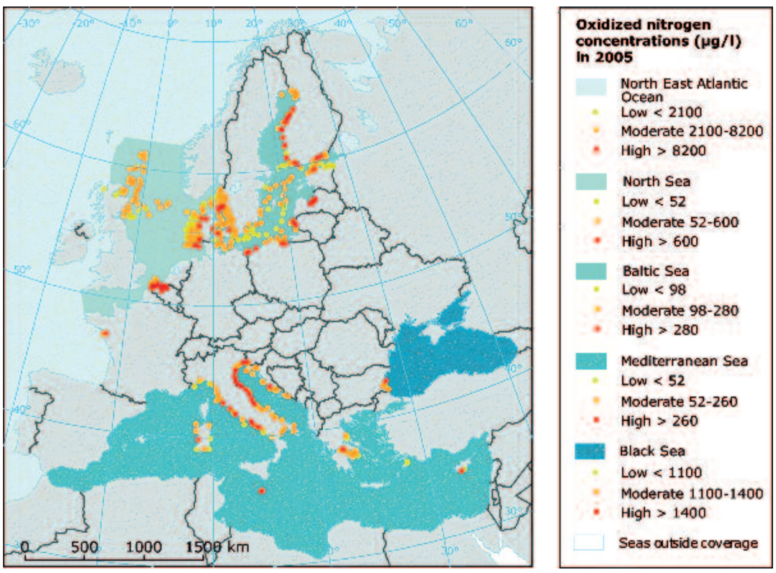

Figure 1: Map of winter oxidized nitrogen concentrations observed in 2005. EEA (2009) Nutrients in transitional, coastal and marine waters.

levels in untreated drinking water, such as cancer and reproductive risks, are poorly understood. Nitrogen compounds emitted to air are also major cause of the acidification of soils and freshwaters following subsequent deposition onto land. Fish mortality is well documented in severely acidified rivers and lakes.'

The climate change link

Nitrogen-based gases are also the most important non-CO_2 greenhouse gases with the greatest warming potential. Although there has been a focus on CO_2, non-CO_2 gases are responsible for about 45% of total radiative forcing (heating the climate), and nitrous oxide makes up nearly a fifth of this amount. Nitrous oxide is of particular concern in driving climate change as it has a long lifetime in the atmosphere – 114 years – and a global warming potential 310 times higher than CO_2 over 100 years. Dr Schlesinger notes that: 'On the positive, nitrogen makes plants grow faster, so they might take up more carbon dioxide from the atmosphere and store it in their tissues – enhancing carbon sequestration. On the negative, nitrogen added to the environment often results in the emissions of nitrous oxide, which is a more powerful 'greenhouse' gas than carbon dioxide.'

What should we do?

The nitrogen pollution problem varies by region. On the positive side, the rate of nitrogen pollution has slowed in some developed countries, but acceptable levels have not yet been achieved. A rare successful response is reported by the European Environment Agency for the European Union (EU)-15 nations, where emissions of nitrogen oxides declined by 31% and ammonia by 22% between 1990-2007 as EU directives were implemented. Dr Collins says: 'Agriculture is a major source of nitrogen emissions to both air and water. In Europe, ongoing implementation of the Nitrates Directive imposes limits on how much nitrogen can be applied to agricultural land, requiring also the provision of sufficient manure storage capacity. Recent reporting under the Nitrates Directive suggests that these and associated measures are beginning to have a positive effect, although substantial improvements are still required in many regions.'

In many developing countries, greater use of nitrogen-based fertilisers is needed to increase food production to reduce poverty. Nitrogen pollution levels are soaring in regions such as Asia. A recent study on China forecast a rise in nitrogen oxides emissions by 30% from 2005 to 2020 and a 40% increase in reactive nitrogen deposition in some south-central and eastern provinces, and concluded with a call for government authorities to set emission standards. Worryingly, greater impacts from nitrogen pollution are expected in tropical regions due to greater (natural) nitrogen fixation, phosphorus- and cation-deficient soils, and increasing environmental impacts from development.

Professor Francisco J Cervantes, from Instituto Potosino de Investigación Científica y Tecnológica in Mexico, argues: 'Decreasing the demand of these kinds of [nitrogen cycle] processes, either by pollution prevention approaches or by nitrogen recovery strategies, would improve nitrogen management.'

Dr Schlesinger picks up this theme: 'The easiest approach is to use less nitrogen fertilizer and to use it more efficiently. Excess ammonium fertilizer in the environment is sure to get nitrified.' One group of scientists have proposed four key measures to reduce nitrogen loads: controlling nitrogen oxides emissions from fossil-fuel combustion, increasing nitrogen uptake efficiency of crops, improved management of livestock, and increasing sewerage treatment. Technology is available to abate most of the industrial sources that contribute around 20% of nitrous oxide fluxes, including through better wastewater treatment. Of the 80% of anthropogenic nitrous oxide fluxes from agriculture, experts estimate that better nitrogen placement and timing could reduce fertilizer use by around 20% now, increasing to around 80% in coming decades with the development of new forms of fertilizers and nitrification inhibitors. Dr Schlesinger adds that 'maintenance and expansion of wetland ecosystems that convert nitrate to N_2,' and perhaps even a 'cap-and-trade system to reduce wasteful inputs to the global nitrogen cycle' are needed. Other scientists warn that agricultural crop-based biofuel production will exacerbate nitrogen loading in the environment and should be avoided.

Despite the urgency, action by global institutions on nitrogen as yet is limited. An International Nitrogen Initiative (www.initrogen.org), with a global network of key academic and government researchers, has been established to increase understanding of the challenges in managing nitrogen. In 2006 the United Nations Environment Program and Woods Hole Research Center (USA) held a major workshop on reactive nitrogen in the environment and proposed capacity building and global scale cooperation on trans-boundary movement of nitrogen in gases, fertilizers, and other products, but (outside the EU) as yet there is little evidence of follow up inter-governmental action commensurate with the scale of the problem.

Macquarie Marshes Ramsar site, Australia. Wetlands can play an important role in treating excess nitrogen and have other benefits. Credit: J Pittock.

The water sector's role

Dr Schlesinger comments that: 'It is important to keep applied nitrogen "on site", where it is meant to do its good. Allowing nitrogen to enter surface and groundwaters lowers the efficiency of nitrogen fertilizer use and maximizes wasteful / harmful losses to the environment.'

Patrick Mulholland elaborates: 'The water sector plays an important role in the removal of nitrogen from the environment if it is not overwhelmed by high inputs of nitrogen. In particular, microbial processes in small headwater streams, mid-size and larger rivers, and floodplain wetlands can remove relatively large quantities of nitrogen by a process known as denitrification, which produces dinitrogen gas, a benign form of nitrogen. What is critically important for maintaining and enhancing nitrogen removal in these ecosystems is to maintain or restore natural features such as physical channel complexity, riparian vegetation, and floodplain connectivity.'

Dr Collins elaborates on the opportunities for further progress in Europe, commenting: 'Agri-environmental measures identified under the Common Agricultural Policy (CAP) could also play a key role and the forthcoming CAP reform offers the opportunity to strengthen water protection. In particular, sufficient funding is needed to support those measures that go beyond "good agricultural practice". Wastewater is also a prominent source of nitrogen discharged to waterbodies. In the European Union, the Urban Waste Water Treatment Directive (UWWTD) requires, in river basins with waters designated as sensitive to eutrophication, removal of much of the nitrogen (and phosphorus) in wastewater. Full implementation of both the Nitrates Directive and UWWTD are also a requirement under the Water Framework Directive (WFD), the single most important piece of EU legislation relating to the quality of fresh and coastal waters. Good ecological status is required under the WFD and provided that full compliance is attained in the coming years, will substantially reduce adverse impacts of nitrogen upon aquatic environments.'

Pointing to the multiple benefits in developing countries of linking management of nitrogen to improved sanitation and fertiliser production to increase food supplies, Professor Cervantes calls for 'nitrogen recovery strategies to be implemented during the treatment of wastewater, especially in world regions lacking sufficient nitrogen to meet even the most basic caloric demands of hundreds of millions of people'. Globally, he goes on to urge the wastewater sector to apply 'new effective technologies for removing recalcitrant nitrogenous pollutants from wastewaters – for example nitroaromatics, dyes, and pharma-ceuticals – in order to prevent serious environmental and public health problems'. Last year, IWA Publishing published a book edited by Professor Cervantes, 'Environmental Technologies to Treat Nitrogen Pollution', detailing the main physical, chemical and biological processes for the removal of nitrogenous contaminants from water, wastewater, leachates and off-gases.

Conclusion

In the shadow of climate change, humanity's addition of excess reactive nitrogen to the environment is a threat to people and nature globally. The severity of the impacts, particularly on water ecosystems and resources, will make concerted action essential in most societies. The water sector has a major role to play in meeting this challenge, as an advocate for responsible controls on reactive nitrogen inputs into the biosphere – especially from agriculture – that will have the added benefits of reducing water treatment costs and enhance public health. Restoring and conserving freshwater ecosystems can ensure these habitats can maximize their treatment of excess nitrogen fluxes. Finally, the need to remove reactive nitrogen is another powerful argument to extend improved sanitation and wastewater treatment services to the world's people. ●

More information

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PUBLICATIONS

Handbook of Chlorination and Alternative Disinfectants

Black & Veatch

The water industry has made substantial advancements in its understanding and application of chlorine, sodium hypochlorite and alternative disinfectants for water and wastewater treatment since 1998, when the fourth edition of Clifford White's 'Handbook of chlorination and alternative disinfectants' was published.

Black & Veatch has therefore completed a two-year revision process for the fifth edition of the handbook, which was authored and reviewed by leading industry experts to reflect the most current scientific advancements available. Cindy Wallis-Lage, Managing Director of Technical Solutions for Black & Veatch's global water business, led the revision process.

The book balances theory with practice and gives details about technological advances in the use of UV and ozone as disinfectants. It explores alternative disinfectants, such as chlorine dioxide, iodine and bromine-related products and discusses advanced oxidation processes for drinking water and wastewater treatment. Along with new developments in the production and handling of chlorine, the book also examines current regulations governing the use of different disinfectants.

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International Trade in Water Rights - The Next Step

Author: Aline Baillat

This book provides a new approach to the questions raised by international water transfer projects: to whom does water belong? More precisely, what rules should govern international water transfers from transboundary watercourses?

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It is argued that the recognition of water as an economic good in domestic water reform will increasingly impact the management of international watercourses.

The book is of key interest to water professionals, economists, lawyers, and political scientists dealing with transboundary disputes over water.

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