CHANGES IN QUALITY AND QUANTITY OF NOM – POSSIBLE CAUSES AND CONSEQUENCES
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Keywords: natural dissolved organic matter, climate change, acid rain, land use changes, water works.

I. INTRODUCTION
The amount of dissolved Natural Organic Matter (NOM) in soil- and surface water is high in the Northern hemisphere due to a cold and wet climate. In fact more than half of the dry matter weight in the water is commonly accounted for by NOM giving it the distinct yellow-brown colour in this region. NOM has strong effects on many biogeochemical processes in the environment and serves to increases the mobility of pollutants in the watershed. NOM also play a major role in the fluxes of carbon and macronutrients and is a source of energy and nutrients for micro-organisms. 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 organochlorine 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), south western Finland, northern great Britain, in the foothills of Central Europe (Grunewald et al., 2003) as well as in North-Eastern USA (ICP-Waters, 2003). The increase in colour has usually been greater than Total Organic Carbon (TOC) content, 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 susceptible to the present increase in colour and NOM, representing a serious concern for waterworks. Furthermore, changes in the characteristics of the NOM may require an adjustment in the Organic Matter (OM) removal methods used by the waterworks. In regards to ecological effects the NOM changes is considered to be one of the most important ways climate change will influence the aquatic biota (Steinberg, 2003). The potential feedback mechanism on climate of these changes in NOM quantity and quality is another major issue that need to be addressed.

It is a prerequisite to understand the causes for the observed changes in NOM quantity and quality in order to develop sound scenarios for future trends in colour and TOC. Such scenarios are required by waterworks in order to ensure that their investments are necessary and are made on the right technologies. The amount and properties of NOM are known to exhibit large temporal and spatial variations. The temporal fluctuations are basically explained by changes in hydrological pathways through the soil and may be fairly well simulated by variations in runoff intensity. However, this effect can not solely account for the recently recorded high values of colour and NOM in surface waters as previous periods with similar runoff amount and intensities did not result in similar high levels of NOM. 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 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. This presentation gives a summery from this meeting. For references not listed in the reference list please refer to the NORDTEST Position Paper available at http://www.nordtest.org/register/position/pos9.pdf.
II. **POSSIBLE CAUSES**

**Climate**

Climatic factors, especially the amount of precipitation and temperature, regulate the soil organic matter (SOM) pool and carbon fluxes. Moreover, there is a strong covariance between runoff intensity and NOM concentration in the discharge from forested sites. The reason is that with increased runoff intensities there is an increased discharge of water from the upper parts of the soil profile, which are rich in SOM. On the other hand, where the discharge comes from mires the effect is opposite due to stronger dilution.

Increased temperature will accelerate the degradation of organic material in soil, which again will generate more mobilizable NOM to be washed out by increased precipitation. Increased winter temperatures 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 and will therefore also lead to enhanced colour and NOM concentrations. Furthermore, decreased retention time and higher water velocities lead to decreased coagulation and sedimentation of organic matter. 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). Moreover, this covariance serves to camouflage other underlying explanations of the changes in quality and quantity of NOM in surface waters.

**Anthropogenic atmospheric deposition**

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 afflicted with acid rain (Gjessing, 1970). This was mainly explained by the protonation of the weak humic acids by the strong mineral acids, rendering them less hydrophilic. Furthermore, the lower pH allowed for enhanced concentration of aluminium (Al) in solution. Increased Al$^{3+}$ in solution then became complexed by the anionic organic matter causing more of the NOM to loose its negative charge and precipitate. Moreover, 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 led to coagulation and sedimentation of the OM. Moreover, the quality of the organic matter in anthropogenically acidified water was shown to change. With the up to 75% decrease in S-deposition since 1980, one could therefore expect the recovery to result in a reverse trend resulting in increases in water colour and NOM, as well as a change in the quality of NOM (Vogt et al., 2003, 2004). Nitrogen is accumulating in the terrestrial ecosystems due to the continued fertilization by deposition of airborne nitrate and ammonia. 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 is 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. It also appears that if wetlands occupy less than 20% of the catchments then minor differences in the proportion of wetland lead to pronounced differences in the concentration of NOM in runoff.

Furthermore, the properties of NOM originating from peat soils are known to differ greatly from that originating from upland soils (Vogt et al., 1994). Extensive afforestation of arable land and heathland, increased forest production and increased proportion of conifers in the growing
stock as well as reduced fires serves to increase the amount of SOM and thereby NOM leaching to surface waters as well as change the quality of the NOM.

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 concentration is now recovering along with reduced acid rain deposition as well as an increase in forest cover and climate change (Grunewald et al., 2003).

III. POSSIBLE CONSEQUENCES

Water treatment
The increase in colour and levels of NOM will, in addition to the apparent aesthetic problem, promote the formation of potentially hazardous by-products from the disinfection, enhance the levels of both inorganic and organic pollutants (by enhancing mobilization from soil), and provide a substrate for undesirable microbiological growth in the distribution system. Moreover, changes in the NOM properties (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 greater health risks.

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

- 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 CO$_2$ 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 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.

Acknowledgements
The Workshop was supported by grants from NORDTEST (1656-03).

References
