

Increase in colour and amount of organic matter in surface waters





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Nordtest, founded in 1973, is an institution under the Nordic Council of Ministers and acts as a joint Nordic body in the field of conformity assessment. The emphasis is on the development of Nordic test methods and on Nordic co-operation concerning conformity assessment. The main task is to take part in the development of international pre-normative activity. Nordtest is yearly funding projects in its field of activity.



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Frontpage Photo:
Water discharge through a weir at Birkenes catchment
in Southermost Norway (Egil Gjessing).

NORDTEST views on increases in colour and amount of organic matter in surface waters

SUMMARY

Some regions of the world are blessed with ample amounts of fresh surface water, but its dissolved Natural Organic Matter (NOM) often poses a serious concern for waterworks. Increases in NOM have largely been responsible for the unprecedented increases in water colour over the last 10-15 years that have been reported in the Nordic countries, the foothills of central Europe, Northern UK and North-eastern US. This increase has poised the water industry to spend hundreds of millions of Euro to deal with the problem. Furthermore, NOM is the single most important biogeochemical factor in the aquatic ecosystems of the northern hemisphere.

A multidisciplinary Workshop was held in the Rondane National Park, in the heart of Norway, on the 22 & 23 May, 2003. The objective of the assembly was to bring together leading scientist from various fields of research but all involved in the study of causes and consequences of the changes in quality and quantity of NOM. The Workshop arrived at the following views and recommendations:

Changes in the amount and properties of NOM are expected to be the most important ways by which climate change will influence aquatic biota. Moreover, many other social pressures that are altering NOM amount and quality are changing at an even greater pace than climate change (e.g. acid rain and land-use). Since changes are going to occur, the challenge is how to manage those changes such that society can achieve its environmental goals.

Due to pending investments, the most pressing challenge is to secure clean drinking water,. What future investments in drinking water treatment are required and what NOM removal technology should be applied are important questions that need to be answered in order to maintain sustainable management of aquatic ecosystem services. To answer these questions we need to understand the processes controlling NOM cycling. NOM cycling is a fundamental feature of ecosystems and a scientific area of great complexity, but also an area of active research. We already know enough to say that the amount, quality and intensity of precipitation is the main driving force of the observed changes in NOM and that the anthropogenic factors, such as climate change (e.g. changes in seasonality of temperature, precipitation), reduced acid rain and land-use changes (e.g. more forests, decreasing drainage), superimpose on the natural variation.

The management of water resources under a regime of changing NOM requires knowledge and understanding about the links between the environmental changes and their impacts, and society's responses to them (i.e. DSPIR (Driving Force; Pressure; State; Impact; Response) framework)). It is therefore of urgent importance to separate the precipitation-runoff effects from the effects of other potential factors as some of these factors are changing dramatically.

NOM is a complex substance, and its significance has been widely recognized by the scientific community only relatively recently. Our knowledge of the causes and consequences of a

change in the NOM cycling is therefore deficient. Unless the importance of NOM for society is acknowledged and its research is included in national/international agenda, the science will not make the contribution it could and should.

INTRODUCTION

In the Northern hemisphere the amount of dissolved Natural Organic Matter (NOM) in soil- and surface water is high due to a cold and wet climate. In fact more than half of the dry matter weight in the water in this region may be due to NOM and mainly responsible for giving the water a distinct yellow-brown colour. NOM is a mix of humic macromolecules with acidic and strong complex/binding properties. Thus NOM increases the mobility of pollutants in the watershed by complex binding heavy metals, sorbing organic pollutants and lowering pH. NOM has strong effects on many biogeochemical processes in the environment. NOM is also important to calculations of fluxes of carbon and macronutrients such as nitrogen and phosphorus (Kortelainen, 2003). Furthermore, NOM is a source of energy and nutrients for micro-organisms (Tranvik, 2003).

NOM cause problems in the production and distribution of drinking water as the NOM has an adverse effect on the aesthetic water quality as well as the biofouling of pipelines. It has also been demonstrated that NOM is the basis for the production of potentially hazardous organo-chlorine compounds when water is disinfected with chlorine.

During the last 10-15 years a considerable increase in colour and NOM has been observed in surface waters in southeast Norway and southern Sweden (Löfgren et al. 2003; Liltved and Gjessing, 2003), south western Finland, northern great Britain (Freeman et al., 2001; Evans and Monteith, 2001), in the foothills of Central Europe (Grunewald et al., 2003) and in North-eastern US (Skjelkvåle et al., 2000). The increase in colour has usually been greater than Organic Carbon (OC) content (see Skjelkvåle et al., 2000), indicating that not only the quantity but also the quality of NOM is changing.

In Norway 80% of the drinking water is from surface water sources. In Sweden and Finland these figures are 70% and 50% respectively. Such raw water sources are vulnerable to the present increase in colour and NOM, representing a serious concern for waterworks. Substantial investments for the removal of organic matter (OM) have already been made. A continued increase in the amount of NOM will demand continued investments in OM removal plants. Water treatment plants therefore need to know whether or not a continued increase in NOM is expected and on what scale in order to know if further investments are warranted. Furthermore, changes in the characteristics of the NOM may require an adjustment in the OM removal methods used by the waterworks.

NOM changes will be one of the most importance ways climate change influence the aquatic biota (Steinberg 2003a,b). Ecological effect and potential feedback effect on climate of these changes in NOM quantity and quality are other major issues that need to be addressed.

It is a prerequisite to understand the causes for the observed NOM increases in order for the scientific community to develop prediction models for future trends in colour and Dissolved Organic Carbon (DOC) and to ensure that the investments are made in the right technologies. The amount and properties of NOM are known to exhibit large temporal and spatial variations. The temporal fluctuations are usually explained by changes in hydrological pathways in the soil and may be fairly well predicted by variations in runoff intensity.

However, this effect can not solely account for the recently recorded high values of colour and DOC as previous periods with similar runoff amount and intensities did not result in similar high levels of NOM in surface waters. It is therefore apparent that the present increase in colour and NOM is a consequence of changes in several factors: climate, anthropogenic atmospheric deposition, land-use, solar radiation and in-lake processes. The challenge therefore lies in unravelling these multivariable effects. A Nordtest Workshop was therefore held to contribute to solving the challenges facing waterworks and to identify causes and potential environmental consequences of the increased and altered NOM.

CHANGES IN QUALITY AND QUANTITY OF NOM – POSSIBLE CAUSES

Climate

Climatic factors, such as precipitation and temperature are central factors regulating the soil organic matter (SOM) pool and carbon fluxes, including NOM dynamics (Gjessing, 2003). There is a strong covariance between intensity of precipitation and NOM concentration (usually measured as dissolved organic carbon (DOC)) in the discharge from forested sites. The reason is that increased runoff intensities lead to increased NOM discharge from the upper parts of the soil profile, which is rich in SOM (Bishop et al., 2003). On the other hand, if the discharge comes from mires the effect is opposite due to stronger dilution. Moreover, this covariance serves to camouflage other explanations of the changes in quality and quantity of NOM in surface waters. Increased temperature will accelerate the degradation of organic material in soil, which again will generate more mobilizeable NOM to be washed out by increased precipitation. Increased winter temperatures in northern latitudes will change the balance between rainfalls and snow as well as soil frost duration and thereby the pattern of leaching and watershed runoff. Solar radiation and microbes play an important role in the degradation of NOM in lakes. Decreased retention time in lake waters causes decreased photo-bleaching (i. e. photochemical degradation of coloured NOM) and degradation by micro-organisms (Tranvik, 2003) and will therefore also lead to enhanced colour and NOM concentrations (Gjessing 1970a). A change in the quality of radiation (e.g. more UV-A and UV-B) may also alter the chemical and physical properties of NOM. Furthermore, decreased retention time and higher water velocities lead to decreased coagulation and sedimentation of organic matter. Consequently there is a clear seasonality in NOM amount and quality as well as a covariance with precipitation. Fluctuations in climate and climate change are therefore believed to be the main reason for the observed changes in surface water colour and NOM (Evans and Monteith, 2001; Skjelkvåle et al., 2001).

Anthropogenic atmospheric depositions

Many of the regions experiencing an increased NOM have also suffered anthropogenic sulphur loading in the past. During the onset of *acid rain* in the 1970 and 1980s a reduction in colour in lakes were reported in the regions suffering from acid rain (Gjessing, 1970b). This was mainly explained by the protonation of the humic acids, as a result of the deposition of strong mineral acids, rendering them less hydrophilic. Furthermore, the lower pH allowed for enhanced solubility of aluminium- (Al) and iron (Fe) hydroxides. Increased Al^{3+} and Fe^{3+} in solution then became complexed by the anionic organic matter causing more of the NOM to loose its negative charge and precipitate. Furthermore, increased ionic strength, as a result of elevated concentrations of sulphate, H^+ and metal cations, resulted in diminished repulsion forces between the organic molecules and thereby also to increased coagulation and precipitation of NOM. Liming, which was widely used to combat the acidification of surface waters, has also has the effect of coagulating and sedimentation of the OM. Moreover, the

quality of the organic matter in anthropogenically acidified water was shown to change; e.g. an increase in the amount of organic sulphur (Gjessing et al., 1988). With the 30-40% decrease in S-deposition since 1980, one could therefore expect the recovery to result in a reversible trend resulting in increases in water colour and NOM, as well as a change in the quality of NOM (Vogt et al., 2003). Furthermore, nitrogen is accumulating in the terrestrial ecosystems, leading to a build-up of the terrestrial biomass, due to the continued fertilization by deposition of airborne nitrate and ammonia, despite decreasing emissions. An increased nitrogen content of the soil humic matter would also encourage decomposition and thereby production of NOM, leading also to more NOM in surface waters.

Land use changes

The large spatial variation in the amount and properties of NOM are a reflection of the spatial variation in watershed land-use. High NOM concentrations are associated with drainage from peatland, shallow upland soils, and watersheds with a high land/water ratio, i.e. watersheds with large soil pools of humus relative to mineral soil and short water retention times. Conversely, low NOM concentrations are found in watersheds with sparse vegetation, poorly developed organic soils and large lakes (i.e. small pools of soil carbon and long water retention times) (Löfgren, 2003; Kortelainen, 2003). Furthermore, the properties of NOM originating from peat soils are known to differ greatly from that originating from upland soils (Vogt et al., 1994, 2001). Reduced fires, grazing and trampling by cattle, extensive afforestation of arable land and heathland, increased forest production and increased proportion of conifers in the growing stock would increase SOM and NOM leaching to surface waters as well as changes in the quality of the NOM.

In the region experiencing unprecedented NOM increases in Norway there has also been reported a significant increase in annual increment and volume of growing forest stock (Tomter, 2000) and an increase in the amount of mosses during the 1980 and 1990s (Økland et al., 2001). These changes may be due to forest management, an enhanced growing season with longer and milder falls, increased atmospheric CO₂ levels, and the fertilizing effect of airborne nitrogen deposition. In the Czech Republic a 50% decrease of forest cover in the 1970 and 1980s was followed by a strong decrease in NOM concentrations in stream water. The NOM is now increasing along with reduced acid rain deposition as well as an increase in forest cover and climate change (Grunewald et al., 2003; Grunewald and Scheithauer, 2003).

There appears to be threshold values governing the significance of the various key land-use features. For example, when wetlands occupy small percentages of catchments (< 20 %), small increases in the proportion of wetland lead to pronounced rises in the concentration of NOM in runoff.

CHANGES IN QUALITY AND QUANTITY OF NOM – POSSIBLE CONSEQUENCES

Water treatment

The increase in colour and levels of NOM will, in addition to the aesthetic problem, promote the formation of potentially hazardous by-products from the disinfection, enhance the levels of both inorganic and organic pollutants, and provide a substrate for undesirable microbiological growth in the distribution system. The water supply industry has already made huge investments on OM removal plants in order to combat present increases in colour and to meet international quality standards. A sustained increase in NOM in the raw water will lower the efficiency of water treatment processes and increase the demand of water purification. Furthermore, waterworks need to invest in additional NOM removal methods

where the existing water treatment process becomes insufficient. Moreover, changes in the properties of the NOM (e.g. molecular size, hydrophobicity and refractoriness) have a great influence on the treatment efficiency. In general, macro-molecules are easier to remove than intermediate or small NOM molecules, but the latter may pose more health risks. Improved knowledge on the possible change in the characteristics of NOM is therefore necessary in order to select proper treatment technologies.

Environment

An increase in NOM and a change in its quality will have significant impacts on numerous environmental conditions.

For example:

- NOM consists of weak organic acids and constitutes an important proton source enhancing mineral weathering processes. The organic anions wash base cations down into the soil profile or out into surface waters leading to natural soil acidification.
- 50 – 60% (w/w) of the NOM is carbon. The carbon dynamics in boreal areas are of special scientific and environmental concern with respect to CO₂ being a greenhouse gas.
- Fluxes of macro-nutrients, such as nitrogen and phosphorus, from soil to surface water is to a large extent controlled by that of NOM as these elements are bound to OM. Furthermore, the NOM constitutes an important source of energy and nutrients for heterotrophic micro-organisms.
- The colour of NOM reduces the penetration of sunlight into the lake water and thereby decreases the photic zone.
- NOM act as weak natural xenobiotics. Changes in quantity or properties of NOM will therefore result in changes in aquatic flora and fauna.
- NOM binds heavy metals and adsorbs organic pollutants. The ability of humic matter to influence both the transport and bioavailability of contaminants is strongly dependent on the quality of the NOM.
- The environment is capable of coping with incessant evolution and fluctuations in the environmental condition; but when the changes occur too rapid, the biodiversity may be threatened.

RECOMMENDATIONS

Statement of the workshop

In regions with a net surplus of water, such as the Nordic countries, the tap water is often produced from surface waters. Another characteristic for these regions is that these surface waters are especially rich in NOM. This represents a major and mounting problem to the functioning of ecosystems, the environment, and for the waterworks.

The objective and approach to the problem at the workshop was to contribute to solving the challenges facing waterworks and the environment by identifying the causes and potential environmental consequences of the increased and altered NOM. There was a clear need to map what we know, what we need to know and what data that are missing. 13 invited experts provided presentations on a wide spectre of aspects related to the issue of increased dissolved Natural Organic Matter. The workshop thereby summarized the status of knowledge on NOM. Through extensive discussions the participants developed speculations and working hypotheses relating to the causes and consequences of an increase in NOM. The meeting was invited to conclude with recommendations of where to direct efforts within NOM research.

The workshop arrived at the following resolution and consensual recommendations:

There is a pressing need to separate precipitation-runoff effects from other potential explanatory factors in order to develop NOM prediction models. Such conceptual models are a necessary prerequisite in order to supply waterworks with sound NOM scenarios enabling them to prevent, reduce and mitigate adverse economical, safety and health effects caused by an increased loading of NOM to raw water sources. Such models are also needed to predict ecological effects on local, regional and global scale of relevance for critical load estimates and decision makers. The workshop therefore strongly advises European countries to:

1. **Acknowledge** that European surface waters are experiencing unprecedented changes in the amount and quality of NOM.
2. **Recognize** the importance of the amount and quality of NOM on raw water quality and environmental biogeochemical processes.
3. **Actively support and fund** networks and programmes for multidisciplinary research between ecologists, environmental chemists and the water treatment industry on NOM.
4. **Enhance and fund** research on, and the development of, management and treatment decision support systems, technologies and other issues related to the prevention, reduction and minimization the effect of elevated levels of NOM in raw water sources.
5. **Augment** the ongoing research on characterization of NOM in order to a) understand temporal and spatial variation; b) conduct risk assessment and selection of proper remedial action; and c) assess the fate of heavy metals and organic micro pollutants in freshwaters.
6. **Promote and support** the valuation of costs of increased NOM in raw water sources, including public health and water treatment in order to conduct cost-benefit analysis.
7. **Promote and support** the development of long-term monitoring, data treatment and research programmes aimed at distinguishing between the role of precipitation-runoff and other key environmental factors as outlined in Table 1.

Table 1

Assumed effects on quality, quantity and fluxes of natural organic matter by changes in key environmental factors. SOM denote Soil Organic Matter. 0, +, – and +/- denote no change, increase, decrease and both increase and decrease, respectively, while ? denote effect unknown. Effect of temperature is based on spatial gradients.

Considered shift	Key variable factors	SOM quality	SOM pools	Flux to water	NOM quality	NOM conc.	Flux to sea
Climate							
Precipitation							
+	Amount	+	+	+	+	+	+
+	Extreme distribution	+	+/-	+/-	+	+/-	+/-
-	Snow relative to rain	+	?	+	+	+	+
-	Spring flood	?	?	+/-	?	+/-	-
+	Hydrologic connectivity	+	0	+	+	+	+
+	Soil moisture	+	+	+	+	+	+
-	Water retention time				+	+	+
Temperature							
+	Fall and winter	+	?	+	+	+	+
Radiation							
		?	?	?	?	?	?
Atmospheric deposition							
+	pH	+	?	+	+	+	+
+	Nitrogen/Sulphur ratio	+	?	+	+	+	+
+	Sea-salts	+	+	?	+	?	
Land use							
+	Aforestation	+	+	+	+	+	+
+/-	Species	+	+/-	+/-	+	+/-	+/-
+	Biomass	+	+	+	+	+	+
+/-	Drainage	+	+	+	+	+/-	+/-
+/-	Site preparation	+	+/-	+/-	+	+/-	+/-
+	Damming-up	?	+/-	+/-	+	+/-	-

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Increased Nordic competitiveness through strong international influence

A substantial proportion of the trade barriers found today, both in the EU and globally, concern regulations, standards and conformity assessment. By promoting Nordic interests in this area internationally, the conditions for Nordic industry, especially SME's, will be greatly improved.

Nordtest endeavours to

- promote viable industrial development and industrial competitiveness, remove technical barriers to trade and promote the concept "Approved Once Accepted Everywhere" in the conformity assessment area
- work for health, safety, environment in methods and standards
- promote Nordic interests in an international context and Nordic participation in European co-operation
- finance joint research in conformity assessment and the development and implementation of test methods
- promote the use of the results of its work in the development of techniques and products, for technology transfer, in setting up standards and rules and in the implementation of these
- co-ordinate and promote Nordic co-operation in conformity assessment
- contribute to the Nordic knowledge market in the field of conformity assessment and to further development of competence among people working in the field

