Ecological Modelling 306 (2015) 145–151

Contents lists available at ScienceDirect

Ecological Modelling

journal homepage: www.elsevier.com/locate/ecolmodel

Modelling of *E. coli* transport in an oligotrophic river in northern Scandinavia

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ARTICLE INFO

Article history:
Available online 27 October 2014

Keywords:
E. coli inactivation
Fecal pollution
Oligotrophic water
Sustainable water management

ABSTRACT

This paper presents the development of a model for calculation of *Escherichia coli* transport in oligotrophic river waters, using temperature dependent inactivation rate for *E. coli* and flow velocity characteristics of the river and lakes. A total of 209 temperature measurements from 11 years surveillance were used to calculate transport distances until 90% inactivation of the *E. coli*. Three scenario sets of different site specific values for the first order reference inactivation rate constant k_{20} (0.145, 0.230 and 0.555 day^{-1}) and temperature coefficient of the rate constant Q_{10} (2.07, 1.50 and 1.86) were tested in the upper parts of river Indalsälven, in northern Scandinavia. The first and third parameter sets represented respectively pristine water and lake water while the second setting was considered most representative of river Indalsälven. All three scenarios demonstrated considerable transport distances of *E. coli* with a clear and structured seasonal variation. The longest transport distances observed during late winter and spring are caused by a combination of low water temperature and high water velocity. The results have implications for water management decisions within the watersheds of oligotrophic rivers in cold and temperate climate.

1. Introduction

Sustainable water management must meet the requirement of securing long-term availability of safe and secure freshwater supplies as well as safeguarding ecosystem functions within the watershed. The naturally oligotrophic rivers in northern Scandinavia are generally characterized by a low pollution level (van Dijk et al., 1994) and the water quality, in remote (upper) parts of the catchment areas, may still meet national standards for drinking water (without further treatment). The occurrence of such clean surface waters is a rather unique feature within Europe. Accumulating evidence indicates however a degradation trend of drinking water quality associated to climate change that leads to an increase of at risk situations related to health impacts (Delpla et al., 2009). The European Water Framework Directive recognizes that there is a considerable pressure on the aquatic environment, including that from pollution and emphasizes the need for sustainable water management (European Commission, 2000, 2012). In scarcely populated areas of northern Sweden there is an increased pressure on scenic sites of land close to rivers and lakes for both permanent dwellings and holiday cottages. The municipalities along river Indalsälven are challenged by the consequences of a negative demographic development. Hence, plots of land are made available by using exemption in the law for building houses within the 100 m-zone of a water body. This is the situation even though water quality data indicate a relationship between settlements near the shore and fecal pollution of water bodies within the catchment area. Clearly there is a need for a better understanding of relationships between settlements within the riparian zone and river water quality.

Long term monitoring of river Indalsälven carried out by Indalsälven Water Conservation Association (IWCA, 2013) show worrying trends of increasing levels of *Escherichia coli* (*E. coli*), a fecal indicator organism. In addition, two recent outbreaks of the *Cryptosporidium hominis* parasite in city drinking water supplies have caused much concern for drinking water security and ecological status of water bodies. Fecal pollution in general is known to spread a range of pathogens, such as virus, bacteria and parasitic protozoa (Lindberg and Lindqvist, 2005). Contamination of human sewage is particularly troublesome due to content of pharmaceutical compounds (Verlicchi et al., 2012), household chemicals (Eriksson et al., 2002), hazardous and endocrine disrupting substances (Gardner et al., 2012) and possible dissemination of antimicrobial resistance to the environment (Figueira et al., 2011; Korzeniewska et al., 2013).

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http://dx.doi.org/10.1016/j.ecolmodel.2014.10.021
0304-3800/

E. coli is a common bacterium in the gastrointestinal tracts of humans and other warm-blooded animals (Harvey, 2006). Presence of *E. coli* in water is therefore used as an indicator of fecal pollution (Myers et al., 2007; Wade et al., 2003). The fecal pollution could have diffuse sources such as agriculture and urban areas (Tran et al., 2010) and through overland flow (Collins et al., 2005). Tornevi et al. (2013) showed a relationship between heavy rainfall in the catchment of a drinking water source and an increasing number of reported gastroenteritis among tap water consumers. Overspill in sewage treatment plants and substandard functioning private sewers are typical point sources for fecal pollution (Kay et al., 2008; Kistemann et al., 2012).

This paper presents a transport model for *E. coli* in a typical oligotrophic and cold water river of northern Scandinavia. Inactivation of *E. coli* depends on the water temperature, nutrient levels (Flint, 1987), turbidity, sedimentation (Kim et al., 2010; Yakirevich et al., 2013) and sunlight (Sinton et al., 2002). However, temperature is often considered the most important parameter in freshwater due to large seasonal fluctuations (Blaustein et al., 2013). The model incorporates temperature dependent inactivation rate for *E. coli* and water velocity characteristics of the river. Site specific parameters such as nutrient levels, turbidity etc. is implicitly included in the model by the use of a site specific Q_{10} coefficient in the model equation, see Section 2.3. The model is used to calculate possible ranges of *E. coli* transport in the river system as a means to aid better planning of safety zones for drinking water security and protection of vulnerable ecosystems within the watershed. The results presented in this paper have implications for water resource management and infrastructure planning in catchment areas of cold and oligotrophic rivers.

2. Material and methods

2.1. Site description

The studied area is a 130 km section of the upper parts of the river Indalsälven with a catchment area of approximately 8400 km^2 (Fig. 1). The western (upstream) part of the study area is dominated by low mountains and the river has many relatively large tributaries. In the eastern part the river flows through forested highland valleys. The average annual precipitation in the area is 800 mm, which predominantly falls as rain in the summer. The precipitation distribution is generally not reflecting the river discharge due to snow accumulation during winter period and water regulation for hydropower purposes. The annual average water flow in the lowest part of the study area is 162 m^3 s^{-1} and maximum flow occurs during snowmelt according to discharge data from the gauging station number 1616 Mörsils KRV (Swedish Meteorological and Hydrological Institute) (SMHI, 2013). The study area is sparsely populated with the exception of the Åre ski resort in the central part of the area.

2.2. Sub-division of the study area

The river was divided into 24 sub-sections. The stream sections were divided into 16, 3–7 km long sub-sections. The length of each sub-section was chosen for maximum homogeneity of the gradient within the section. The eight lakes in the study area formed the remaining subsections (Fig. 2).

2.3. Experimental data

Input parameters used for model calculations are shown in Table 1. The reference inactivation rate constant k_{ref} and the temperature coefficient Q_{10} was taken from Blaustein et al. (2013)

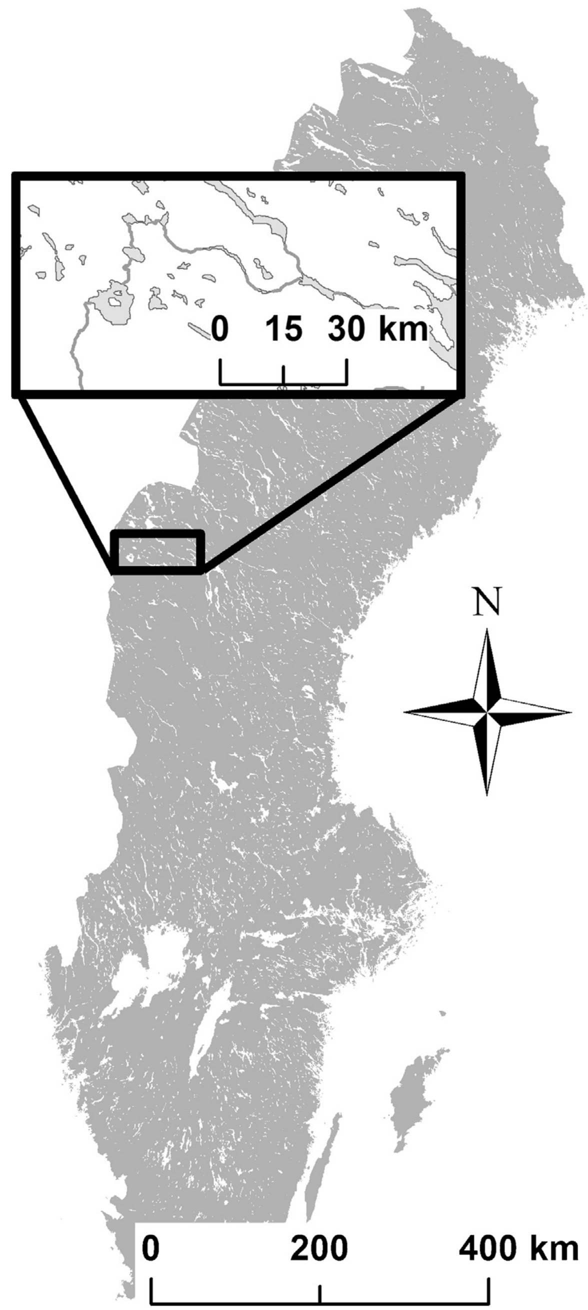

Fig. 1. Location of the study area in northern Sweden ©Lantmäteriet.

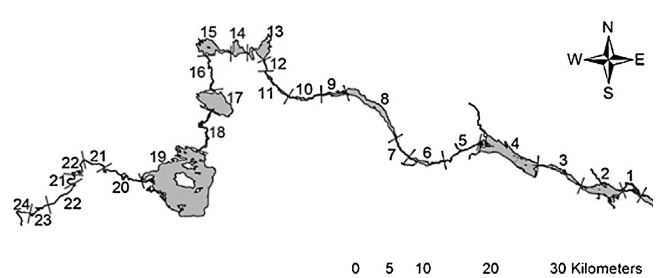

Fig. 2. The division of river sub-sections. Section 2, 4, 8, 13, 14, 15, 17 and 19 are lakes. The others are stream sections. Flow direction is towards east.