Journal of Environmental Management 217 (2018) 677–689

Contents lists available at ScienceDirect

Journal of Environmental Management

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

Research article

Agricultural implications of providing soil-based constraints on urban expansion: Land use forecasts to 2050

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A R T I C L E I N F O

Article history:
Received 10 October 2017
Received in revised form
9 March 2018
Accepted 10 March 2018
Available online 24 April 2018

Keywords:
Urbanization
Land transformation model
Soil conservation
Land use change
Urban planning
Agriculture

A B S T R A C T

Urbanization onto adjacent farmlands directly reduces the agricultural area available to meet the resource needs of a growing society. Soil conservation is a common objective in urban planning, but little focus has been placed on targeting soil value as a metric for conservation. This study assigns commodity and water storage values to the agricultural soils across all of the watersheds in Michigan's Lower Peninsula to evaluate how cities might respond to a soil conservation-based urbanization strategy. Land Transformation Model (LTM) simulations representing both traditional and soil conservation-based urbanization, are used to forecast urban area growth from 2010 to 2050 at five year intervals. The expansion of urban areas onto adjacent farmland is then evaluated to quantify the conservation effects of soil-based development. Results indicate that a soil-based protection strategy significantly conserves total farmland, especially more fertile soils within each soil type. In terms of revenue, ~$88 million (in current dollars) would be conserved in 2050 using soil-based constraints, with the projected savings from 2011 to 2050 totaling more than $1.5 billion. Soil-based urbanization also increased urban density for each major metropolitan area. For example, there were 94,640 more acres directly adjacent to urban land by 2050 under traditional development compared to the soil-based urbanization strategy, indicating that urban sprawl was more tightly contained when including soil value as a metric to guide development. This study indicates that implementing a soil-based urbanization strategy would better satisfy future agricultural resource needs than traditional urban planning.

1. Introduction

Capturing the economic and environmental impacts of urban expansion is highly desired for urban planning strategies, though doing so is notably complex due to the changing factors that drive land use change (e.g., government action, transportation development, and employment growth or decline; Parker et al., 2003; Irwin and Geoghegan, 2001). Many modeling studies exist to better understand the impacts and patterns to urban development (Wu, 2006; Deal and Schunk, 2004; Eppink et al., 2004; Parker et al., 2003), but these studies are often limited in producing spatially disaggregate datasets (Irwin and Geoghegan, 2001). Here, we strictly isolate the agricultural and economic implications of localized farmland conversion when a soil-based development constraint is integrated as an urban planning strategy. We specifically target farmland for its unique combination of quality (i.e., annual yield potential), value (i.e., annual revenue from overlying crops), and spatial distribution around metropolitan areas (i.e., high density around urban centers).

Urbanization onto adjacent farmland largely follows economic drivers; that is, farmland is sold to developers based on profit incentives, among other drivers such as market optimism or risk aversion, for both the farmer and developer (Satterthwaite et al., 2010; Devadoss and Manchu, 2007; Tobin and Brainard, 1990). Two major problems exist with such transactions: 1) land values are often based on the *current* market value of production and risk rather than a market value based on *future* resource demands

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https://doi.org/10.1016/j.jenvman.2018.03.042
0301-4797/

(Goodwin et al., 2003), and 2) land values are driven by location (e.g., proximity to urban areas) and not the relative quality of soils across possible development sites (Huang et al., 2006; Livanis et al., 2006); both discount the long-term resource needs of a growing society. Given that most cities have historically been located in fertile agricultural areas (Seto and Ramankutty, 2016), it is common for the most fertile soils in a region to be the first converted to urban land as cities expand onto adjacent farmland. Proportionally, the soils remaining undeveloped are then of lower agricultural value, and have lower yield potentials (Martellozzo et al., 2015). This is a particularly important oversight because once farmland is converted to urban land, it can no longer produce food and energy for the public (Dunlap and Jorgenson, 2012; Thompson and Prokopy, 2009). Unfortunately, the value of fertile soil is still not adequately included in long-term urban planning (Blanco-Canqui and Lal, 2008).

Every state has policies in place to preserve farmland (e.g., tax relief, right-to-farm laws, development rights, or zoning restrictions; Nelson, 1992), but these policies generally do not differentiate soil types based on yield potential. This generates a fundamental disconnect between current development practices and future resource needs. One reason why soil-based development is not widely implemented is that urbanization is considered to only impact a small fraction of total agricultural land across a region (Thompson and Prokopy, 2009; Chen, 2007; Hart, 2001). However, at smaller spatial scales, urbanization can have a substantial impact on the total area of key commodities and the total revenue of local economies. Furthermore, lost production and revenue is compounded annually as maximum annual crop yields can no longer be achieved due to the development of the most fertile soils.

This study assigns commodity and water storage values to the agricultural soils across watersheds in Michigan's Lower Peninsula to evaluate how cities might respond to a soil conservation-based urbanization strategy. The Lower Peninsula region of Michigan is selected for its many isolated urban areas and successful agricultural markets that include commodity row and field crops along with localized specialty crops. To this end the Land Transformation Model (LTM) is used to simulate two development scenarios: 1) non-penalized urban expansion (i.e., traditional development), and 2) penalized urban expansion using soil value as a way to develop less valuable agricultural land first (i.e., soil-based development). Results from this study target 1) urban expansion, 2) soil quality conservation, 3) agricultural revenue conservation, and 4) urban density. These results provide an initial framework for soil-based urban planning, which could be used to inform further targeted modeling studies, land development policies, and resource conservation strategies. This paper first introduces the study area, the LTM, and the baseline simulation results, followed by extensive results and discussion on the implications of adding a soil-based development strategy for urban planning.

2. Methods

2.1. Study area and early trends

The study region includes Michigan's Lower Peninsula (LP) and adjoining areas that drain to the Laurentian Great Lakes, including parts of Illinois, Indiana, and Ohio (Fig. 1). This region has a total population of more than 15 million, most of which is in major metropolitan areas including Chicago, Detroit, Toledo, Lansing, Grand Rapids, Kalamazoo, South Bend, and Traverse City (US Census, 2010). Agricultural land covers 36% of the study area; 98% of which is used to grow 11 main commodities: corn, soybeans, wheat, hay, cherries, apples, blueberries, potatoes, cucumbers, dry beans, and sugar beets (Homer et al., 2015; USDA, 2014). These 11 commodities were selected as the most valuable for the region given their total dollar production; in 2014, production accounted for \$2.87 billion from corn, \$1.94 billion from soybeans, \$893 million from dry beans, \$691 million from hay, \$415 million from wheat, \$169 million from cucumbers, \$159 million from apples, \$132 million from potatoes, \$114 million from cherries, \$73 million from sugar beets, and \$58 million from blueberries. Collectively across all commodities, agriculture in this region accounts for more than \$9 billion per year (NASS-USDA).

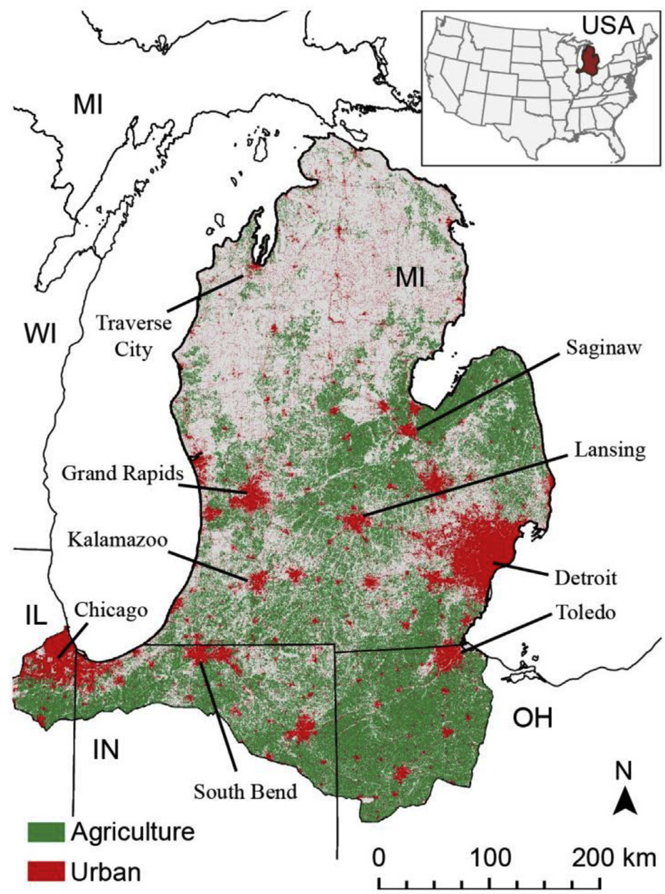

Fig. 1. Site map of the Lower Peninsula watershed study region with major metropolitan areas indicated (modified from Tayyebi et al., 2017; Homer et al., 2015). The region includes the entire watersheds of all stream basins within lower Michigan, encompassing portions of Ohio, Indiana and Illinois.

The southern half of the region contains the majority of the population and most of the agricultural land. Crops in this southern portion primarily consist of the major commodity crops (corn, soybeans, wheat, and hay), while the western and eastern portions respectively grow mostly specialty fruits (cherries, blueberries, apples, and grapes) and other commodities (dry beans, cucumbers, potatoes, and sugar beets). The southern half of the boundary is widely characterized by flat lands with highly fertile, silty soils, where the northern half of the boundary includes more distinct glacial topography and sandy soils. All of the major metropolitan regions are situated within agricultural land, except for Traverse City, which is located in the northern LP adjacent to cherry farms and vineyards; almost all urbanization must expand into nearby farmlands. Land other than agriculture primarily consists of other urban land (14%), forest (25%) or grassland (12%; Homer et al., 2015).