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## Cause and effect relationship between foam formation and treated wastewater effluents in a transboundary river

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### Abstract

The occurrence of foam at weirs in a lowland river in Austria and shortly after the Austrian border with Hungary, as well as, the associated protests from Hungarian locals led to investigations concerning the reasons for foam formation. Three aspects were the main subject of investigation, namely, (i) to assess the dimension of the appearing foam, (ii) to evaluate the reasons for the formation of foam, and (iii) to set abatement-measures.

A 1 year monitoring programme included a close network of surface water sampling sites, as well as, the sampling of thirteen municipal and industrial wastewater treatment plants along the river stretch. In addition to classical parameters (physical and chemical) the surface tension and tensides were analysed. Constant observation of foam formation in Hungary was achieved by the installation of an online webcam with combined data recording, which resulted in the development of a seven-stage foam index (0–6) for semi quantitative assessment of foam formation on the river. Also, the effluents of the wastewater treatment plants that were considered were the subject of standardised foaming tests. The basis of the tests was to detect, (i) foam on the sample and, (ii) the dilution of a sample at which no more foam could be observed. The dilution factor was used to calculate the foam potential of an effluent, which is an size for the potential volume of river water that may be foamed by waste water treatment plants' effluents. The spatial distribution of foam along the river stretch, as well as, the results of the foam tests allowed the identification of three tanneries as the main contributors to foam, although wastewater from these tanneries is treated at wastewater treatment plants by the best available technology (biological treatment with nitrification and denitrification, sludge retention time >20 days, temperature in the activated sludge tank >20 °C).

The implementation of an accepted degree of foam formation was desirable to develop measures to reduce the foam index. As no criterion exists for foam in rivers in Austria, as well as in Hungary, the not accepted degree of foam formation was defined as the limit at which population protests from Hungary arose. This approach resulted in a foam index higher than 3.5, which was observed with 40% probability during the investigation period. By developing and performing a simple mathematical regression model the required reduction of foam potential emissions could be calculated in order to minimize the foam index to an accepted standard. By the elimination of 75% of foam potential, a foam index lower than 3.5 would be assured with 95% probability based on long term discharge development.

**Keywords:** Foam; River basin management; Surface tension; Transboundary pollution

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## 1. Introduction

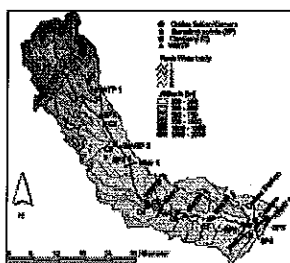
Rivers play a major role in receiving or carrying industrial and municipal wastewater, manure discharges and runoff from agricultural fields, roadways and streets, which are responsible for river pollution. As rivers constitute main water resources in inland areas for drinking, irrigation, industrial and recreational purposes (Vega et al., 1998), the deterioration of surface water quality with toxic chemicals and eutrophication of rivers due to excessive nutrients deposition is of great environmental concern (Ouyang et al., 2006). Compared to these water quality issues, the formation of foam on rivers is at present an overlooked subject in scientific discussions. Whereas some literature is available on the occurrence of foam in the marine environment ([Bälje and Michealis, 1986], [Craig et al., 1989], [Eberlein et al., 1985] and [Bärlocher et al., 1988]) and foam formation on wastewater treatment plants ([Defrain and Schulze-Rettmer, 1989], [Hladikova et al., 2002], [Torregrossa et al., 2005], [Lánský et al., 2005] and [Westlund et al., 1998]), information on foam in freshwater ecosystems is rare ([Fisenko, 2004], [Madrang et al., 1992] and [Wegner and Hamburger, 2002]). The massive occurrence of foam on rivers was supposed to be eliminated after the introduction of biodegradable contents in detergents and the biological treatment of wastewater in wastewater treatment plants. Nevertheless, the formation of foam remains an increasingly relevant topic in freshwater ecosystems. Certainly, the visibility of foam addresses the people's ecological "conscience" more than "hidden" chemical pollution. Production of foam can be caused by multiple factors of different origins. Anthropogenic sources are, e.g. industrial effluents containing tannins, polyamids, amino acids and lipids as well as effluents of municipal wastewater treatment plants ([Defrain and Schulze-Rettmer, 1989] and [Madrang et al., 1992]). Natural foams can be created by algal blooms causing massive release of dissolved organic carbon as well as carbohydrates, proteins and humic substances originating from higher plants, plankton and microorganisms ([Madrang et al., 1992] and [Wegner and Hamburger, 2002]). These compounds possess a surface active character, which causes a reduction of surface tension and therefore create favourable conditions for foaming. Turbulence of a river, as well as, the existence of cascades, bed drops and weirs on the river bed may also promote foam formation by introducing air bubbles into the water.

Regulation of in-stream foam by-laws is a difficult and an improper topic in many countries. For example, in the United States the US Clean Water Act proclaims that "all surface waters should be free of scum in amounts that are unsightly" (Anonymous, 2002). The Regulation for Water Pollution Control in

Switzerland states that "treated wastewater discharge must not lead to foam formation after advanced mixing in the river with exception from rainfalls" (Anonymous, 1998). The EU Water Framework Directive (EU WFD) claims the "good chemical and ecological status" for river water bodies, which means only a minor deviation from the reference (natural) status. The chemical status is regulated by environmental quality standards for priority substances, which contain also foam related parameters such as tensides (e.g. nonylphenols). Thus an indirect criterion for foam exists by the regulation of tensioactive compounds. However, neither in the United States nor in Europe are there explicit emission or immission criteria, let alone thresholds for foaming ([Defrain and Schulze-Rettmer, 1989], [Anonymous, 1998], [Anonymous, 2000] and [Anonymous, 2003]). Instead of regulating foam by an immission criterion, at present the "allowed" amount of foam on a river is subject to the aesthetic of the beholder, while the emission of foam lies in the responsibility of the operators of wastewater treatment plants. In Austria, the only existing restrictions for wastewater treatment plants regarding foam are emission criteria for foam related parameters such as tensioactive compounds, e.g. the sum parameter for anionic and non-ionic surfactants (Anonymous, 1991). As foam formation on wastewater treatment plants is a widely observed phenomenon, the common solutions are sprinkling of foam with water and, in particular, the application of anti-foaming agents. Such measures minimize the foaming effect temporarily, but do not eliminate the reasons, i.e. the surface active compounds. Biodegradability of anti-foaming agents leads to the recovery of foam and displaces the foaming problem from the wastewater treatment plants to the receiving waters (Defrain and Schulze-Rettmer, 1989). Thus, identification of foam causing substances, their origin and elimination, as well as, the handling of the legal aspects and the public concern are new challenges to be met in order to solve foam formation problems. Occurrence of foam below weirs in a lowland river in Austria and at the border region to Hungary and the associated protest by Hungarian locals, led to a causal research within the river basin. The suspect of environmental pollution by industry associated with foam formation in Hungary affected the political relationship between the neighbouring countries profoundly. Thus a fast and effective solution was required. The challenge of river basin wide approaches lies in understanding the effects of emissions on the in-stream river quality. Only if this cause and effect relationship is well known and understood, could the development and implementation of useful and cost-effective measures be made possible. Thus, the paper is mainly focused on the development of a model to quantify the impact of emitted foam causing substances on the in-stream foam formation. The methods used and the results that were achieved, as well as a brief discussion of the investigated measures are given in the following pages.

## 2. Study site

The investigated river has its source in a crystalline low mountain range, flows through the south-eastern part of Austria and discharges into the Danube in central Hungary. The Austrian part of the river basin (Fig. 1) covers an area of about 980 km<sup>2</sup>, the climate is characterised by moderate precipitation (784 mm/a), which results in seasonal low discharge conditions (low flow during investigation period was around 2 m<sup>3</sup>/s or 63 mm/a based on the river basin area, average flow is around 6 m<sup>3</sup>/s or 189 mm/a based on the river basin area). The land use within the basin is dominated by agriculture (arable land 34%, grassland 17%) and forestry (45%). Urban areas cover 4% of the catchment. Spatial distribution of different land use types result in a short upper river section, which is almost unaffected by human impact, while the largest part of it is characterised by high agricultural, municipal and industrial exploitation.



Full-size image (63K)

Fig. 1. Austrian river basin of the investigated river, location of sampling points (SP), municipal wastewater treatment plants (WWTP), industrial companies (C), online station and online camera are displayed.

### 3. Material and methods

#### 3.1. Sampling sites

To locate the origin of foam, a river basin wide approach was chosen to gain information on the river's chemistry, the quality and composition of the different point source discharges and the incoming diffuse loads. This resulted in the design of a 1 year monitoring programme, which included a close network of surface water sampling points (SP1-5), as well as, the sampling of five municipal and eight industrial wastewater treatment plants (WWTP) along the river stretch (Fig. 1 and Table 1). Sampling site 1 served as the reference site with low anthropogenic impact to investigate the "natural" chemical and foaming conditions, whereas, sampling sites 2, 3 and 4 were chosen to assess the impact of various dischargers along the river. As foam forms after passing a weir, all sampling sites were located shortly after a weir. The characteristics of the weirs, e.g. height and broadness, affect the energy impact on the water, the amount of introduced air and thus the volume of created foam. Therefore it was important to choose sampling sites at similar weirs to observe foam formation. Table 1.

Summary of sampled industrial companies and wastewater treatment plants in the Austrian part of the river basin.