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Fecal bacteria in the rivers of the Seine drainage network (France): Sources, fate and modelling

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Abstract

The Seine river watershed (France) is a deeply anthropogenically impacted area, due to the high population density, intense industrial activities and intensive agriculture. The water quality and ecological functioning of the different rivers of the Seine drainage network have been extensively studied during the last fifteen years within the framework of a large French multidisciplinary scientific program (PIREN Seine program). This paper presents a synthesis of the main data gained in the scope of this program concerning the microbiological water contamination of the rivers of the Seine drainage network. The more common indicator of fecal contamination (fecal coliforms) was mainly used; some complementary works used *E. coli* and intestinal enterococci as alternative fecal indicators. Point sources (outfall of wastewater treatment plants) and non point sources (surface runoff and soil leaching) of fecal pollution to the rivers of the watershed were quantified. Results showed that, at the scale of a large urbanised watershed as the Seine basin, the input of fecal micro-organisms by non-point sources is much lower than the inputs by point sources. However, the local impact of diffuse non-human sources (especially surface runoff of pastured fields) can be of major importance on the microbiological quality of small headwater rivers. Fecal contamination of the main rivers of the Seine watershed (Seine, Marne, Oise rivers) was studied showing high level of microbiological pollution when compared to European guidelines for bathing waters. The strong negative impact of treated wastewater effluents outfall on the microbiological quality of receiving rivers was observed in different areas of the watershed. Once released in rivers, culturable fecal bacteria disappeared relatively rapidly due to mortality (protozoan grazing, lysis) or loss of culturability induced by stress conditions (sunlight effect, nutrient concentration, temperature). Mortality rates of *E. coli* were studied in different types of rivers within the watershed showing, in summer conditions, no major difference in the mortality rates in small and large rivers. As a result of these studies, a module describing the dynamics of fecal bacteria has been developed and embedded within a hydro-ecological model describing the functioning of the rivers of the whole watershed (the SENEQUE model). Once validated, such a model can be used for testing predictive scenarios and thus can be a very useful tool for the management of microbiological water quality at the scale of the whole basin.

Keywords: Seine; Microbiology; Fecal indicators; Fecal coliforms; *Escherichia coli*; Urban wastewater; Soil leaching; Modelling

1. Introduction

The Seine river watershed of Northern part of France is highly anthropogenically impacted, due to the high population density, intense industrial activities and intensive agriculture. The water quality and ecological functioning

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of the different rivers of the Seine river drainage network have been extensively studied during the last fifteen years within the framework of a French multidisciplinary scientific program (PIREN Seine program) (Meybeck et al., 1988). A complementary multidisciplinary scientific program is specifically devoted to the study of the Seine estuary (Seine-Aval program). Works concerning the microbiological water quality have been included in both programs (Servais et al., 1999a; George et al., 2001a,b). The present paper synthesizes the main data gained in the scope of the PIREN Seine program concerning the microbiological water contamination of the rivers of the Seine drainage network.

Freshwaters polluted by fecal discharges from men and animals may transport a variety of human pathogenic micro-organisms (viruses, bacteria, protozoa). Because the detection of all waterborne fecal pathogens is very difficult, various indicators of fecal contamination are usually used to detect fecal pollution in natural waters. The abundance of these indicators is supposed to be correlated to the density of pathogenic micro-organisms from fecal origin and is thus an indication of the sanitary risk associated with the various water utilisations (bathing, shellfish harvesting, production of drinking water,…). For years, the group of fecal (also called thermotolerant) coliforms (FC) has been the most widely used as fecal indicator. In recent years, some organisations (USEPA, 1999; WHO, 2001) have proposed to use *Escherichia coli* and intestinal enteroccoci (IE) as indicators of fecal pollution. In this study, FC were mainly used as model of fecal bacteria; however, some data concerning *E. coli* and IE are also presented in the paper.

For enumerating FC, *E. coli* and IE in waters, usual methods are culture-based techniques as the Most Probable Number (MPN) technique (incubation of sample dilutions in a specific liquid medium) or the Membrane Filter (MF) technique (incubation on a specific solid medium) (plate counts) (Rompré et al., 2002). During the last years, several alternative methods were also developed for the enumeration of FC and *E. coli*; they are based on the direct measurement of a specific enzymatic activity (George et al., 2000; Servais et al., 2005) or on molecular biology techniques (Rompré et al., 2002). However, none of these techniques has been presently normalised; therefore culture based methods are still used for the routine control of microbiological water quality. Most of the data presented in this paper were obtained by standardised culture-based methods and some with a fluorescent in situ hybridisation (FISH) technique (Garcia-Armisen and Servais, 2004).

The objective of the present study was to understand the dynamics of fecal bacteria in the different types of rivers (from small streams to large fluvial sectors) of the Seine watershed. For this, the sources of fecal bacteria to the rivers were first investigated. Fecal pollution of rivers can be from human and animal origin and point sources and non-point sources of contamination can be differentiated. In an urbanised area as the Seine river watershed, the major point source of fecal bacteria consists of wastewater treatment plants (WWTPs) effluents, since most of the inhabitants are connected to sewers driving their wastewaters to WWTPs. Fecal pollution brought to the rivers through soil leaching or surface runoff represents the non-point source; its origin can be the wild life animals and grazing livestock feces and also cattle manure spread on cultivated areas. Quantification of fecal contamination of rivers through non point sources is relatively difficult and consequently there are only a few publications on this subject (Wyer et al., 1996, 1997; Avery et al., 2004; George et al., 2004). Fecal contamination of the main rivers of the Seine watershed (Seine, Marne, Oise rivers) was studied in the scope of this study with a special attention to the impact of treated wastewater effluents outfall on the microbiological quality of receiving rivers. Once released in rivers, fecal bacteria are subjected to different processes leading to their disappearance (protozoan grazing, lysis)(Barcina et al., 1989, 1997; Pommepuy et al., 1992) or inducing stress (sunlight effect, nutrient concentration, temperature,…) often leading to a loss of culturability (Roszak et al., 1984; Grimes and Colwell, 1986). In addition, fecal bacteria can be removed from the water column through sedimentation (Characklis et al., 2005; Jamieson et al., 2005). Mortality rates of *E. coli* were studied in different types of rivers. Thanks to the data accumulated on the hydrological and biogeochemical functioning of the rivers of the Seine watershed, several ecological predictive models have been developed (Billen et al., 1994; Garnier et al., 1995; Even et al., 1998). The final purpose of this study was to include in such models a module describing the dynamics of fecal bacteria in the rivers of the watershed. Once validated, such a model can be used for testing predictive scenarios and thus can be a very useful tool for the management of microbiological water quality in this highly anthropogenically impacted basin.

2. Materials and methods

2.1. The Seine river watershed

The Seine catchment (75,000 km^2) in France (Fig. 1) is characterised by a high population (average density of 230 inh km^{-2}), mainly present in the urban area of Paris