Spatial analysis of land use change in a flood-prone watershed: S. Ore Creek, MI, USA

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ABSTRACT

The S. Ore Creek watershed in Hamburg, Michigan is a 93.2 km^2 watershed that flows into Ore Lake, whose community is vulnerable to increasing flooding. There have been no studies investigating the influences of upstream inputs on flooding in this watershed, such as urban development and vegetation changes within wetlands. The current study uses the Online ArcGIS software to examine shifts in wetlands and urban development from 2000 to 2019 in the S. Ore Creek watershed. We divided the watershed into four sections from north to south, and identified regions of land use changes within and surrounding wetlands in each section. Using the National Land Cover Database, we identified the area of urban and wetland land use change. We found that there were changes within wetlands (e.g., herbaceous to woody wetlands) in 745,200 m^2, increases in intensity of urban development surrounding wetlands in 150,300 m^2, and urban development encroaching into wetlands in 62,100 m^2. Urban development encroaching into wetlands (and some waterways) occurred in the southern half of the watershed (31,500 m^2) with some encroachment in the northernmost section of the watershed (30,600 m^2). Relatedly, regions where herbaceous and woody wetlands disappeared occurred in 50,400 m^2. Studies have found that increases in urban development and shifts in vegetation within wetlands have been found to increase the potential of flooding. The current study has potential implications for the recent increases in downstream regional flooding.

Introduction

Hamburg Township, Michigan (USA) is increasingly vulnerable to flooding; there have been 29 floods since 2000, 15 of which were in the top 20 historic crests (National Weather Service, 2020). This region includes the Huron River, which is a major waterway in metro-Detroit spanning over 900 square miles, and the tributaries of Ore Lake, S. Ore Creek, and Dibrova Creek (Huron River Watershed Council, 2012). With the propensity of flooding, the region is understudied.

The United States Army Corps of Engineers (USACE) conducted a flood inundation study on Ore Lake and sections of the Huron River (Prokopec, 2018; United States Army Corps of Engineers, D.D., 2019). They indicated that “Summer months, from approximately May to September, have higher water-surface elevations compared to the winter months for the same discharge value. Aquatic vegetation contributes to the higher water-surface elevations during the warmer months, because the vegetation can cause backwater conditions along the Huron River thus raising water stages” (Prokopec, 2018, p. 4).

Hamburg Township municipality has focused attention on weed harvesting in the Huron River to increase outflow of water through the river, including outflow from Ore Lake (Hamburg Township, 2014).

Wetlands have a naturally occurring benefit of decreasing flood events. For example, floodplain wetlands (wetlands adjacent to rivers) have been found to serve as water retention because of their proximity to rivers and therefore can diminish flood events through the flood attenuation effect (e.g., Acreman & Holden, 2013; United States Army Corps of Engineers, D.D., 1972). Land use changes from wetlands or open land to rural/urban development has led to increases in flood events (e.g., Detenbeck et al., 1999; Brody et al., 2007).

Changing land use from permeable land to impermeable surfaces leads to greater runoff with a diminished capacity for water retention (e.g., Brody et al., 2007), which can lead to increased frequency or severity of flood events. For example, in Texas and Florida, changes in land use to increase development and therefore impermeable surfaces (including increased intensity of development) (e.g., parking lots; shopping malls) and to decrease naturally occurring wetlands have led to increases in flood events (Brody et al., 2007). Similarly, related disturbances can lead to changes in vegetation, decreased wildlife production and biodiversity, increased above-ground production, decreased downstream water quality, loss of aquatic plant species, and increased flooding (both severity and frequency) (Detenbeck et al., 1999). For this reason, in flooded communities, it is important to consider the impact of land use changes from wetlands to rural or urban development on the amount and frequency of flood events.

Currently, no studies have investigated the role of upstream inputs on flooding in the Ore Lake area. Ore Lake is fed by S. Ore Creek, whose watershed extends 93,200,000 m^2 (Huron River Watershed Council, 2012). The S. Ore Creek watershed includes the City of Brighton, extends into six different townships (Hartland, Oceola, Genoa, Green Oak, Brighton, and Hamburg), and includes various residential and urban regions. It has 34 lakes and 34 ponds. Across the watershed, the total land use is made up of 47% rural and urban development (43,800,000 m^2), 16% open land (14,900,000 m^2), 15% wetlands (14,000,000 m^2), 8% forested lands (7,500,000 m^2), and 8% agriculture (7,500,000 m^2) (Huron River Watershed Council, 2012). Yet, this has not previously been investigated. In the current study, we focus on the shifts in wetlands and urban development and the potential impacts on flooding.

Due to the role of wetlands in mitigating flooding events along with the negative impacts of increasing development on flooding, we investigated the changes of development in and around wetland areas, as well as changes to wetlands themselves over a 21-year timespan.

We asked,

- How did wetland type and extent change from 2000-2019 within the S. Ore Creek watershed?
- How did the urban development surrounding wetlands change from 2000-2019 in the the S. Ore Creek watershed?
- To what extent did urban development encroach into wetlands in the S. Ore Creek watershed?
- To what extent did urban development encroach into waterways in the S. Ore Creek watershed?

By comparing differences between 2000 and 2019 (see Figures 1A and 1B), we found that changes within wetlands were the most common, followed by urban development changing around wetlands and then urban development encroaching into wetlands. This was similar within each region of the S. Ore Creek watershed. Changes within wetlands included shifts from herbaceous to woody (most common), as well as shifts from woody to herbaceous, herbaceous wetlands appearing, woody wetlands appearing, and then unknown changes. Woody and herbaceous wetlands disappearing were the least common. Urban development increased in intensity and extent throughout the watershed. Findings from the current study will inform further studies in this region on the impact of land use changes on runoff and increased flood events.

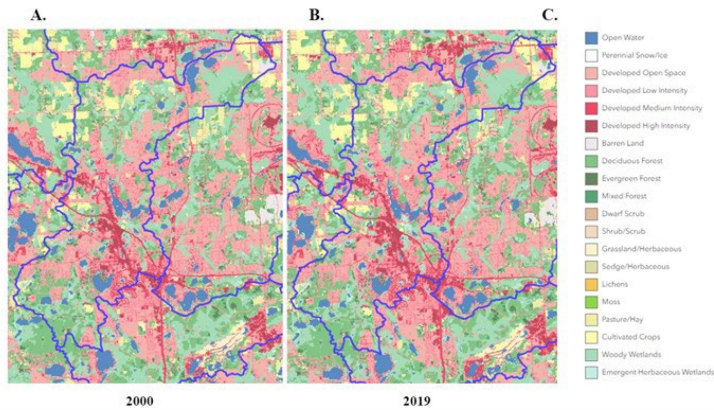

Figure 1. Images of watershed in 2000 and 2019. This map shows areas of development (in light and dark pink) and wetlands (in light blue and light green) in the years 2000 and 2019. 1A serves as a baseline for our analysis, while 1B shows changes since the year 2000. 1C is a key of land use changes from the USA NLCD Land Cover Layer from the years 2001 (Homer et al., 2001) and 2019 (Dewitz and U.S. Geological Survey, 2021).

Methods

We used the educational version of ArcGIS to study land use changes within and surrounding wetlands in the S. Ore Creek watershed. We added and removed layers using the ArcGIS Online feature to read layers (particularly those from different time periods), add sketches (e.g., circling areas within and surrounding a watershed), and save maps. The ArcGIS Online only provided access to certain layers to be added to maps. We used the U.S. Geological Survey Watershed Boundary Dataset 12-unit code (U.S. Geological Survey, 2022) for S. Ore Creek to narrow our study.. We used the development & land cover change layer (USA NLCD Land Cover) between the years 2001 (Homer et al., 2001) and 2019 (Dewitz and U.S. Geological Survey, 2021), because this indicated the greatest changes of urban development and wetlands. These layers allowed us to identify relationships between urban development and wetlands, as well as an increase and decrease of wetlands within the watershed. Due to the limited capabilities of the ArcGIS Online software and our interest in the potential impacts of urban development and wetlands on flooding, we focused on three types of land use changes: Development going into wetlands, changes within wetlands, and development surrounding wetlands.

First, we divided the watershed into four sections to analyze the relationships between land use changes within certain sections of the S. Ore Creek watershed. We labeled each section as A, B, C, and D. Next, we analyzed each section for land use changes surrounding and encroaching into wetlands between the years from 2000-2019. Any land use changes were marked with a colored circle. For example, Figure 5 demonstrates urban development encroaching into wetlands.

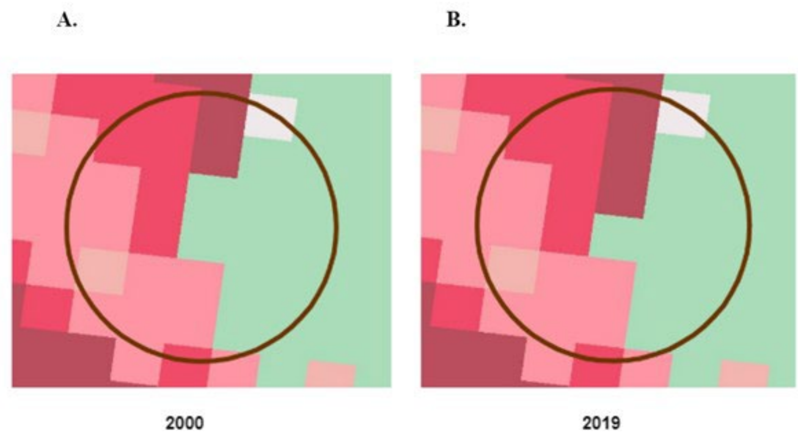

Figure 2. Example of development encroaching into wetlands inside a brown circle. Figure 5A is an enlargement of one area of the map from the year 2000. Figure 5B shows the same area as it appeared in 2021. In figure 5B, you can see that dark red (urban development) replaced light green (woody wetlands) shown in figure 5A.

Once we completed these analyses for an entire section, we went back and identified any changes within a wetland (e.g., changes of type of wetland; increasing or decreasing wetlands). We marked any wetland changes with a different colored circle (purple). For example, Figure 6 shows changes from herbaceous to woody wetlands.

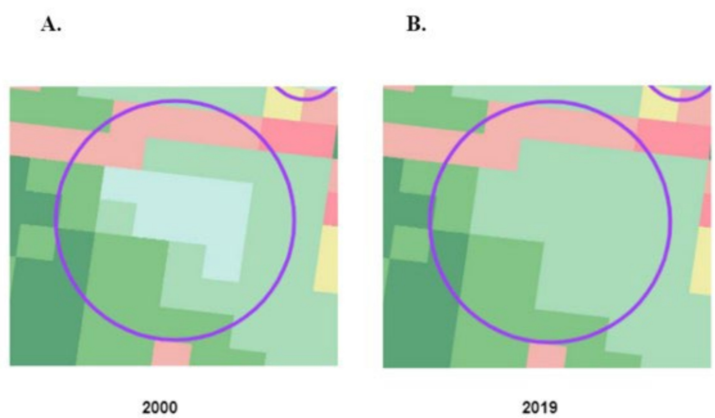

Figure 3. Example of wetlands changing inside a purple circle. Figure 3A is an enlargement of one area of the map from the year 2000. Figure 3B shows the same area as it appeared in 2019. In figure 3B, you can see that the light green (woody wetlands) replaced the light blue (herbaceous wetlands) shown in figure 3A.

Lastly, we analyzed the map for any urban development that was changing surrounding wetlands and indicated those changes with a black circle. For example, Figure 7 indicates an increase in intensity of urban development surrounding a wetland.

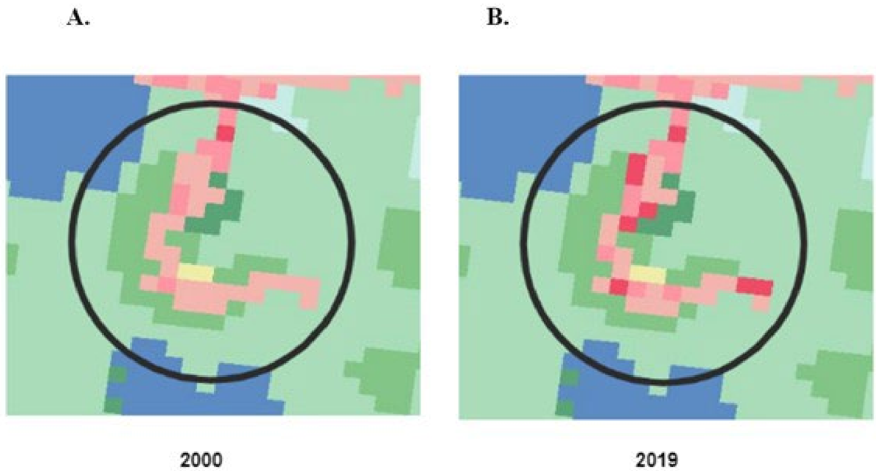

Figure 4. Example of development changing around wetlands. Figure 4A is an enlargement of one area of the map from the year 2000. Figure 4B shows the same area as it appeared in 2021 In figure 4B, you can see that the development is a greater intensity (darker pink) compared to the development in figure 4A. This signifies increased development from 2000-2021 in this specific area.

Once we completed the analyses in a single section, we repeated the process in another section until we analyzed the entire watershed. Through our analyses we also found four places with development encroaching into a waterway. These were indicated with light blue circles. For example, Figure 8 indicates development encroaching into a waterway.

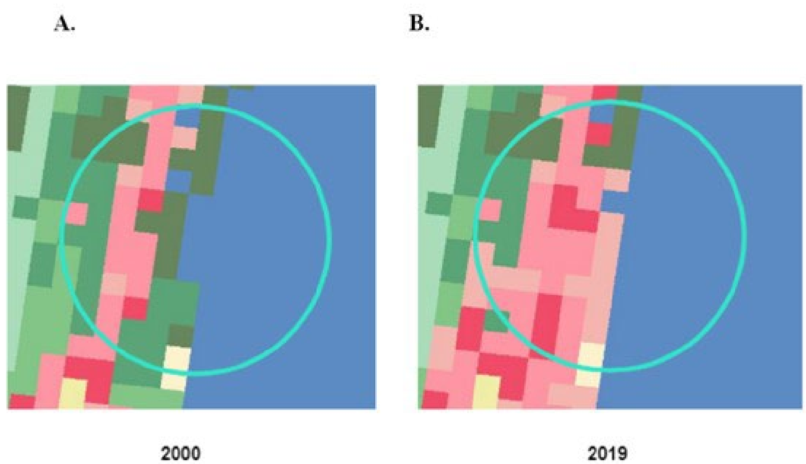

Figure 5. Example of development going into water. Figure 5A is an enlargement of one area of the map from the year 2000. Figure 5B shows the same area as it appeared in 2019. In figure 5B, you can see that there is some light and darker pink (urban development) that replaced some blue (water) which is shown in 5A.

Once we identified regions of changing land use throughout the watershed and indicated by colored circles, we then counted each region of land within each circle to the amount of change in meters squared. We then reported these changes across the entire watershed. We also reported changes in area (meters squared) within each section of the watershed to indicate comparisons between sections.

Results

To focus our analysis, we divided the S. Ore Creek watershed into four sections (A, B, C, and D) (see Figure 2). Within each section, regions that indicated changes of land use related to wetlands or urban development were marked with a colored circle. Changes were identified based on shifts in the development and land use change layer. The changes we identified were (a) changes within wetlands circled in purple (e.g., herbaceous wetlands evolving into woody wetlands), (b) urban development encroaching into wetlands circled in brown , and (c) urban development changes surrounding wetlands circled in black (e.g., increased intensity of urban development). We extended our analysis to then identify how wetlands changed. This included shifts in (a) woody to herbaceous wetlands (woody-herbaceous), (b) herbaceous to woody wetlands (herbaceous-woody), (c) woody wetlands appearing, (d) herbaceous wetlands appearing, (e) woody wetlands disappearing, and (f) herbaceous wetlands disappearing. It is also important to note that some circles overlap each other when multiple changes occur in the same region (e.g., urban development increasing in intensity around wetlands and also encroaching into wetlands). After using circles to identify regions of change, we then calculated the land area that changed (in square meters) within each circle to determine the quantity of change across the watershed.

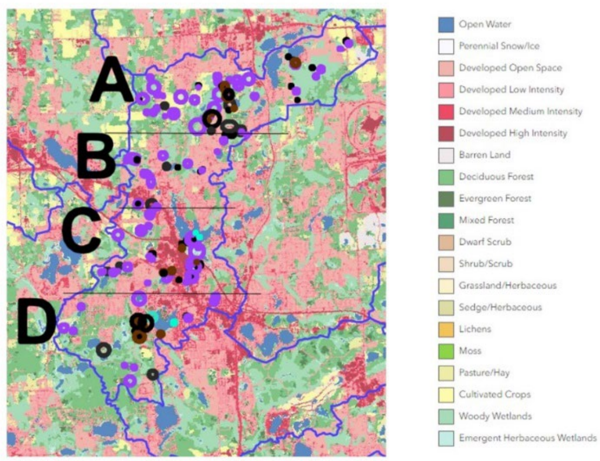

Figure 6. Map of the watershed showing how the watershed was divided into sections and the use of circles to indicate land use changes within or around wetlands. Each section is labeled as A, B, C, and D. In each section, you can see the different colored circles based on land use changes.

Land Use Changes Across the S. Ore Creek Watershed

Throughout the S. Ore Creek watershed, we identified 957,600 m^2 of land use changes related to wetlands. Within that, changes within wetlands occurred in 745,200 m^2 (77.8%), increased intensity of urban development surrounding wetlands occurred in 150,300 m^2 (15.7%), development encroaching into wetlands occurred in 62,100 m^2 (6.5%), and urban development encroaching into a waterway occurred in 7,200 (0.75%) m^2.

Of the 745,200 meters where changes within wetlands occurred, 255,600 m^2 (32.3%) were wetlands changing from herbaceous to woody wetlands. Approximately 228,600 m^2 (30.7%) were wetlands changing from woody to herbaceous wetlands. Herbaceous wetlands appeared in 171,900 m^2 (23.1%) and woody wetlands appeared in 38,700 m^2 (5.1%). Finally, herbaceous wetlands disappeared in 35,100 m^2 (4.7%) woody wetlands disappeared in 15,300 m^2 (2.1%).

Land Use Changes Within Each Section

Next, we describe land use changes that occurred within each section of the S. Ore Creek watershed to determine any variation across the watershed (see Figure 3). Overall, changes within wetlands were the most common changes for all sections and ranged from 71,100-305,100 m^2 across the sections. Also across all sections, though less evident, there were increases in the intensity of urban development around wetlands. This ranged from 9,000-59,400 m^2. In comparison, only three of the four sections indicated development encroaching into wetlands. This occurred in the southern two sections of the S. Ore Creek watershed (6,300 m^2 in section C and 25,200 m^2 in section D), along with section A (30,600 m^2). Similarly, we only found development encroaching into waterways in southern two sections of the watershed (1,800 m^2 in section C and 5,400 m^2 in section D).

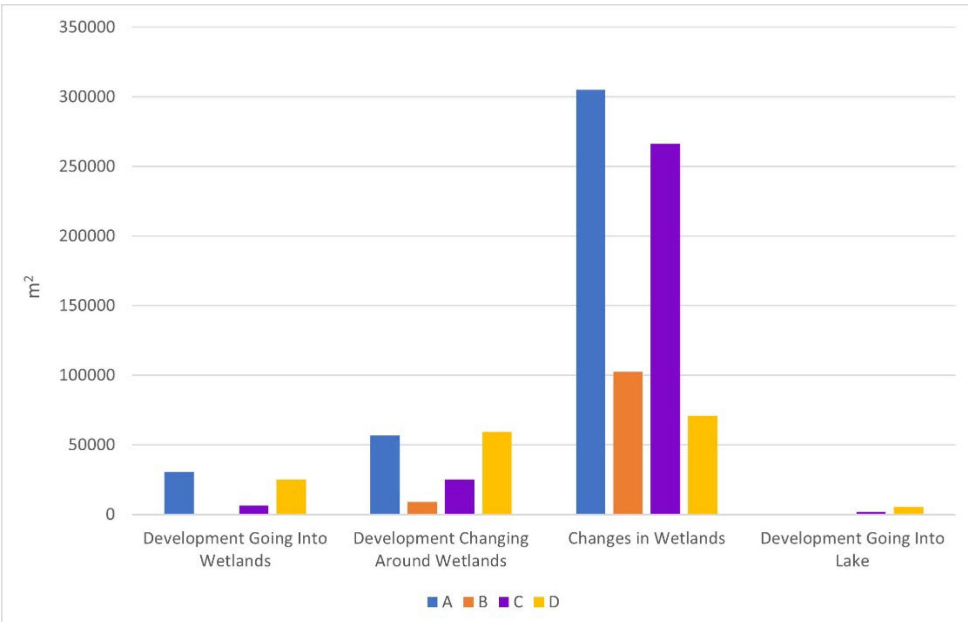

Figure 7. Changes of Wetlands & Development in Each Section (A, B, C, D) in Meters Squared. Each type of change has its own group with what their results were for each section of the watershed within its group.

Lastly, we indicate wetland changes that occurred within each section of the S. Ore Creek watershed to determine variation across the watershed (see Figure 4). Overall, we found that the changes from woody to herbaceous wetlands tended to occur in the northern three sections (71,100 m^2 in section A, 30,600 m^2 in section B, and 116,100 m^2 in section C) with only some changes in the southernmost section (10,800 m^2 in section D). We also found that changes from herbaceous to woody wetlands were most common in section A, with some changes in sections B, C, and D, which were 14,400 m^2, 22,500 m^2, and 28,800 m^2, respectively.

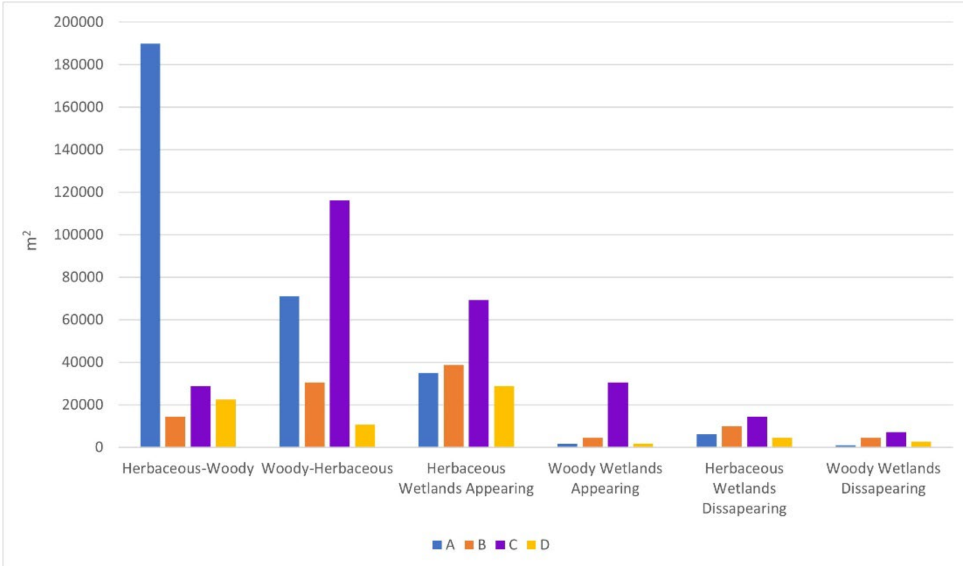

Figure 8. Changes Within Wetlands in Each Section (A, B, C, D) in Meters Squared. Each type of change of wetland has its own group with what their results were for each section of the watershed within its group.

When looking at wetlands appearing and disappearing, we found a consistent pattern in woody and herbaceous wetlands. For example, both woody and herbaceous wetlands appeared and disappeared in all sections, but were most evident in the middle two sections. Woody wetlands appeared more in section C (30,600 m^2), compared with sections A, B, and C (4,500 m^2 in section B and 1,800 m^2 for sections A and C). Similarly, herbaceous wetlands appeared the most in section C (69,300 m^2), compared with sections A, B, and D (35,100 m^2 in section A, 38,700 m^2 in section B, and 28,800 m^2 in section D). Also, the herbaceous wetlands decreased in sections B and C by 9,900 m^2 and 14,400 m^2, respectively. This compared to decreases in sections A and D of only 6,300 m^2 and 4,500 m^2, respectively. The woody wetlands also decreased the most in sections B and C (4,500 meters and 7,200 meters, respectively). This compared to decreases in sections A and D of only 900 m^2 and 2,700 m^2, respectively.

Overall, we found variation in land use changes within and surrounding wetlands in the S. Ore Creek watershed. The shifts in wetland-types, increased urban development intensity surrounding wetlands, and encroachment of urban development into wetlands and waterways is concerning for their potential impacts on regional flooding. In particular, we are most concerned with the disappearing wetlands and development encroaching in wetlands and waterways occurring in the southernmost sections of the watershed due to their proximity to flood-prone communities. The extensive shifts in wetlands and urban development in the S. Ore Creek watershed has the potential to negatively impact regional downstream flooding.

Discussion

The current study found changes within and surrounding wetlands in the understudied S. Ore Creek watershed that flows into the frequently flooded community of Ore Lake in Hamburg Township, Michigan. In particular, we found that the majority of the land use changes occurred within wetlands with most being shifts from herbaceous to woody wetlands. We also found that all changes to urban development involved increasing intensity of development surrounding wetlands. Lastly, the main areas where development encroached into wetlands occurred in the southern sections of the S. Ore Creek watershed.

Expanding development around and into wetlands, along with shifts in types of wetlands can impact regional flooding (e.g., Acreman & Holden, 2013; Brody et al., 2007; Price & Berkowitz, 2020). Similar to other studies (e.g., Detenbeck et al., 1999), we found that local disturbances can lead to changes in the vegetation; for the current study this included shifts from herbaceous to woody wetlands, as well as some shifting from woody to herbaceous wetlands. The shifts from herbaceous to woody wetlands indicate potentially impactful changes that may affect future regional flooding.

A limitation of the current study is that we were not able to calculate the quantitative impacts of land use changes on run off and regional flooding due to software limitations. For this reason, and to provide an initial study of land use changes in the S. Ore Creek watershed, we manually calculated the percent of regions with land use change surrounding and within watersheds from 2000-2019.

As an initial study of the S. Ore Creek watershed, we drew on qualitative methods to identify where changes in land use have occurred surrounding and within wetlands due to their potential impacts of regional flooding. These qualitative methods will inform future research on quantitative changes to runoff and flooding with access to more advanced software that can support such methodology. The current study has implications for addressing land use changes within Hamburg Township and communities within the S. Ore Creek watershed when investigating the impacts of flooding. This will begin to inform our understanding of the regional flooding issues and will inform future mitigation efforts.

Acknowledgements

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