Science of the Total Environment 649 (2019) 712–721

Contents lists available at ScienceDirect

Science of the Total Environment

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

Hydraulic conditions affect pollutant removal efficiency in distributed ditches and ponds in agricultural landscapes

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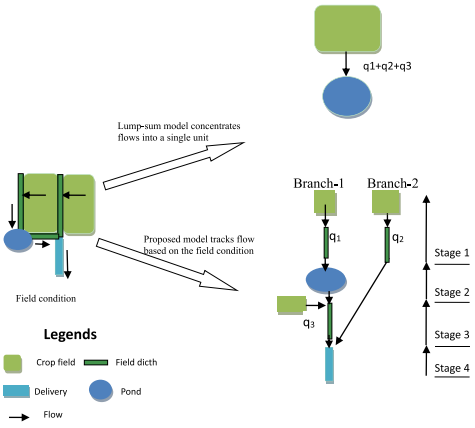
HIGHLIGHTS

- We proposed a method to evaluate the water quality effect of distributed ditches/ponds considering their specific hydraulic conditions (HC).
- A realization factor (RF) was used to compare pollutant removal rates with and without considering specific HCs.
- The predicted RFs were 0.70–0.84 for various removal rate constants.
- The uneven distribution of ditches and ponds is the major limiting factor of their water quality function in agricultural landscapes.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 11 June 2018
Received in revised form 24 August 2018
Accepted 24 August 2018
Available online 25 August 2018

Editor: Paola Verlicchi

Keywords:
Ditches and ponds
Hydraulic condition
Pollutant removal
Distributed system

ABSTRACT

Distributed ditches and ponds in agricultural landscapes can retain agricultural pollutants (such as nutrients and pesticides) like wetlands while facilitating crop field drainage. Their complex hydraulic conditions affect pollutant transport and degradation processes, but the existing lump-sum method for estimating pollutant removal treats the total area simply as one unit without considering their specific hydraulic conditions (HCs). In this paper we proposed an analytical method for evaluating pollutant removal efficiencies of distributed ditches and ponds by considering their different HCs explicitly. A realization factor (RF) was used to compare pollutant removal rates with and without considering specific HCs. Application of the method was demonstrated with a case study based on field investigations in an intensively farmed area in southeastern China. The total area of ditches and ponds accounts for 15% of drained crop fields; and the calculated RFs were 0.70–0.84% for various removal rate constants. The difference was mainly caused by the uneven distribution of ditches and ponds along different drainage paths. For pollutants with small values of removal rate constants, the calculated concentration reductions along different flow paths were proportional to their wetland sizes, making the pollutant removal as area limited. For pollutants with larger values of removal rate constant, however, the calculated pollutant removal became concentration limited when the wetland to farmland area ratio was high. Large ponds and ditches were major contributors (85–94%) of pollutant removal in the whole system, while the field ditches contributed to less than 10% of the total removal due to their small dimension and shallow water depth. The distributed nature of ditches and ponds poses some inherent limitations to their water quality functions due to variable hydraulic conditions; understanding such underlying constraints may help guide proper evaluation and conservation of the existing ditches and ponds in agricultural landscapes.

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https://doi.org/10.1016/j.scitotenv.2018.08.340
0048-9697/

1. Introduction

The *river network* area in the lower reaches of the Yangtze River in southeastern China is well known for its bountiful waters in ponds/lakes and channels of natural waterways or man-made drainage ditches. But agricultural intensification in recent years has resulted in significant decline of ditches and ponds in agricultural landscapes; as reported by Liu et al. (2011), stream/ditch density dropped by 7.5% between 1965 and 2006 in the area, and 52.3% reduction in water surface was due to elimination of small waterways.

Ditches and ponds distributed in agricultural landscapes are required to facilitate farmland drainage for crop production; but they also have wetland functions in retaining agricultural non-point source pollution (Dollinger et al., 2015; Moore et al., 2010). These distributed ditches and ponds are favorably positioned to intercept agricultural pollutants; they are self-operational and excellent surrogates wetlands in reducing agricultural non-point source pollution (Tournebize et al., 2017; Vymazal and Brezinova, 2015; Kröger et al., 2013; Mitsch et al., 2001).

Distributed ditches and ponds may enhance ecological resilience of agricultural landscape by providing environmental services like wetlands; but they differ from the constructed wetlands in their hydraulic conditions. As designated pollutant removal devices, constructed wetlands normally have clearly defined flow inlets and outlets that allow monitoring devices to record flow discharge and pollutant dynamics (Persson et al., 1999). The distributed ditches and ponds, on the other hand, often exhibit much more complicated hydraulic conditions that are required by their primary function of field drainage; they are arranged to allow efficient discharge of drainage flows that affect residence time of pollutants in waters (Collins et al., 2016; Kröger et al., 2008). Different ditch or pond segments as limited by their functions and locations may carry variable flow rates and pollutants. Consequently, some ditches or ponds are less effective than the others in pollutant removal due to their unfavorable hydraulic conditions (Fremier

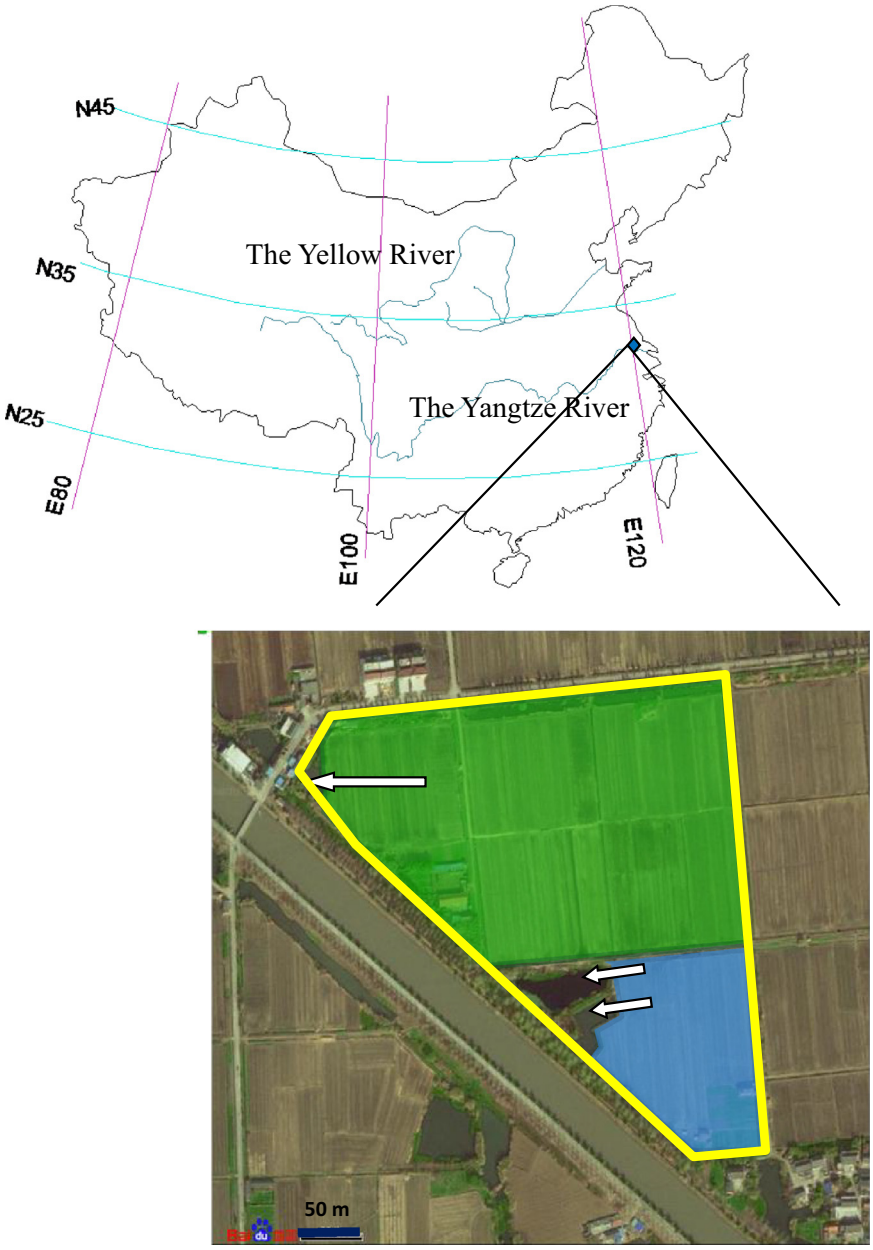

Fig. 1. General location and delineation of the study area (arrows indicate flow direction: crop fields in green shade drain to a pond at top left; fields in blue shade drain to a pond and a delivery ditch at bottom left). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)