THE EUTROPHICATION OF PULP AND PAPER WASTEWATER RECIPIENTS

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ABSTRACT

During recent years the BOD-loading of pulp and paper mill wastewaters has decreased dramatically, due to more effective circulation of water in the processes, and the new activated sludge biological treatment plants. This traditional threat to the environment has been forgotten by the scientists who nowadays are more interested in the role of chlorine compounds discharged from bleaching processes. However, eutrophication due to nutrient loading is still present in many recipients of pulp and paper industry. The BOD-reduction has often been carried out on the cost of adding nutrients, phosphorus and nitrogen to the purification processes. The biological treatment has also decreased the inhibitive effect of wastewater on the biological production of the recipient water body. Therefore, the eutrophication arises immediately. The authors worry about the research of nutrients; loadings, development trends and eutrophication effects.

KEYWORDS

Pulp and paper industry; phosphorus; nitrogen; eutrophication; primary production; recovery of lakes

INTRODUCTION

Eutrophication is one of the harmful anthropogenic changes in water bodies. Eutrophication can be considered as an increase in primary production, including all the related processes (e.g. Ohle 1955, Vollenweider 1968). Too high a level of primary production has arisen in many water bodies in Finland as a key factor which limits recreational use. Fish stocks have lost their value when the most appreciated species have declined. Increased algal biomass has caused problems in water supply and unpleasant odours and sometimes poisonous blue-green algae have limited the recreational usability of water bodies.

The primary production is regulated by several physical and chemical factors, e.g. temperature, illumination and concentrations of growth nutrients. In inland waters, phosphorus and nitrogen have been understood to be the most important minimum nutrients which regulate the primary production. In Finland, especially phosphorus concentration is low in lakes and rivers. Natural concentration of oligotrophic lake water is usually less than 10 µg/l. Relatively small wastewater loading is able to multiply the concentration quite easily. According to Wiederholm (1989), the eutrophication is very strong after the threefold increase in phosphorus concentration.
The main sources of nutrients in water are the natural background, wastewater loading and the diffuse non-point loading. Besides the absolute loading parameters, other important factors which influence on eutrophication are the diurnal and other variations of the nutrient discharge, as well as chemical mode of nutrients, and their suitability for immediate utilization in algal growth. Pure hydrological factors are also important in the eutrophication of waters.

Nutrients were important earlier, when quite trivial mechanic-biological methods were applied in wastewater treatment. Nowadays the reduction of phosphorus is more than 90% in the purification of domestic sewage; some effective plants even meet the level of 95%. In this kind of situation there is a very good reason to study the whole nutrient flow in each water body, as a subject of water pollution control efforts. In many cases, the non-point loading and industrial wastewaters have a major role in the eutrophication of recipients, in comparison to the role of domestic sewage.

**NUTRIENT LOAD FROM PULP AND PAPER INDUSTRY**

The amount of total loading provides an opportunity to approach the effects of different loading factors on the quality and usability of waters. The loadings from domestic sewages and from the pulp and paper industry in 1972 and 1988 are presented in Table 1 (National Board of Waters 1976, National Board of Waters and the Environment 1990). The daily industrial loading is calculated per production day.

<table>
<thead>
<tr>
<th>Year</th>
<th>Phosphorus, td⁻¹</th>
<th>Nitrogen, td⁻¹</th>
<th>BOD, td⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>1972</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Domestic sewage</td>
<td>15.6</td>
<td>72</td>
<td>345</td>
</tr>
<tr>
<td>Pulp and paper industry</td>
<td>2.0</td>
<td>15</td>
<td>1328</td>
</tr>
<tr>
<td>1988</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Domestic sewage</td>
<td>1.3</td>
<td>40</td>
<td>34</td>
</tr>
<tr>
<td>Pulp and paper industry</td>
<td>2.3</td>
<td>13</td>
<td>400</td>
</tr>
</tbody>
</table>

During these 15 years the total loading of domestic sewage has decreased a lot: 90% of BOD-loading and almost 92% of phosphorus loading. The decrease of nitrogen loading is smaller. The BOD-loading from pulp and paper industry has decreased although the production of the mills has increased greatly.

**THE EFFECT OF LOADING IN DIFFERENT WATERCOURSES**

The effect of wastewater loading varies by receiving water body. A lake, a river and the sea have each their characteristic reactions. The ordinary Finnish lakes are shallow, and have small volume. However, they become stratified both in winter and usually also in summer, due to the different density of limnic layers. And they are ice-covered 150-200 days every year.

Depending on the recipients' type, the wastewaters of pulp and paper mills are usually transported and primarily diluted near to the bottom. Their effects are seen in the deeper water layer at first. The primary effects are oxygen consumption in water and changes in the bottom sediments. Autumn-spawning fish are the most sensitive, when the loading increases. The circulations mix the water masses in spring and in autumn, and wastewaters have an influence also on the epilimninc layer; primary production becomes more intensive because of the nutrients. The strengthened primary production increases the amount of decomposing organic matter, and leads to additional secondary oxygen consumption, especially in the hypolimnic water layer.
Eutrophication of pulp and paper mill recipients

Rivers are the best recipient waters for wastewaters. The mixing and dilution are usually effective, thus significant oxygen deficit does not occur, and biological purification process continues. In a river the eutrophication caused by nutrients is limited mostly to the increase of periphyton on the rocky shores. The current usually prohibits the growth of harmful plankton masses.

In the sea the effects depend on the characteristics of the part of the coast receiving wastewaters of the pulp and paper industry either directly or via the rivers. In general the mixing conditions are such that the primary oxygen consumption does not have any major effect. On the other hand, nutrients increase the primary production and that way the harmful eutrophication.

THE REDUCTION OF LOADING; WHAT HAPPENS IN WATERCOURSES?

In pulp and paper industry, the treatment of wastewaters has specifically been aimed to the removal of organic matter. The discharge of fibers has been minimized and the discharge of dissolved organic matter has been reduced by almost 70% since 1972. Simultaneously with the reduction of organic loading the toxicity of wastewaters has probably also decreased. However, as far as nutrients are concerned the situation has deteriorated. What are the subsequent effects on a body of water?

This process can be described by using as an example a body of water where the prolonged loading by pulp and paper industry was discontinued. This is Lake Lievestuoreenjärvi, in Central Finland, which until the autumn of 1985 was loaded by wastewaters of a pulp mill using the sulphite method. Lake Lievestuoreenjärvi has the surface area of 41.7 sq kms and its calculated residence time is about four years (Yli-Karjanmaa 1980). The changes of some water quality characteristics in 1983-89 are presented in Table 2. The figures represent the end of summer stratification period.

**TABLE 2. Selected water quality characteristics of Lake Lievestuoreenjärvi in 1983-89 (Aug.-Sept.)**

<table>
<thead>
<tr>
<th>Year</th>
<th>chlorophyll a, µg l⁻¹</th>
<th>tot.P, µg l⁻¹</th>
<th>tot.N, µg l⁻¹</th>
<th>O₂, mg l⁻¹</th>
<th>NaLS, mg l⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0-2 m</td>
<td>1 m</td>
<td>2h-1*</td>
<td>1 m</td>
<td>2h-1</td>
</tr>
<tr>
<td>1983</td>
<td>2.9</td>
<td>76</td>
<td>160</td>
<td>710</td>
<td>1100</td>
</tr>
<tr>
<td>84</td>
<td>7.1</td>
<td>54</td>
<td>140</td>
<td>640</td>
<td>1100</td>
</tr>
<tr>
<td>85</td>
<td>21.0</td>
<td>53</td>
<td>190</td>
<td>700</td>
<td>1100</td>
</tr>
<tr>
<td>1986</td>
<td>3.9</td>
<td>42</td>
<td>61</td>
<td>630</td>
<td>850</td>
</tr>
<tr>
<td>87</td>
<td>6.7</td>
<td>43</td>
<td>65</td>
<td>670</td>
<td>810</td>
</tr>
<tr>
<td>88</td>
<td>5.0</td>
<td>34</td>
<td>60</td>
<td>630</td>
<td>700</td>
</tr>
<tr>
<td>1989</td>
<td>5.3</td>
<td>31</td>
<td>66</td>
<td>620</td>
<td>780</td>
</tr>
</tbody>
</table>

* 2h-1 = sampled one metre from the bottom

In 1985 the loading at the mill decreased and the treatment apparently resulted in reduced toxicity of the wastewater. In 1986 wastewater discharge was discontinued. The change was immediately observed as the improved oxygen conditions, the reduction of lignosulfonates and the decrease of the phosphorus content near the bottom. The decrease of nutrient contents has been quite slow and has not yet affected the level of eutrophication.
PHOSPHORUS, NITROGEN OR OTHER NUTRIENTS

Since the minimum growth factor theory phosphorus, nitrogen and numerous other elements have given positive reactions in eutrophication tests. Also it is widely known that growth conditions of algae and water plants vary in different recipients of industrial waste waters. However, growth factor testing is seldom carried out in practical cases, to state the reasonable objectives for the treatment of pulp and paper industry effluents. In future, the treatment plants shall be planned to prevent harmful eutrophication of lakes and rivers, as well as for prevention of oxygen deficit, sedimentation of suspended solids, and toxic effects of organic chlorine compounds. The future treatment plants are also able to accommodate the purification processes according to the productivity state of the receiving water body.

Phosphorus removal has been the main interest in Finland because the ratio of inorganic nitrogen to inorganic phosphorus often is higher than 15, the theoretical approximation of ideal ratio for proteine synthesis. The recent interest to decrease nitrogen concentration in wastewater is evidently based on the ammonia - nitrate relationship to the oxygen balance of lakes. Nitrification in treatment plant advances the storage of oxygen in lake. Is it probable that nitrogen removal shall provoke nitrogen fixation and blooming of blue-green algae in the recipient? Is it always useful to decrease the loading of total nitrogen instead of ammonia only?

Another question arising from the old minimum factor thinking of professor Liebig is related to the observation that usually there are several minimum factors in a Finnish lake ecosystem. Light and temperature are the primary ones, and inside the primary productivity limits allowed of these basic factors, the nutrients often show synergistic effects in stimulating photosynthesis. The key role of phosphorus and nitrogen alone should be suspected especially in polluted lakes where numerous other minerals and vitamins are available. Is it probable that certain catalysts, as an example, explain the eutrophication caused by wastewaters? And how often are nutrient conditions calculated on the basis of total nitrogen concentration and total phosphorus concentration, instead of comparison between inorganic compounds during the varying seasonal conditions?

In practice, harmful effects of phosphorus and BOD are often compared on the basis of oxygen-consumption coefficients. The evaluators assume that the effect of phosphorus in comparison to the effect of BOD is related to the amount of consumed oxygen when the algal biomass or other results of primary production are decomposed in a lake ecosystem. These calculations have been useful and practical, it has been reasonable to forget the insufficient scientific background. A new feature of the problem arises when recent scientific results show that inorganic carbon can also act as a nutrient. Is it time to revise the concept of nutrient in waste-water - eutrophication interactions?

There has been fast development in the management techniques of biological treatment plants; i.e. in the utilization of nutrients to decompose organic matter. Should there be rapid development in stating the reasonable interactions between nutrients of treatment plant and nutrients of water body?

OBJECTIVES OF WASTE-WATER TREATMENT

There is a common misconception in discussions concerning the objectives of waste-water treatment. The statements can be made from the viewpoint of treatment plant planning or from the viewpoint of real environmental impact. Naturally, there are also the viewpoints of legislation, economy and social effects etc. We can ask why the wastewaters of pulp and paper industries should be treated. The answer varies case by case but always the correct answer covers the prevention of negative effects in the receiving water body, eutrophication being often one of these effects. And a more detailed question arises: how to prevent eutrophication? Further, a typical answer is that decrease of nutrient loading is important. The next step should be to ask which nutrients, and to which level, should be decreased in this special case? After that we are ready to state and evaluate the technical objectives of the treatment plant.
FUTURE PREVENTION OF EUTROPHICATION IN PULP AND PAPER WASTE-WATER RECIPIENTS

There has been a remarkable and extensive development in the prevention of eutrophication of pulp and paper waste-water recipient water bodies. The treatment has been carried out effectively, from suspended solids to oxygen demand, to the decrease in phosphorus loading and management of chlorinated compounds. Are we brave enough to confess that eutrophication related to nutrients is still a real problem? Are we able to define which nutrient in each case is important? Are we able to plan treatment plants according to the demands of preventing eutrophication? Is it possible that a modern plant reacts to the varying conditions in the recipient, season by season? Or do we accept the increase of eutrophication as a price of decreased BOD-loading?

REFERENCES


