Science of the Total Environment 583 (2017) 133–141

Contents lists available at ScienceDirect

Science of the Total Environment

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

Evaluation of factors affecting soil carbon sequestration services of stormwater wet retention ponds in varying climate zones

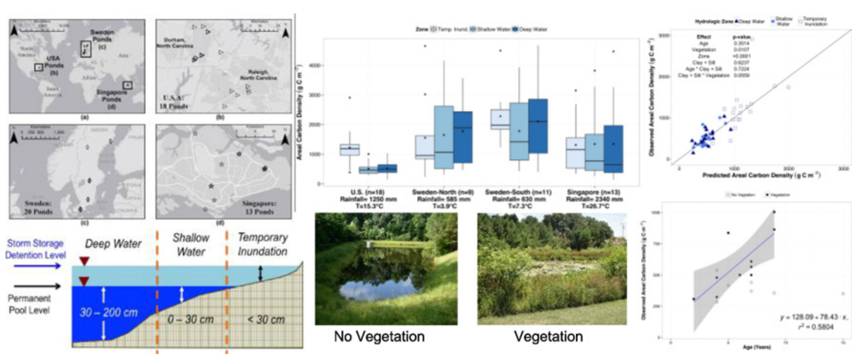
L.S. Merriman [a,*,1], T.L.C. Moore [b], J.W. Wang [c], D.L. Osmond [d], A.M. Al-Rubaei [e], A.P. Smolek [a], G.T. Blecken [e], M. Viklander [e], W.F. Hunt [a]

[a] *Biological & Agricultural Engineering, North Carolina State University, Campus Box 7625, Raleigh, NC 27695, United States*
[b] *Biological & Agricultural Engineering, Kansas State University, 129 Seaton Hall, Manhattan, KS 66506, United States*
[c] *Centre for Urban Greenery and Ecology, National Parks Board, 1E Cluny Road, 259569, Singapore*
[d] *Soil Science, North Carolina State University, Campus Box 7619, Raleigh, NC 27695, United States*
[e] *Urban Water Engineering, Luleå University of Technology, SBN 971 87 Luleå, Sweden*

HIGHLIGHTS

- Carbon sequestration is becoming a valuable ecosystem service.
- Stormwater ponds: intersection of biosphere, lithosphere, and hydrosphere.
- Soil C accumulation in 4 climates: U.S., North Sweden, South Sweden, and Singapore.
- Increased rainfall and growing season length outweighed decomposition rates.
- Establishment of vegetation in retention ponds is vital to carbon sequestration.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 9 October 2016
Received in revised form 4 December 2016
Accepted 7 January 2017
Available online 16 January 2017

Editor: D. Barcelo

Keywords:
Soil carbon
Carbon sequestration
Wet retention ponds
Climate change
Stormwater control measures
Ecosystem services

ABSTRACT

The carbon sequestration services of stormwater wet retention ponds were investigated in four different climates: U.S., Northern Sweden, Southern Sweden, and Singapore, representing a range of annual mean temperatures, growing season lengths and rainfall depths: geographic factors that were not statistically compared, but have great effect on carbon (C) accumulation. A chronosequence was used to estimate C accumulations rates; C accumulation and decomposition rates were not directly measured. C accumulated significantly over time in vegetated shallow water areas (0–30 cm) in the USA (78.4 g C m^{-2} yr^{-1}), in vegetated temporary inundation zones in Sweden (75.8 g C m^{-2} yr^{-1}), and in all ponds in Singapore (135 g C m^{-2} yr^{-1}). Vegetative production appeared to exert a stronger influence on relative C accumulation rates than decomposition. Comparing among the four climatic zones, the effects of increasing rainfall and growing season lengths (vegetative production) outweighed the effects of higher temperature on decomposition rates. Littoral vegetation was a significant source to the soil C pool relative to C sources draining from watersheds. Establishment of vegetation in the shallow water zones of retention ponds is vital to providing a C source to the soil. Thus, the width of littoral shelves containing this vegetation along the perimeter may be increased if C sequestration is a design goal. This assessment

* Corresponding author.
E-mail address: laura.merriman@amecfw.com (L.S. Merriman).
[1] Present address: 9711 Sky Park Court, San Diego, California, USA 92123-4341.

http://dx.doi.org/10.1016/j.scitotenv.2017.01.040

establishes that stormwater wet retention ponds can sequester C across different climate zones with generally annual rainfall and lengths of growing season being important general factors for C accumulation.

1. Introduction

The use of fossil fuels is the largest anthropogenic greenhouse gas source, and land use conversion (implicitly or through agricultural emissions) is the second leading contributor (IPCC, 2013). With C storage in biomass and soils becoming an increasingly valuable ecosystem service (Newell et al., 2013), policymakers have realized the need to mitigate climate change through better land use management (Lal, 2004). Globally, urban development continues to increase; by 2050, 2.3 billion new inhabitants will be living in urban areas (UN, 2010). This provides motivation to know how these new urban areas impact soil C and the global C budget.

This concept of ecosystem services has been utilized in environmental planning and management (De Groot, 2006) and is now extending to the design and management of stormwater infrastructure (Moore and Hunt, 2013; Kandulu et al., 2014). Runoff water quality and hydrology regulation remain the primary drivers for stormwater control measure (SCM) implementation and research, and accordingly, the primary metrics for evaluating performance (Lenhart and Hunt, 2011; Lucke and Nichols, 2015); however, as created ecosystems, SCMs can provide a variety of additional ecosystem services (Moore and Hunt, 2012). Accounting for these enables a more comprehensive estimation of the multifunctional values of SCMs. Given rising interest in and potential for regulation of C emissions, establishing C sequestration services of vegetated SCMs has become a recent research pursuit (Getter et al., 2009; Moore and Hunt, 2012; Bouchard et al., 2013).

Constructed wet retention ponds (referred to as "ponds" hereafter) are engineered ecosystems designed to provide runoff hydrology and quality regulating services. Ponds can significantly reduce peak runoff rates, remove solids, and provide nitrogen and phosphorus removal (Hancock et al., 2010; Gallagher et al., 2011). Moore and Hunt (2012) also demonstrated the ability of ponds in North Carolina (humid subtropical climate), especially with a littoral shelf, to sequester C into the soil. Carbon sequestration could vary depending on ambient and climatic conditions; thus, the results of Moore and Hunt (2012) are not directly transferrable to other regions, which limits their relevance worldwide. This is important given ponds are one of the few SCMs used globally for stormwater management (Lundberg et al., 1999; Vezzaro et al., 2011; Borne et al., 2013); yet, there has not been a global effort to quantify the C sequestration of these engineered ecosystems.

The goal of this study was to evaluate the soil C sequestration provided by wet retention ponds in four climate zones, with specific objectives to investigate the effects of design components (internal landforms and vegetation establishment) on C accumulation rates and making general, not statistical, comparisons of geographic effects (growing season, rainfall, temperature) these rates among the climate zones.

2. Methods

2.1. Wet retention pond design characteristics

Ponds are permanently wet basins that receive runoff from a watershed. Ponds are designed to have a permanent pool of water and additional capacity (typically 30 cm) above the permanent pool to store and slowly release water volume from a design storm event (typically 25–40 mm) over a period of two to five days. There are three different landforms (also known as hydrologic zones) in the pond: deep water, shallow water, and temporary inundation (Fig. 1). The deep water and shallow water depths are measured from the permanent pool level and range from 30 to 200 cm and 0–30 cm, respectively (MDE, 2016; NCDEQ, 2016). The temporary inundation zone is an internal-to-pond floodplain and is designed for a maximum depth of (e.g.) 30 cm above the permanent pool level when a water quality event occurs. The temporary inundation zone has no significant standing water several days after the storm.

The deep water zone typically comprises most of the pond's surface area (approximately 90% coverage), leaving the remaining 10% divided between the shallow water and temporary inundation zones. Some ponds are designed with a littoral shelf, where shallow water and temporary inundation zones are purposely vegetated with emergent macrophytes. The littoral shelf is typically a 1–3-m wide perimeter around the pond (NCDEQ, 2016). This vegetation enhances pollutant removal (Knowles, 1982; Lenhart et al., 2012), protects the shoreline from erosion (Zhou et al., 2008), and could contribute to volume losses due to evapotranspiration (Lott and Hunt, 2001).

2.2. Study sites

Ponds were sampled in four different climate zones (Fig. 2): the United States, specifically in the state of North Carolina, (sub-humid, sub-tropical climate), Sweden (Southern Sweden—continental and Northern-subarctic climates), and Singapore (humid, tropical climate) (Peel et al., 2007). Moore and Hunt (2012) sampled 18 ponds, ranging from 2 to 15 years of age, in North Carolina, USA. Ten of the surveyed ponds possessed a littoral shelf (Table 1). North Carolina has four distinct seasons, with average temperatures in December–February (winter) and June–August (summer) of 3.8 °C and 25.6 °C, respectively (NCDC, 2014). The annual mean temperature is 15.3 °C, and annual rainfall is 1250 mm (NCDC, 2014). Precipitation is relatively well distributed throughout the year.

Twenty ponds, 3–26 years of age, were sampled in Sweden. All ponds examined had highly vegetated temporary inundation zones, but only eight possessed littoral shelves that extended into the shallow water zone (Table 1). The sampling in Sweden crossed two different climate zones: humid continental and subarctic (Peel et al., 2007). The humid continental climate region of Sweden has a wide variation in average seasonal temperature, with December–February (winter) ranging from −1 °C to 2 °C and June–August (summer) ranging from 14.5 °C to 15.5 °C (WWIS, 2014). Precipitation is relatively well distributed throughout the year with annual rainfall of approximately 600 mm (WWIS, 2014). The subarctic climate covers most of northern Sweden. Average seasonal temperatures for winter range from −10 °C to −4 °C, with 13 °C to 16 °C in summer. The annual mean temperature

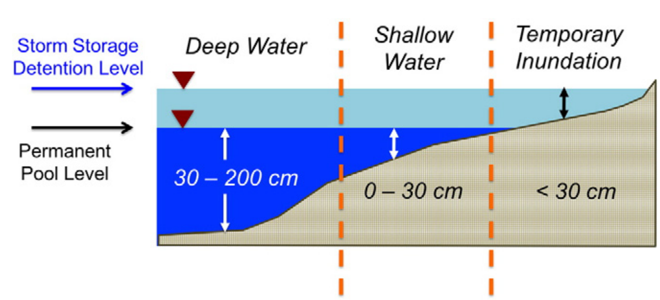


Fig. 1. Cross section schematic of pond illustrating the three hydrologic zones: deep water, shallow water, and temporary inundation (schematic not to scale).