Science of the Total Environment 630 (2018) 869–877

Contents lists available at ScienceDirect

Science of the Total Environment

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

Minimal climate change impacts on natural organic matter forecasted for a potable water supply in Ireland

Connie O'Driscoll [a,d,*], José L.J. Ledesma [b,**], John Coll [c], John G. Murnane [d,g], Paul Nolan [e], Eva M. Mockler [f], Martyn N. Futter [b], Liwen W. Xiao [a,**]

[a] Department of Civil, Structural and Environmental Engineering, TCD, Dublin, Ireland
[b] Department of Aquatic Sciences and Assessment, SLU, Uppsala, Sweden
[c] Irish Climate Analysis and Research Units, Department of Geography, NUI Maynooth, Maynooth, Co Kildare, Ireland
[d] Department of Civil Engineering, NUIG, Galway, Ireland
[e] Irish Centre for High End Computing (ICHEC), Research and Applications Division, Met Éireann, Dublin, Ireland
[f] UCD School of Civil Engineering, UCD, Dublin, Ireland
[g] School of Engineering, University of Limerick, Ireland

HIGHLIGHTS

- Potential impacts of climate change on NOM were projected.
- Results show future behaviours are similar to current conditions.
- Projected increases are offset by parallel decreases in precipitation and flow.

GRAPHICAL ABSTRACT

ARTICLE INFO

Article history:
Received 22 December 2017
Received in revised form 19 February 2018
Accepted 20 February 2018
Available online xxxx

Editor: D. Barcelo

Keywords:
Natural organic matter
Carbon cycle
Surface water
Climate change
INCA-C
Ireland

ABSTRACT

Natural organic matter poses an increasing challenge to water managers because of its potential adverse impacts on water treatment and distribution, and subsequently human health. Projections were made of impacts of climate change on dissolved organic carbon (DOC) in the primarily agricultural Boyne catchment which is used as a potable water supply in Ireland. The results indicated that excluding a potential rise in extreme precipitation, future projected loads are not dissimilar to those observed under current conditions. This is because projected increases in DOC concentrations are offset by corresponding decreases in precipitation and hence river flow. However, the results presented assume no changes in land use and highlight the predicted increase in DOC loads from abstracted waters at water treatment plants.

1. Introduction

Declines in the quality of potable surface waters, including increasing concentrations of natural organic matter (NOM) have the potential to impact on human health and the costs of drinking water treatment (Whitehead et al., 2009; Delpla et al., 2009). NOM, which can be approximated and measured as dissolved organic carbon (DOC), are

* Correspondence to: C. O'Driscoll, Department of Civil Engineering, NUIG, Galway, Ireland.
** Corresponding authors.
E-mail addresses: odriscco@tcd.ie, connieodriscoll@gmail.com (C. O'Driscoll), jose.ledesma@slu.se (J.L.J. Ledesma), liwen.xiao@tcd.ie (L.W. Xiao).

https://doi.org/10.1016/j.scitotenv.2018.02.248
0048-9697/© 2018 Published by Elsevier B.V.

susceptible to higher concentrations as a consequence of extreme precipitation events in temperate ecoregions (Delpla et al., 2009).

Elevated DOC concentrations can affect the functioning and cost of water treatment processes (Eikebrokk et al., 2004), as DOC can increase mobility of contaminants and toxic compounds, and is a precursor for harmful disinfection by-products produced during chlorination including potentially carcinogenic trihalomethanes (THMs). Additionally, elevated DOC concentrations in drinking water supply systems can lead to increased problems with microbial growth and biofouling. Labile DOC (i.e. polysaccharides and proteins) can promote microbial growth in water distribution networks, providing habitats for potentially harmful microorganisms which are protected from disinfectants such as chlorine (Kilb et al., 2003). Thus, local and regional scale predictions of DOC concentrations in drinking water supplies are warranted so as to safely and economically manage water treatment and distribution.

Ireland has the highest reported THM exceedances in potable water across the European Union (EU) (O'Driscoll et al., 2018). In Ireland, most drinking water is abstracted from surface sources which are more susceptible to high DOC concentrations. Karst geology may further compromise many groundwater sources (Daly, 2009) as swallow holes and other surface karst features provide increased connectivity between surface water and groundwater. As is the case with other northern mid-high latitude areas (de Wit et al., 2016a), it is anticipated that climate change will also increase DOC in Irish surface waters (Naden et al., 2010).

Leaching of organic carbon from soils is considered to be the key contributor to DOC in surface waters (Hejzlar et al., 2003) with 2.9 Pg C yr^{-1} reported to be mobilised (Regnier et al., 2013). Anthropogenic disturbance, i.e. deforestation, agricultural intensification, and wastewater discharge is believed to be responsible for up to 1.0 Pg C yr^{-1} since the beginning of the industrial revolution (Regnier et al., 2013). Some degree of anthropogenic climate change is unavoidable; and while much effort has been given to quantitative assessment of water supply, relatively less is known about human induced climate change on the factors controlling organic carbon dynamics (Delpla et al., 2009). Both positive and negative effects of a changing climate on DOC leaching can be hypothesized. Warmer and wetter soils may support higher rates of biological activity and DOC production, while increased drought frequency and severity may suppress DOC production and intensify hydrophobicity (Moore et al., 2008).

Multiple DOC simulation models exist for both terrestrial and aquatic environments (summarised in de Wit et al., 2016a). The Integrated Catchments model for Carbon (INCA-C; Futter et al., 2007) has been used to simulate the effect of climatic, land use and acidification-related variables on DOC fluxes from soils to surface waters and under current and future conditions for a range of catchment sizes and across different land use categories in Fennoscandia and Canada (de Wit et al., 2016a).

INCA-C modelling of a forestry catchment in southern Finland has shown that (1) historical increases in DOC concentration can be attributed to declines in sulfate deposition and (2) future DOC increases are associated with a changing climate (Futter et al., 2009). Increased DOC concentrations have also been projected for a large, primarily agricultural catchment in Southern Ontario, Canada (Oni et al., 2012). Large seasonal variations in DOC concentrations associated with a shift of maximum summer temperatures towards winter and a longer persistence of elevated summertime DOC concentrations were observed in the same area (Oni et al., 2015a). Given the considerable uncertainties associated with the complexity of processes regulating soil carbon flux (de Wit et al., 2016a), we believe there is a pressing need for further impact studies which follow standardised protocols and allow for intercomparison of the effect of climate extremes on terrestrial carbon cycling (Frank et al., 2015). Such studies can also help in decision-making processes for current and future use of rivers for drinking water supply (Ledesma et al., 2012). The main objective of this study was to project potential future climatic impacts on flow and DOC concentrations and fluxes for a representative agricultural catchment (Boyne catchment, Fig. 1) which provides potable water to large supply zones in Ireland. INCA-C models were first used to simulate current DOC concentrations and fluxes. Downscaled temperature and precipitation outputs from two Regional Climate Models (RCMs) were then used to drive the INCA-C model.

2. Methods

2.1. Study area

The Boyne catchment (2693 km^2) is located in east-central Ireland. On average, it receives 900 mm annual rainfall and has an average gradient of 1.24 m km^{-1} along its main channel length (113 km), which discharges to the Irish Sea (Fig. 1). The Boyne River drains the southern part of catchment and the Kells Blackwater River drains the northern part of the catchment. The confluence of the two tributaries is approximately 30 km west of the discharge point. The main anthropogenic pressures in the catchment are associated with diffuse pollution from agricultural runoff, point source effluent discharges from 21 Municipal Wastewater Treatment Plants (WWTP), and peat harvesting in the upper parts of the catchment. The Boyne catchment has a history of deteriorating water quality, the most prominent being eutrophication of lakes in the upper reaches of the Kells Blackwater (Toner et al., 2005).

Soils in the Southern and central parts of the catchment are dominated by grey brown podzols and gley soils with significant peat deposits, whereas soils in the north are more typically acid brown earths and gleys. Land use in the catchment has been characterized using the CORINE Land Cover Dataset 2012. Arable land used for crop cultivation accounts for 11% of the total area, and pasture is the accounts for a further 80%. Forest, semi-natural areas, moors and heathland, and transitional woodland-scrub cover 3% of the catchment, while peat, urban areas and lakes account for the other 6%. Catchment soils are not sensitive to acidification (Aherne et al., 2002).

2.2. Model data

Daily temperature and precipitation data were obtained from Mullingar and Kilskyre for 1st January 2005 to 30th April 2016 (Met Éireann, Fig. 1). Daily flows at Roughgrange (2475 km^2), approximately 15 km upstream the main catchment outlet (Fig. 1), were obtained from the EPA (www.epa.ie/hydronet/#07059) for the period 22nd December 2005 to 2nd February 2015. An on-line submersible spectrophotometer, spectro::lyser™ equipped with a 35 mm measuring cell (s::can Messtechnik), installed on the raw water abstraction point at the Staleen water treatment plant (the same location as for the flow measurements), was used to estimate daily DOC values for 7th September 2014 to 2nd December 2015. Daily time series of agricultural manure spreading, reported as kg DOC ha^{-1} day^{-1} were generated based on typical manure concentrations in the area (Murnane et al., 2016) applied at rates permitted under current legislation (SI No. 31 of 2014).

2.3. Hydrological modelling

The Precipitation, Evapotranspiration and Runoff Simulator for Solute Transport (PERSiST) rainfall-runoff model (Futter et al., 2014) was used to generate daily stream flow, soil moisture deficit (SMD) and hydrologically effective rainfall (HER) datasets for use in INCA-C carbon simulations. The Boyne catchment was divided into 6 land use classes: pasture (75%), agriculture (13%), forest (5%), peatland (4%), urban (2%), and lake (1%). These proportions differ slightly from those of the whole catchment because simulations were performed only for the area draining Roughgrange (where flow and DOC measurements were taken), which is approximately 200 km^2 smaller than the total Boyne catchment area. PERSiST was calibrated using long-term (December 2005–February 2015) observed stream flow at Roughgrange and