Washtenaw County Green Infrastructure Development Analysis

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Final Report for the Washtenaw County Water Resources Office

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Executive Summary

Rain gardens and other types of green infrastructure help reduce surface water runoff from entering nearby water sources. Our goal is to locate areas that would benefit from the installation of green infrastructure, based on the three priority areas of water quality, equity, and wildlife, in the context of a changing climate.

In this report, we show our analysis determining ideal locations in Washtenaw County for the development of green infrastructure based on the three priority areas. We incorporate parameters such as land-use tract areas, poverty status data, roadways, precipitation intensity, degraded creeksheds, etc. in order to calculate preference values that will show where to install green infrastructure. Final maps for each of the three priority areas are shown. We also discuss how climate change may affect the locations we have identified in the long term.

Green infrastructure has numerous environmental, social, and financial benefits and therefore it may be beneficial for the Washtenaw County Water Resources Office to consider coordinating with SEMCOG and their green infrastructure efforts to increase resilience and avoid maladaptation.

The outline of the report is as follows:

1. Introduction
2. Literature Review
3. Methods
    a. Notes About the Included Criteria
    b. GIS Data
4. Runoff and Water Quality
5. Social Inequality
6. Wildlife Corridors
7. Discussion, Summary, and Conclusions
8. Bibliography
9. Appendix: Layers Included in Final ArcGIS Layer Package

Section 1) Introduction

Rain gardens are a type of green infrastructure that reduce runoff from entering nearby lakes and rivers and provide food and shelter to wildlife. Currently, the Washtenaw County Rain Garden Program has built over 1,000 rain gardens through the Rain Garden Assistance visits and Master Rain Gardener program.

Increased precipitation as a result of climate change would lead to increased surface runoff, thus degrading water quality. By mid-century, annual total precipitation values in the Washtenaw County area are projected to increase by several inches per year under climate scenario RCP 8.5, the high-emissions global warming scenario.[1] The installation of more rain gardens throughout Washtenaw County is an important tool to protect water quality and increase resilience in the face of climate change.

For this project, our goal is to identify priority areas in Washtenaw County for the installation of rain gardens and other types of green infrastructure. We seek areas that would benefit from these installations from a stormwater, equity, and wildlife perspective. This work is set in the context of a changing climate and considers the impacts of increased precipitation and runoff.

In this report, we show recommended locations to build rain gardens in Washtenaw County using data processed with ArcGIS Pro. A more concise workflow description of planned GIS analysis (and how it will inform where to install rain gardens) is included in the Flow Diagram (Fig. 1).

The outline for this report is as follows: In Section 2, we provide a summary about the literature we used to guide this analysis. In Section 3, we discuss our methods, the data used, and the parameters we focus on. Sections 4, 5, and 6 discuss the water quality, social inequality and wildlife corridor lenses, respectively. We discuss and summarize our findings in Section 7.

Section 2) Literature Review

Previous studies by Goodspeed et. al[2] and Meerow and Newell[3] detail the methods employed for spatial planning and mapping of green infrastructure in the Southeastern Michigan region. These methods seek to take full advantage of the multifunctional nature of green infrastructure, as its benefits extend beyond stormwater runoff management to air quality improvement, reduction of the urban heat island effect, and increased landscape connectivity, all of which have positive impacts on public health, local biodiversity, and property values.

The main goal of this project is to reduce pollution of waterways by stormwater runoff. Both of the aforementioned studies employ the Rational Method to estimate total runoff, which they incorporate into their models, and we intend to employ the same algorithm here. (See Section 3 - Methods).

These studies have already established a useful framework to incorporate the multifaceted goals of stakeholders in the Southeast Michigan region, and as such, we have incorporated much of their methodology into our own. More details about the literature review available upon request.

Section 3) Methods

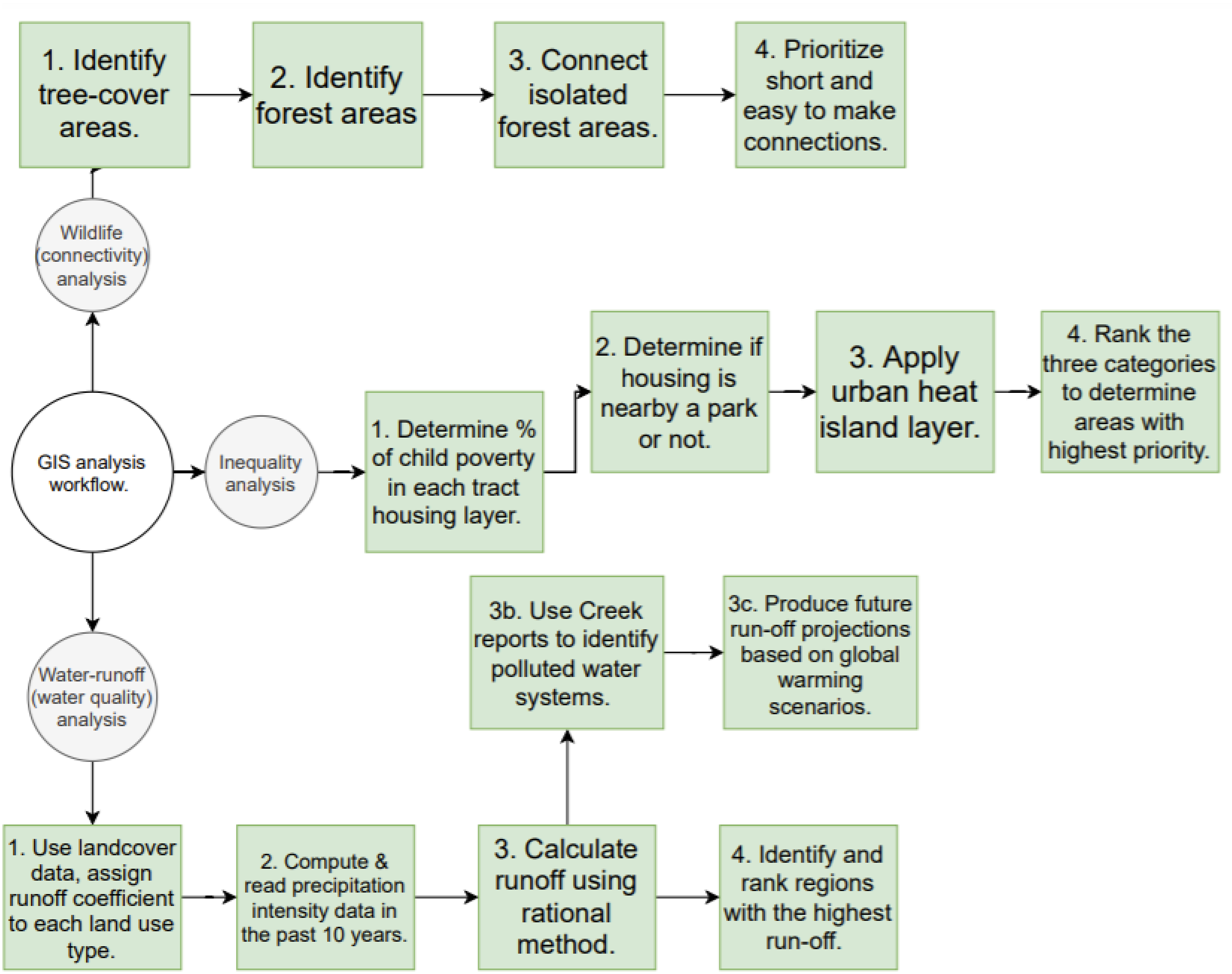

Fig. 1: Workflow methodology for prioritizing potential rain garden (and green infrastructure) locations based on the three specified criteria of importance (water quality, inequality and wildlife access).

3.1 Notes About the Included Criteria

1a. Social inequality (Poverty level)

For the first step in the inequality analysis, we import the American Community Survey poverty status data at tract level (Estimates of the population for 2015 - 2019). The data is clipped using the SEMCOG Washtenaw County boundary outline. We tested a number of criteria that would visualize poverty across Washtenaw county and opted to use '% of Children (under 18 years) whose household income is below the poverty line in the past 12 months'. We select this criteria as it provides an easy to interpret metric and helps to identify areas of Washtenaw in which permanent residents are living within poverty. In contrast, we tested other categories such as the adult population living below the poverty line; however, this would bias high poverty levels within Ann Arbor due to the large and temporary student population.

We allow ArcGIS to automatically separate the percentage of children living below the poverty line into four distinct percentage groups: 0-5%, 5-14%, 14-31%, >31%. The percentage groups are converted into 'priority values' of 1, 2, 3, 4 respectively (tracts with higher poverty are given a higher priority rank) using the reclassify tool. As the final goal of the analysis is to combine many different criteria together, we must ensure that they all have the same resolution. The original goal was to allow a fluid analysis between the three different criteria (Run-off, Social Inequality, Wildlife Access) by keeping the resolutions similar, hence why we have chosen to use this rather coarse resolution. For ease of comparison between the other layers, we do a raster conversion on the tract data into 1 x 1 km. pixels.

Upon raster conversion, we apply an additional priority rank of 0 (lowest priority) to pixels in which there is no housing using the SEMCOG land use layer (Updated on 23rd June 2015).

1b. Distance to Park

The next criteria was calculated by determining whether a housing layer had access to a nearby recreational space. Prior to running the analysis, we filter out all private recreational spaces that are not accessible to all members of the public (i.e., Golf Courses, Private Land). The analysis is conducted such that a housing must be within 'walking distance' 0.3 miles (0.5 km.) to a recreational space[3]. We apply a 0.3 mile buffer layer around each recreational land use. We use the spatial join tool to identify housing layers within the 0.3 mile buffer zone. We run this analysis once more but this time accounting for the size of the park. We filter out all parks that are greater than 2 acres and only keep mini-parks and other small-scale green spaces[4].

Once the aforementioned recreational space analysis is complete, we convert the data to raster and reclassify the layers with values of 0, 1, 2. The value of 0 relates to pixels in which housing has access to a park greater than 2 acres or a pixel with no housing within its domain. The value of 1 relates to pixels with housing that have access to recreational space less than 2 acres. The value of 2 relates to pixels with housing that have no access to recreational space.

1c. Urban Heat Island

We include the urban heat island (UHI) effect as part of the social inequality analysis due to the known socio-environmental impact of the UHI effect on underserved communities, that being: Excess heat is the leading cause of weather related deaths in the United States; respiratory issues and fatality from excess heat predominantly impacts the elderly and children[5].

We use NASA's Landsat 8 imagery data (we use band 10, a ground-level thermal sensor) that has been averaged for the summers of 2018 and 2019. The data contains the relative heat severity for 30 x 30 m. pixels (data is already in a raster format). The relative heat severity is defined as areas that have an excessive UHI effect. For example, the data is categorized from values of 1 to 5. A value of 1 corresponds to a slightly above average UHI effect for an urbanized area while a value of 5 corresponds to a severe UHI effect.

The ArcGIS analysis is completed by interpolating the data into 1 x 1 km. pixels in order to be averaged into the final map product. We reclassify the data to have priority values ranging from 0, 1, 2, 3, 4. A value of 0 corresponds to no excess UHI effect, while the values from 1 to 4 indicate an increasingly excessive UHI effect.

As a final step, we combine the three aforementioned criteria using the raster calculator to sum up the total priority value (out of 10) for each pixel within Washtenaw County. The values with the highest scores indicate areas where the analysis has determined the highest priority for green infrastructure.

1d. Caveats of Methodology

We outline some of the key caveats of this methodology that may impact the final map product.

The tract poverty layer was determined by the percent of children living below the poverty line. The advantage of this metric is that it is intuitive and is less prone to biases associated with the non-permanent population of Washtenaw County (i.e., Adult students). However, the disadvantage lies in the large variation in total tract area. Notably, some rural areas have a sizable percentage of children living below the poverty line; however, it is very likely that only specific regions of the tract are associated with higher poverty levels. As a result, this analysis is particularly geared towards tracts in urban areas where tracts are spatially small with respect to rural ones.

We note that the distance to park metric would emphasize rural communities where the number of parks are considerably less. However, it is important to note that rural communities are more likely to own private transportation compared to urban ones; hence the lack of accessibility to a park within an urban area may be of greater priority. In order to factor this into the analysis, we have gone with applying a lower score weighting for this criteria.

Another issue lies in what is defined as a recreational space. The SEMCOG recreational space data may be missing areas with public green space access. One example includes open-to-public Universities in Washtenaw County as they are categorized as educational spaces.

2a. Wildlife Corridors

Finding areas in Washtenaw County in need of improved wildlife connectivity first requires mapping out areas that are inhabited by wildlife. A simple way to accomplish this is by determining the spatial distribution of forestland across the county, as forests support the vast majority of unique living species globally[6] and so in general represent the largest contribution to distinct animal habitats in any given area. We define forests as land tracts larger than 0.5 hectares with tree heights larger than 5 m. and tree canopies of at least 10%, following the 2010 US-specific Global Forest Resources Assessment released by the Forestry Department of the Food and Agriculture Organization of the United Nations.[7]

We identify forestlands throughout Washtenaw County by importing the US Forest Service (USFS) "Cartographic" Tree Canopy Cover dataset into ArcGIS and clipping it to the SEMCOG Washtenaw County boundary outline. We extract the tracts of the data that contain more than 10% of tree canopy cover. Following a similar process with the Global Land Analysis & Discovery (GLAD) 2019 Global Forest Canopy Height dataset, we isolate the tracts containing trees taller than 5 m. We then combine the 10% tree canopy and 5 m. canopy height datasets, and remove the tracts 0.5 hectares in area or smaller, to generate a map of the areas within the county that qualify as forests.

2b. Prioritization of Areas with Low Wildlife Connectivity

We seek to identify priority areas for improving wildlife connectivity using the Cost Connectivity analysis function built into ArcGIS, which is designed to find the lowest "cost" paths between areas based on some input raster "cost function." Our goal is to assign lower cost values to regions that are most lacking in green space, and therefore most lacking in animal habitats, because these are the areas that are most likely to benefit from improved wildlife connectivity.

In order to build the cost raster that we need, we first input the SEMCOG land use map and clip it to the SEMCOG Washtenaw County boundary outline. Then, we use ArcGIS to calculate the average percentage by area of each land use type covered by forest. We convert each of these percentages to a decimal value, ranging between zero and one, and assign a value of one to water bodies (to ensure that we don't try to place green infrastructure in the water).

This raster map of percentage values provides what we need to use the Cost Connectivity tool, which gives us a collection of the lowest cost zero-width paths between disparate forest areas. However, real wildlife corridors have finite widths; more specifically, the Indiana Division of Fish & Wildlife defines wildlife corridors as needing widths of 50-200 ft. in order to provide habitat support to the largest variety of wildlife.[8] Based on this, we apply a 100 ft. rectangular buffer zone with rounded tips around each of our zero-width paths, thus generating a county map of 200-foot-wide corridors representing priority locations for green infrastructure placement.

3. Stormwater runoff

The Rational Method allows us to calculate the magnitude of stormwater runoff via the equation

$$\textbf{Runoff} = \textbf{(Precipitation intensity)} \times \textbf{(Area)} \times \textbf{(Runoff coefficient)}$$

where the runoff coefficient is defined per type of land-use category.[2]

3.2 GIS Data

The following lists the data used for the GIS analysis:

- County boundary
  - Southeast Michigan Council of Governments (SEMCOG) County Boundaries Map
    - This dataset includes polygons for seven counties in Southeast Michigan, for use in GIS analysis.
- Land use
  - SEMCOG Land Use Map
    - The dataset includes the land-use types within seven counties of Southeast Michigan. For our use, the land use types have been clipped to be within the boundaries of Washtenaw county.
- Poverty status
  - American Community Survey (ACS) Poverty Status Map
    - This dataset includes estimated poverty status data from the most recent ACS five year data. Poverty status is quantified by the percentage of the population whose income in the last 12 months falls below the Federal poverty line.
- Road Networks
  - SEMCOG Roads Map
    - This dataset includes roads across Southeast Michigan.
- Precipitation data
  - Daymet: Daily Surface Weather Data on a 1-km Grid for North America, Ver. 3
    - Daymet provides 1 $km.^2$ gridded weather data across North America. We used 2011-2020 annual accumulated precipitation data to calculate the 10-year average daily precipitation intensity.
    - See: Thornton, P.E., M.M. Thornton, B.W. Mayer, Y. Wei, R. Devarakonda, R.S. Vose, and R.B. Cook. 2016. Daymet: Daily Surface Weather Data on a 1-km. Grid for North America, Version 3. ORNL DAAC, Oak Ridge, Tennessee, USA.

        https://doi.org/10.3334/ORNLDAAC/1328
- TerraClimate
  - This dataset provides 4 km.^{2} gridded monthly climatologies for 1981-2010, 2°C warming (future projection), and 4°C warming (future projection)
  - See: Abatzoglou, J., Dobrowski, S., Parks, S. et al. TerraClimate, a high-resolution global dataset of monthly climate and climatic water balance from 1958–2015. Sci Data 5, 170191 (2018). https://doi.org/10.1038/sdata.2017.191

- Hydrologic Units
  - USGS National Hydrogeography
    - This dataset provides hydrologic units at multiple levels. We used the Michigan 12-digit Hydrologic Unit data.
- Tree Cover
  - USA NLCD Tree Canopy Cover
    - This dataset includes a percentage of tree cover across the USA.
  - US Forest Service (USFS) 2016 Cartographic Tree Canopy Cover
    - This dataset provides a 30 x 30 m. resolution map of tree cover percentages across the United States. We used the “Cartographic” dataset to best accommodate our visualizations.
- Urban Heat Island Effect
  - Urban Heat Island Severity Map
    - The dataset includes 30 x 30 m. pixels of the severity of the urban heat island effect across US cities for the summers of 2018 - 2019.
- Parks Layer
  - Map of Parks in South-East Michigan
    - Much like the land use dataset, the layer provides the locations of parks within South-East Michigan. This layer comes with additional detailed information such as whether parks are privately owned or accessible to the public.
- Forest Canopy Height
  - Global Land Analysis & Discovery (GLAD) Global Forest Canopy Height, 2019
    - This dataset provides a 30 x 30 meter resolution global map of forest canopy heights.

Section 4) Runoff and Water Quality

4.1 Using Runoff to Prioritize Green Infrastructure Installation Locations

Building green infrastructure is a cost-efficient and nature-friendly solution to manage stormwater runoff. Green infrastructures can reduce the volume of surface water runoff, filter out the pollutants in runoff water, recharge the groundwater, and therefore improve the water quality. In this session, we map the spatial distribution of stormwater runoff across Washtenaw County, the highest runoff regions will have high priority to build green infrastructures.

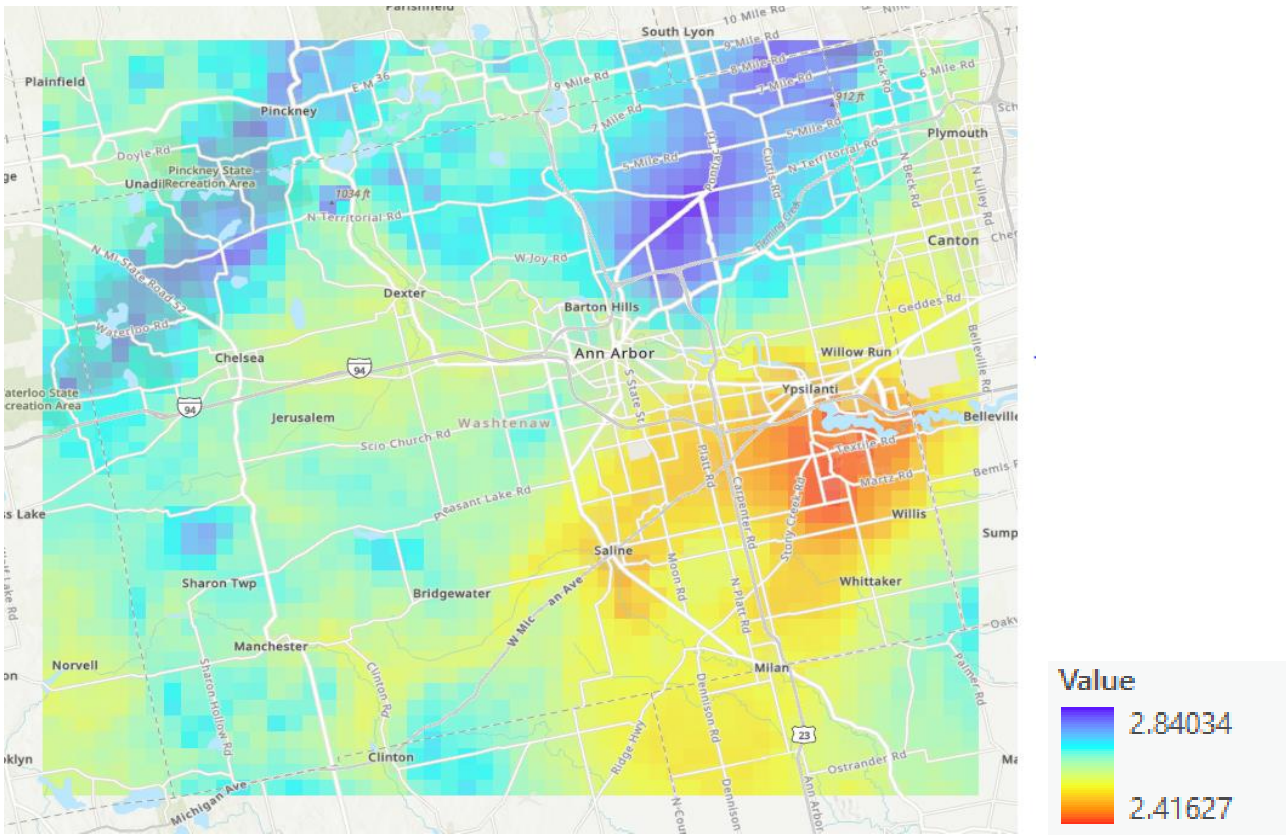

Fig.1: Map of 2011-2020 average precipitation intensity (mm/day) from Daymet Ver. 3 in Washtenaw County.

The stormwater runoff is calculated using the rational method (section 3.1). Firstly, we map the climatology average precipitation intensity in the past 10 years (2011-2020) using DayMet data (Fig. 1). According to the result, North and West regions of Washtenaw county tend to be wetter, while Southeast (e.g., south Ann Arbor and Ypsilanti region) tends to be drier. Then we map the runoff coefficient based on the land use types. Land use distributions are taken from SEMCOG, shown in Fig. 2, and each type is assigned a characteristic runoff coefficient value[2,3] (see, e.g., Runoff Coefficient Fact Sheet) based on their impervious level in Fig. 2. In order to calculate the runoff, all of the layers are transformed into raster layers with 1x1 km. resolution.

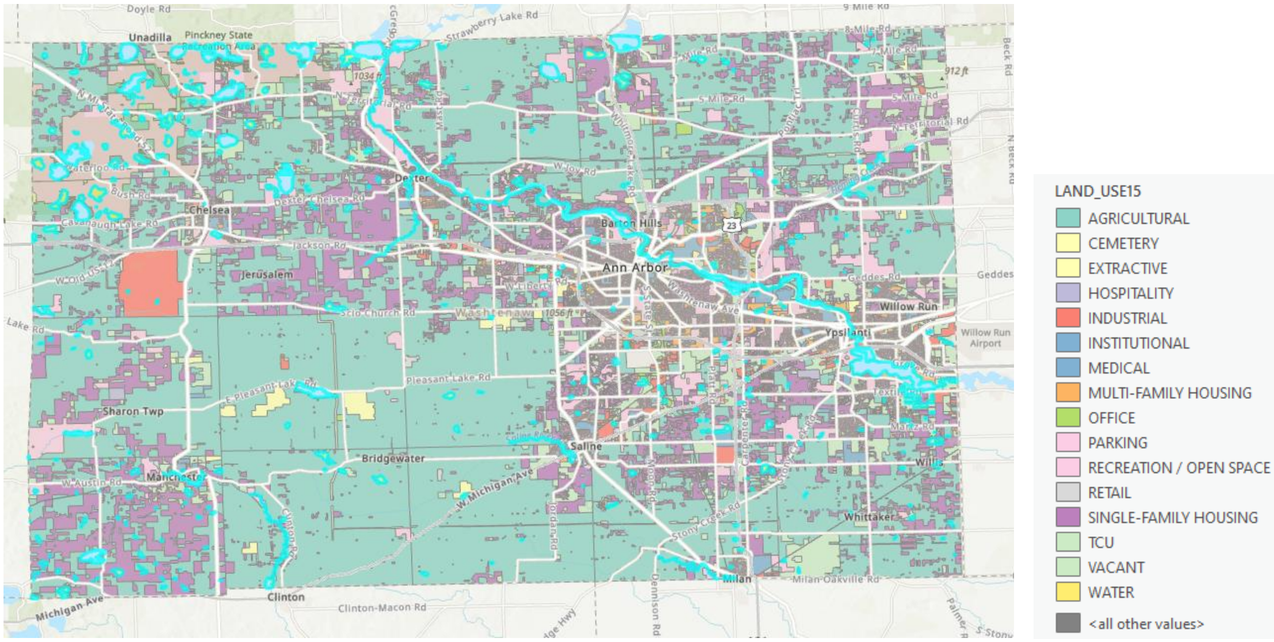

Fig. 2: Washtenaw County divided into its constituent land-use types.

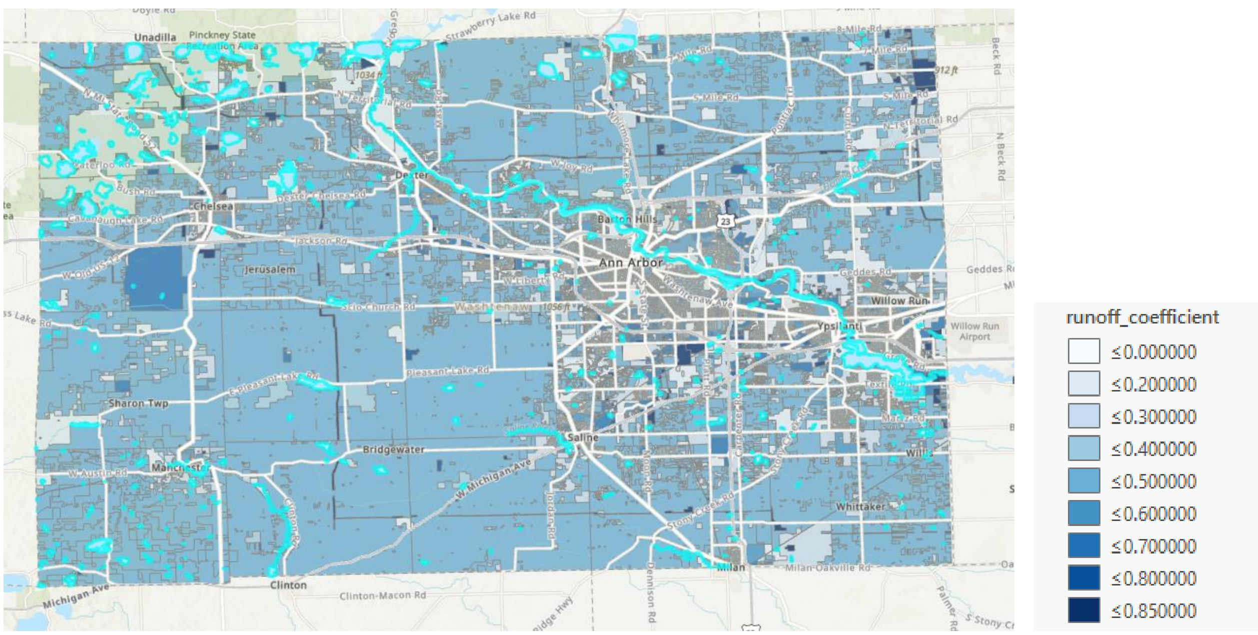

Fig. 3: Washtenaw County's various land-use types from Fig. 2 assigned their corresponding runoff coefficient values[2,3] for the Rational Method.

According to the magnitude of stormwater runoff, we rank the priority of building green infrastructures into five levels. Generally, the regions with larger magnitude of stormwater runoff will have higher risk of water pollution, thus these regions have higher priority of building green infrastures. Compared to precipitation intensity, land use type plays a more important role for spatial variability of stormwater runoff. Overall, the recreation region (e.g., Pinckney State Recreation Area) and open spaces show lower priority (blue regions in Fig. 4), and the retail place (e.g. Briarwood Mall) or the region with parking or extensive road coverage (e.g. south Ann Arbor) have higher priority (orange and red regions in Fig. 4). It's important to note that the land use map (SEMCOG) we use may not perfectly represent all of the characteristics, since the land use map was created in 2015, and there may be changes in land use types or already built green infrastructure since then. Additionally, we have computed an averaged run-off value for each land-use type; in reality, run-off is likely to vary between the same land-use types (i.e., some industrial areas may have a lot of green infrastructure around it while others may not), which may skew some of the analysis.

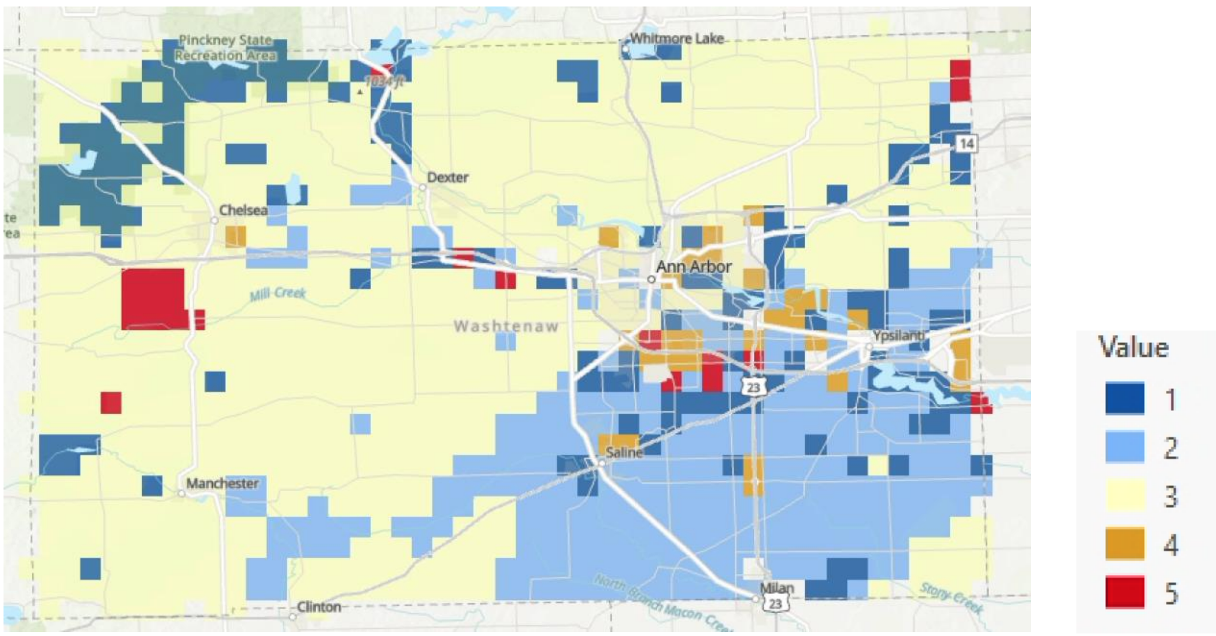

Fig. 4: Green infrastructure priority map in Washtenaw County, based on stormwater runoff criteria.

4.2 Identification of Degraded Creeksheds as Additional Priority Areas

A main benefit of installing green infrastructure in Washtenaw County is to improve water quality, and we seek to prioritize areas that would benefit the most from these installations. Degraded creeksheds are one type of area to prioritize. While there are a number of criteria that may be used to consider a creekshed "degraded," the main one we use here is total impervious surface. Studies have shown that fish and insect communities are less diverse when the percentage of impervious surface in a watershed is greater than 10-12% of the total watershed area.[9]

The Huron River Watershed Council (HRWC) has written reports on status and trends in water quality, biodiversity, habitat, land use, and other types of criteria relating to individual creeksheds that make up the Huron River Watershed.[9] These reports list the amount of impervious surface in each creekshed, and also many of them include explicit recommendations for the installation of rain gardens and other types of green infrastructure.

The following creeksheds within the Huron River Watershed and Washtenaw County have been identified as degraded based on the HRWC's creek reports:

- Davis Creek: 12% total impervious surface
- Fleming Creek: 11% total impervious surface
- Honey Creek: 14% total impervious surface; creek report includes recommendation to install rain gardens, rainbarrels, and other methods to reduce runoff
- Malletts Creek: 40% total impervious surface; creek report indicates that Malletts is an "urban creek" and that runoff and sedimentation can be mitigated by "building green roofs, rain gardens, porous pavement, native landscaping, and a host of other 'green infrastructure' stormwater management methods"
- Millers Creek: 30% total impervious surface; creek report indicates that Millers is an urban creek and that "Green Infrastructure like rain gardens, permeable pavement, green roofs, and other elements is necessary to help the creek function"
- Swift Run Creek: 22% total impervious surface; creek report indicates that Swift Run Creek is an urban creek and that "Green Infrastructure like rain gardens, permeable pavement, green roofs, and other elements is necessary to help the creek function"
- Traver Creek: 14% total impervious surface; creek report includes recommendation to install rain gardens, rainbarrels, and plant deep rooted native plants to reduce runoff

The USGS's 12-digit hydrologic units for that state of Michigan were the smallest hydrologic units we had access to. Some of them correspond directly to creeksheds identified above, while others either are made up of several creeksheds or can be combined to make an identified creekshed. We compared the hydrologic units to the HRWC's map of the Huron River Watershed and its corresponding creeksheds[10] in order to find which hydrologic units to prioritize. The following are the hydrologic units of interest, with the corresponding creeksheds from above in parentheses (shown in Fig. 5):

- Davis Creek (Davis Creek)
- Fleming Creek
- Honey Creek
- Inchwagh Lake (Davis Creek)
- Swift Drain - Huron River (Mallets Creek, Millers Creek, Swift Run Creek, Traver Creek)

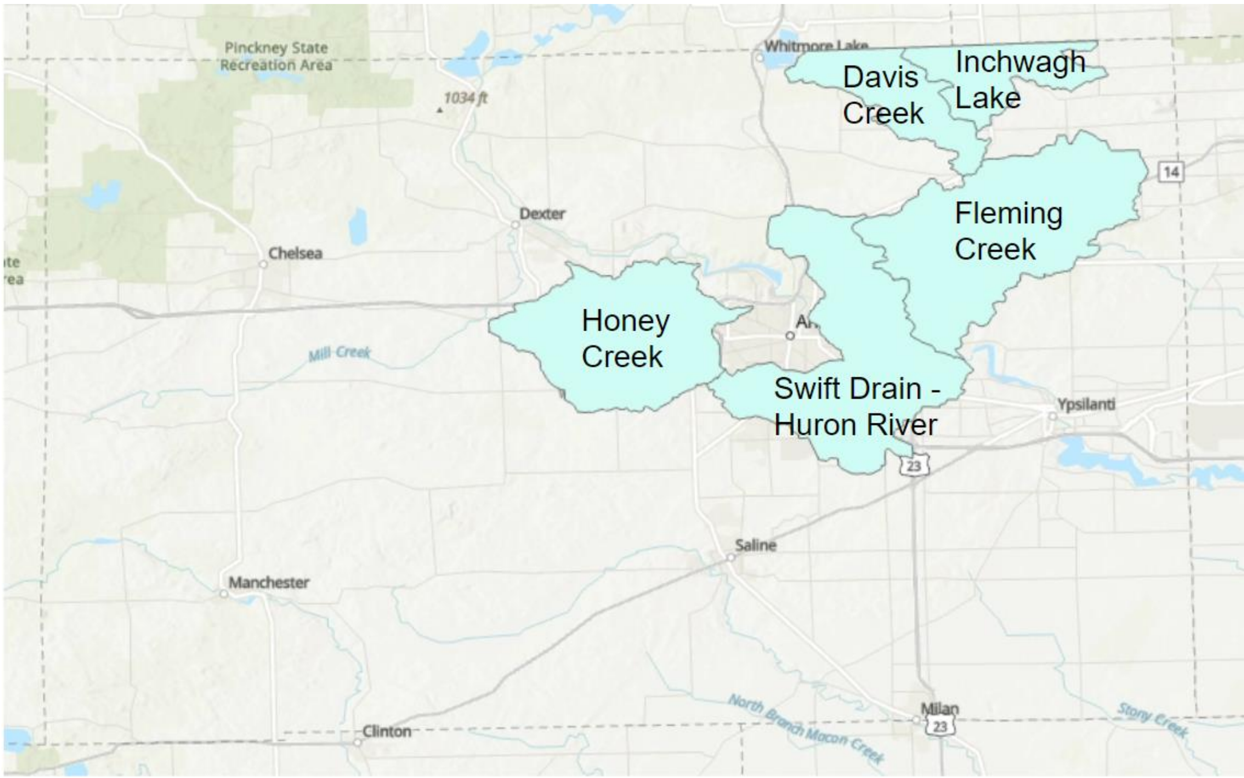

Fig. 5: Hydrologic units to prioritize overlaid on a map of Washtenaw County.

The hydrologic units of interest can be used as they are for informing the location of green infrastructure installation, or they can be combined with the runoff prioritization map to form a singular map showing priority areas based on water quality. When we combine the degraded creekshed priority and the runoff priority, we weight the two criteria in a ratio of 1:9, with the former holding a relatively low weight. We do this for two reasons: 1) The creekshed information that we have from the Huron River Watershed Council does not cover the entire Washtenaw County area, so we do not want to necessarily prioritize what falls in the Huron River Watershed over the rest of the county. 2) There is some level of redundancy when we include the two criteria in the same map, since the creekshed priority is influenced by total impervious surface and would thus have higher runoff anyway. However, we believe that there is some amount of priority we should add to areas that fall in the boundaries of the degraded creeksheds because they were singled out over other creeksheds by the HRWC as in need of attention. Fig. 6 shows the combined runoff and creekshed priority map.

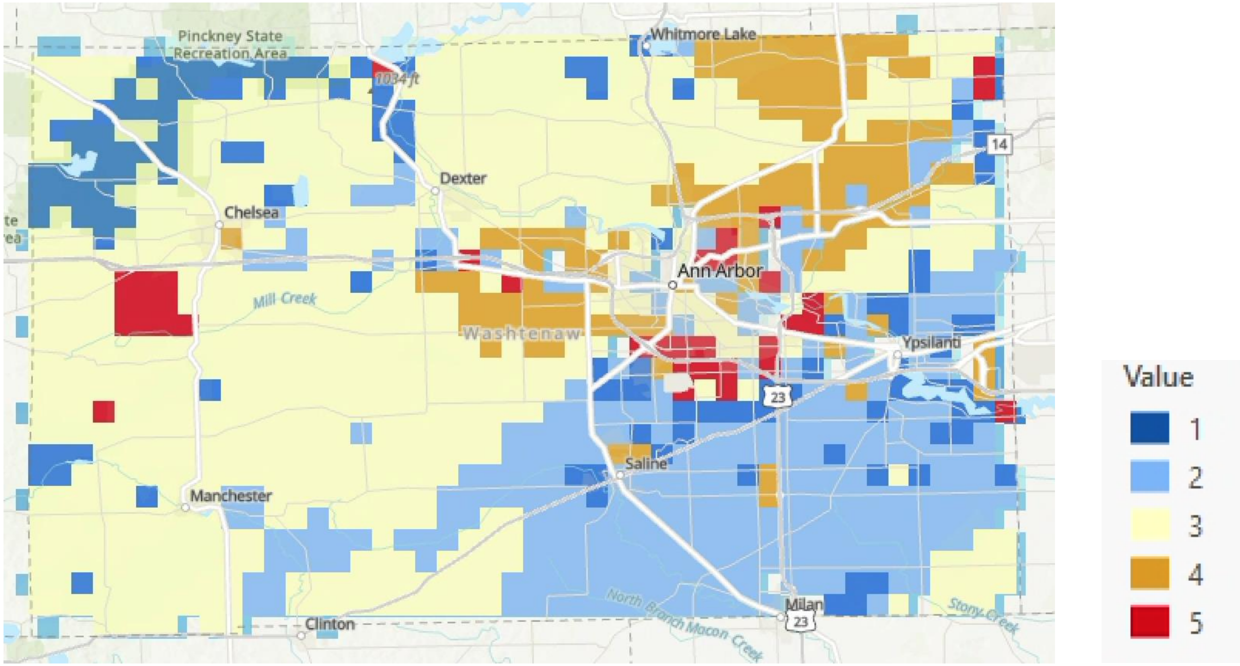

Fig. 6: Water quality-based priority for Washtenaw County, with both runoff and degraded creeksheds criteria included.

4.3 Assessing the Impact of Climate Change on Runoff-based Prioritization

With the knowledge that climate change will impact the amount of precipitation that falls on Washtenaw County, we need to determine if the prioritization based on runoff that we have found based on past precipitation data will change due to climate change. Here, we use precipitation data from TerraClimate to answer this question. The datasets are monthly climatologies for three different scenarios: recent (1981-2010), future with 2°C warming above pre-industrial levels, and future with 4°C warming above pre-industrial levels. We took averages across the 12 months for each scenario to determine general trends as a means to assess how our prioritizations will change due to climate change. The spatial resolution of 4 km.[2] for these datasets is lower than the spatial resolution of the Daymet data used for the main runoff analysis in our work, which is why we limit the use of the TerraClimate data to this climate change analysis.

When we map the three scenarios (Fig. 7), we see that the TerraClimate model predicts changes in the precipitation amounts expected based on the three scenarios. However, the spatial distribution of the precipitation generally remains the same. These characteristics also apply to maps of runoff for the three scenarios (Fig. 8) that were calculated by multiplying precipitation intensity for each scenario with the same runoff coefficients as used in the main runoff analysis.

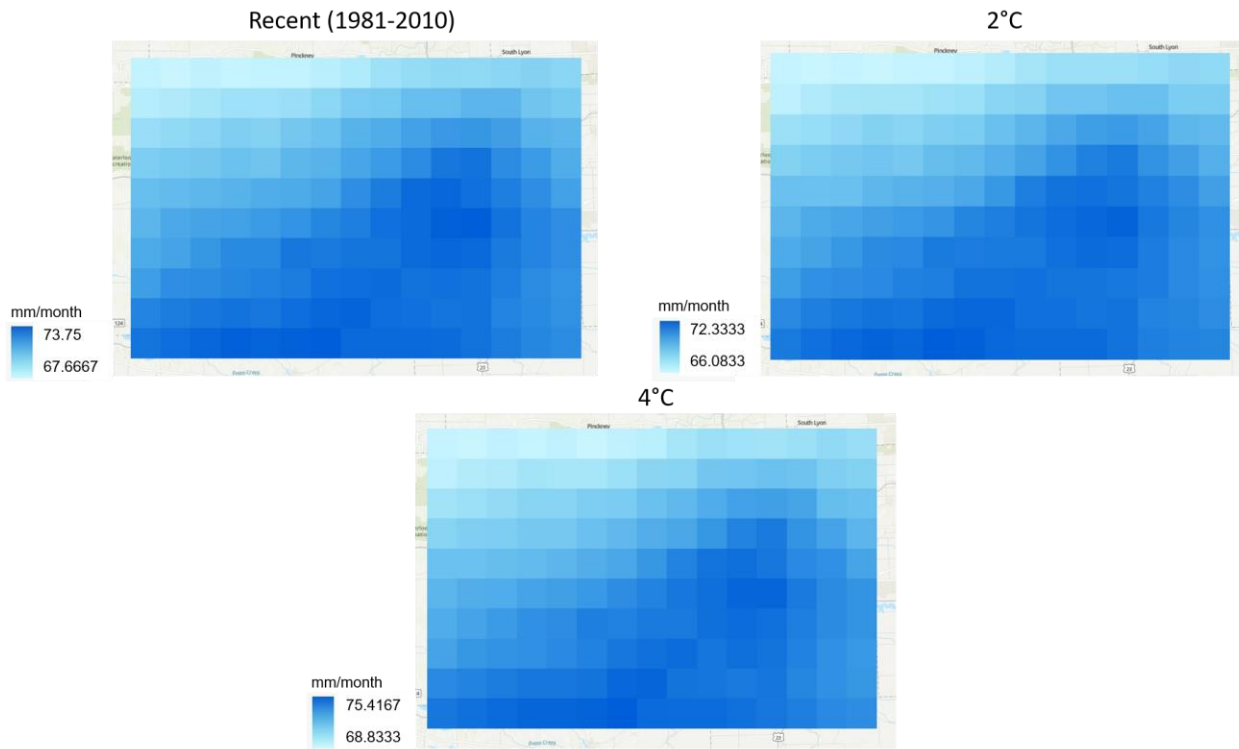

Fig. 7: Precipitation in Washtenaw County calculated with TerraClimate data for three scenarios: recent (1981-2010), a future with 2°C warming above pre-industrial levels, and future with 4°C warming above pre-industrial levels

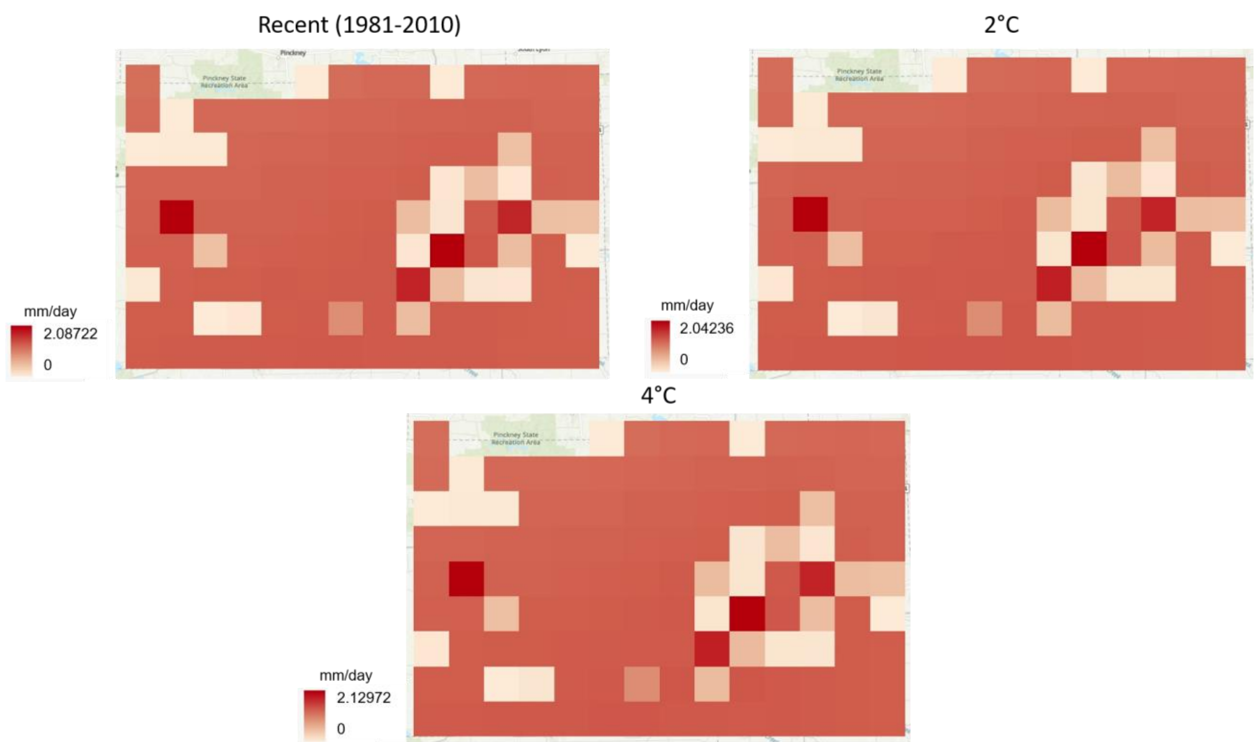

Fig. 8: Runoff in the county calculated with TerraClimate data for the same scenarios as in Fig. 7

The spatial distribution of runoff under these three scenarios also matches that of the runoff found in the main analysis (Fig. 4). This suggests that, despite some changes in the amount of runoff that could occur as a result of climate change, we expect the areas most impacted by runoff to remain the same. We thus do not recommend any changes to prioritization areas found in the main runoff analysis. However, in order to prepare for a higher warming scenario, it may be worthwhile to make efforts to install more green infrastructure in priority areas in the event of increased precipitation and runoff.

Section 5) Social Inequality

Three criteria were used to form the social inequality index: ‘Tract poverty’ (Population under 18 living below the poverty line), ‘park accessibility’ and the ‘urban heat island effect’. We plot each criteria individually followed by the summation of all three for a final map product.

5.1 Tract Poverty

We map the percentage of the Washtenaw County population (under age 18) below the poverty line, per tract in Fig. 9. Much of the highest priority areas (highest rates of child poverty) are located in urbanized communities. For Ann Arbor, high priority values are located just south of West Liberty Street as well as the north east corner surrounded by Nixon Road and Plymouth Road. We also note that the south side of Ann Arbor, at the border with Pittsfield Charter Township, appears to have a high percentage tract poverty. On a neighbourhood scale, the highest percentage of poverty is observed between Stone School Road and Platt Road. Areas south of Ann Arbor with high poverty include parts of Pittsfield such as housing nearby West Payeur Road as well as across the Northern side of Saline.

Most of the Ypsilanti area has some of the highest prioritization values (> 31% children living below the poverty line). The area of high poverty around Ypsilanti begins from around Eastern Michigan University and downtown Ypsilanti and continues eastwards until reaching Willow Run. We note that other rural communities can have notable poverty priority values; however, a direct neighbourhood analysis of these tracts is more complicated due to their large spatial extent.

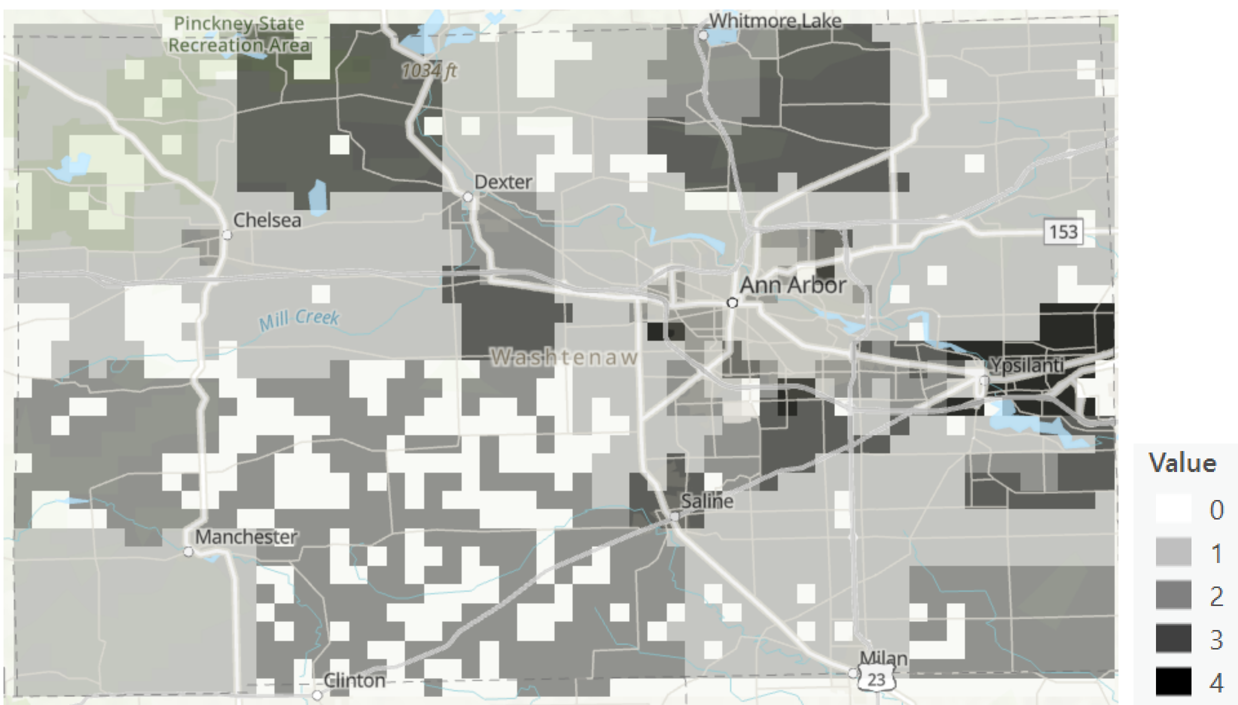

Fig. 9: Tract priority values based on the percentage of children living below the poverty line in Washtenaw County.

5.2 Park Accessibility

We map the areas in Washtenaw with different priority 'levels' of park access in Fig. 10. Priority values are skewed towards rural areas where there is notably less park infrastructure.

When focusing on urban areas without access to parks, we notice an isolated pocket within Ann Arbor sitting between the I-23 and southwest of Furstenburg Park (i.e., along Geddes Avenue as well as surrounding neighbourhoods). Between Ann Arbor and Ypsilanti, there is a sizable area without access to park infrastructure just to the right of the I-23 and along the M-17 all the way down to the intersection of North Hewitt Road. We also note a number of housing areas without access to nearby green space around Ellsworth Road and the Willow Run area along East Michigan Avenue.

South-West of Ann Arbor, there are a number of housing areas without access to green space such as along Ann Arbor Saline Road just south of the I-94. We also note other urbanized areas with no access to nearby green space such as much of the Northern side of Chelsea and housing communities just south of Ford Lake Park.

Lastly, touching on housing that has access to small areas of park space (< 2 acres), much of these areas can typically be found in urbanized areas such as across most of central Ypsilanti, central and south-west Ann Arbor, Saline and Whitmore Lake.

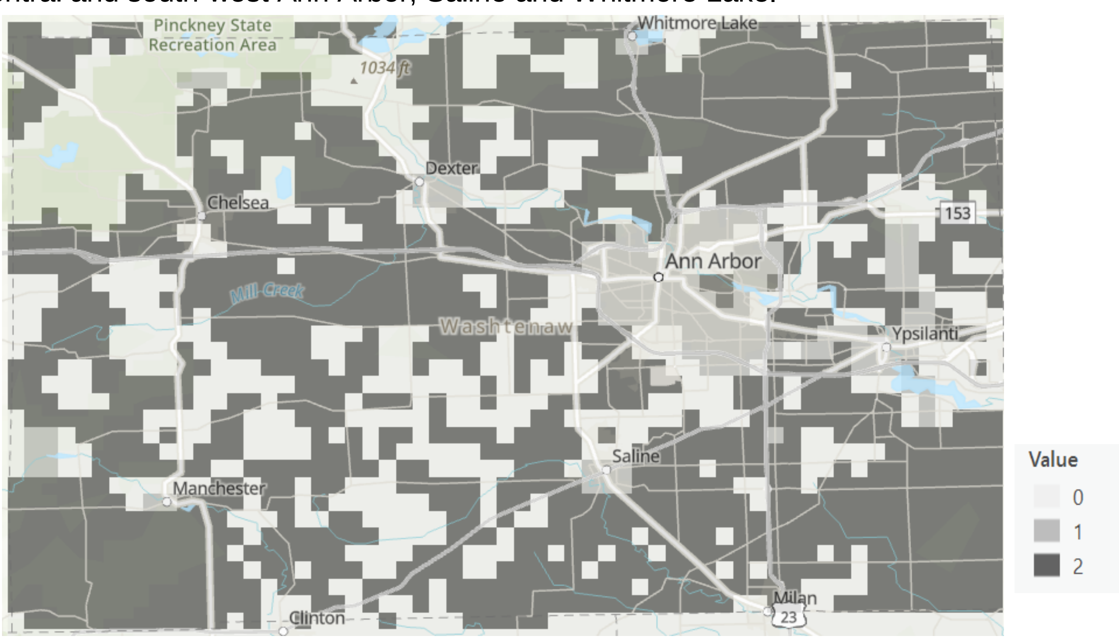

Fig. 10: Priority values based on whether a residential area has access to a park within walkable distance.

5.3 Urban Heat Island Effect

The UHI effect is mapped at 30 x 30 m. and 1 x 1 km. resolution when calculating the final product. We focus the analysis on the higher resolution data. The UHI effect priority values are largest in urbanized areas, particularly in areas congested with industry or in areas with minimal green infrastructure. We specifically take note of residential areas impacted by the UHI effect.

The majority of Ann Arbor is associated with an enhanced UHI effect (Fig. 11a); most notably downtown. Other particular areas within Ann Arbor associated with an enhanced UHI effect include just south of Dexter Avenue just to the right of the I-94 corridor. Large parts of the south of Ann Arbor also have maximum priority values such as areas within Briarwood Mall as well as between East Eisenhower Parkway and West Ellsworth Road. We also note the Arborland Center and shopping/industry areas along Plymouth Road also contribute to a large UHI effect.

Ypsilanti is another area with a unique UHI signature. Downtown Ypsilanti notably stands out as a strong contributor to the UHI effect due to the build up of infrastructure. We also note housing areas that are also co-located with a very strong UHI effect such as along Harriet Street and Spring Street as well as the overall surrounding area of Eastern Michigan University.

We also note that North Saline has a considerably large UHI effect (Figure 11b), mainly around East Michigan Avenue (largely industry and no housing) and Woodland Drive. Chelsea and Whitmore lake have high priority UHI values particularly in the town centers and often related to industrial areas. Lastly, we take note of the south side of Dexter in which there is a strong UHI effect along Dan Hoey Road and Ryan Drive and co-located with residential housing.

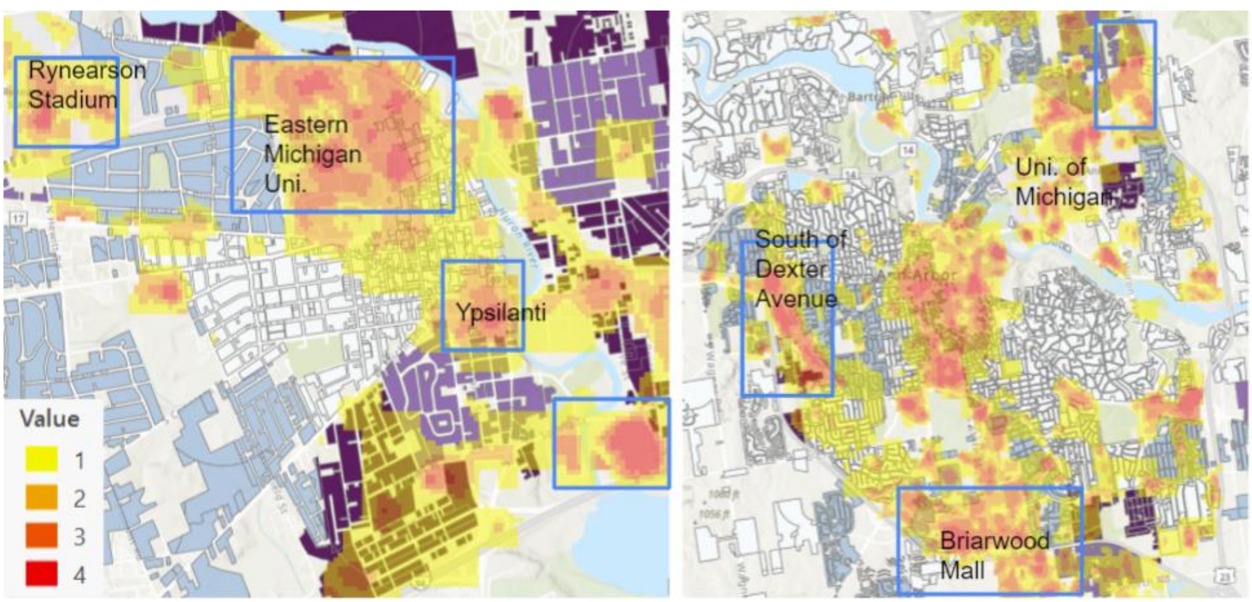

Fig. 11a: Urban Heat Island effect priority values zoomed in on Ypsilanti and Ann Arbor. As an aid to the analysis, we also include residential housing with their respective 'tract poverty'. (Priority values of 1 = white, 2 = blue, 3 = light purple, 4 = dark purple) to show where the UHI effect impacts residential communities.

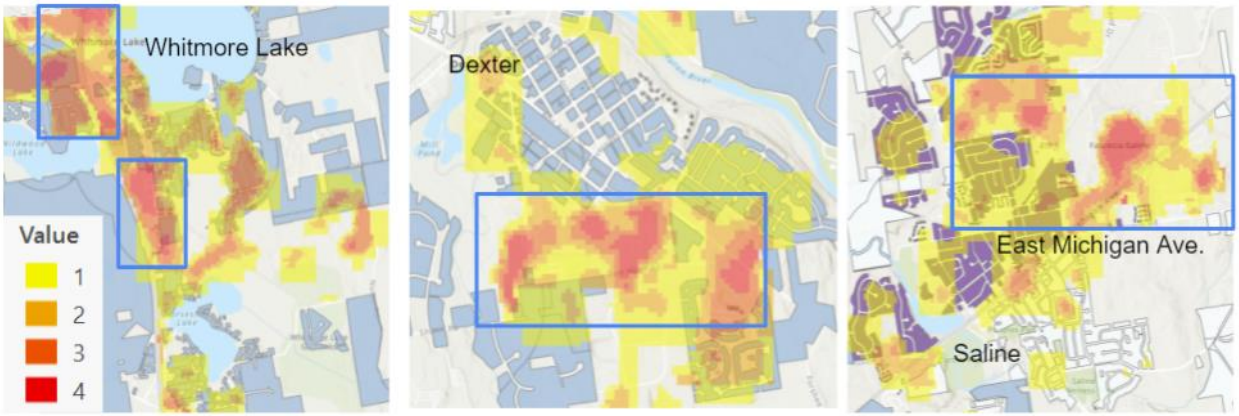

Fig. 11b: Urban Heat Island effect priority values zoomed in on Whitmore Lake, Dexter and Saline. As an aid to the analysis, we also include residential housing with their respective 'tract poverty'. (Priority values of 1 = white, 2 = blue, 3 = light purple, 4 = dark purple) to show where the UHI effect impacts residential communities.

5.4 Total Combined Map

The total combined map (Fig. 12a) is scored out of 10 (A maximum of 4 points for tract poverty, 2 points for park distance and 4 points for the UHI effect). We identify a number of priority areas with this analysis and briefly note which of the three factors contribute to these high priority scores. Beginning with the Ann Arbor area, the highest priority values (> 5) are located north-east off of Plymouth Road particularly due to the higher poverty values and the enhanced UHI effect in this area. This combination also explains the high priority values observed in the south and south-east of Ann Arbor. Another high priority area identified in Ann Arbor is in the west, just south of Dexter Avenue which is primarily driven by a very large UHI effect (highest priority value) as well as modest poverty and park accessibility values.

The Ypsilanti area (Figure 12b) has a number of priority areas driven by different criteria. Areas around Rynearson Stadium and Eastern Michigan University are primarily driven by a strong UHI effect, modest park access (priority value of 1) and nearby tracts with higher poverty levels. The high priority pixels nearby downtown Ypsilanti result from very high poverty values (level 4 priority) as well as notable UHI pockets (e.g., Neighborhoods between I-94 and West Michigan Avenue as well as nearby residential areas along and just south of Woodward Street). Other areas just east of Ypsilanti that are prioritized due to this combination include neighborhoods near Towner Street and much of East Michigan Avenue. Other areas nearby Ypsilanti are highlighted as a result of lack of park access and high poverty values.

We also identify other areas of interest such as the high priority value of 8 just North East of Saline. We note that this point may be somewhat anomalous as there is only a small portion of high-poverty housing that is near to this pixel and has skewed the pixel to be a high value. In reality, this area is just industry, hence prioritizing green infrastructure in this area would not serve local residents. We thus recommend also looking at where the housing land use types are located in each pixel as the analysis does not take into account how populated a particular pixel area is. In contrast, the other high priority value of 8 located near Whitmore Lake is driven by a strong UHI effect due to nearby industry, lack of park accessibility and a modest level of tract poverty. The reasoning for high priority values observed in Chelsea and Dexter can be similarly related back to the aforementioned analysis of Whitmore Lake. As a final point, we recommend to look through the housing layer within the packaged data to understand the relationship between the tract poverty in each pixel and residential housing

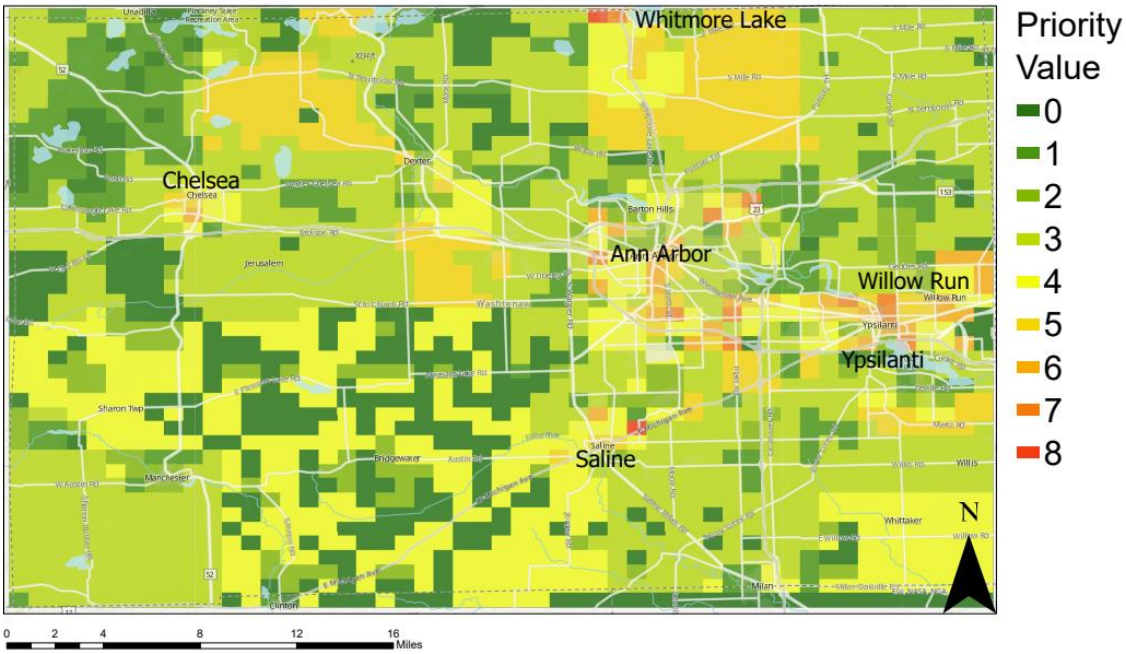

Fig. 12a: Combined criteria priority map of Washtenaw County.

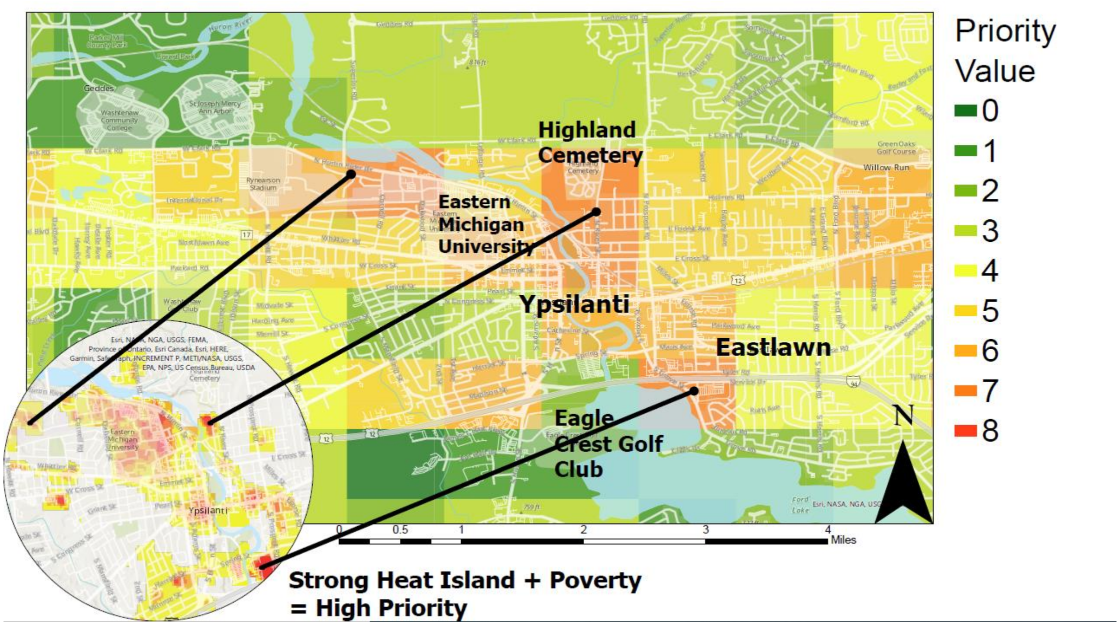

Fig. 12b: Combined criteria priority map of Washtenaw with reference to the UHI effect.

Section 6) Wildlife Corridors

Land development for use by human activities inevitably fragments natural habitats. This fragmentation, in addition to directly shrinking the livable area available to individual wildlife communities, reduces the resilience of animal populations by limiting their access to necessary resources and increasing genetic isolation.[11] Figure 13 shows the tracts of forestland in Washtenaw County that can support wildlife populations, showing explicitly the level of fragmentation that local habitats experience.

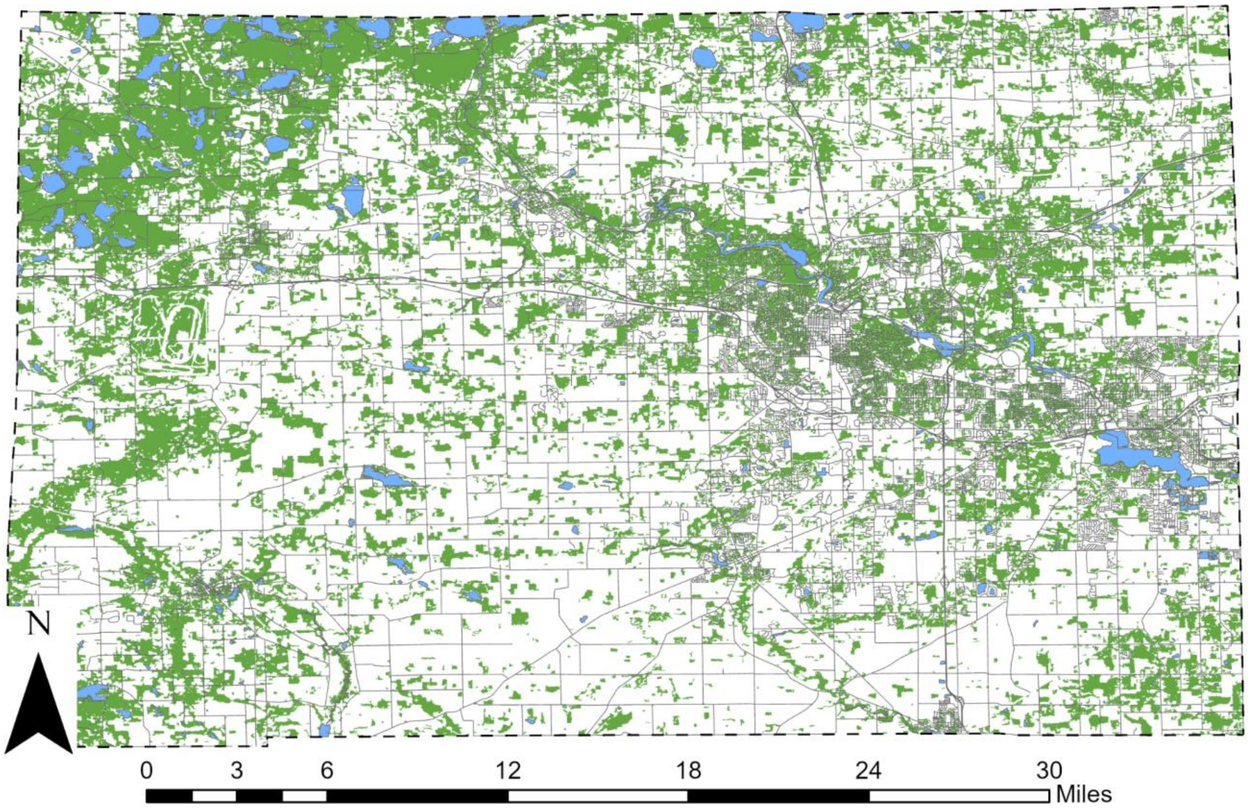

Fig. 13: Map of forested land tracts across Washtenaw County (green). Roads are shown as light gray lines and water bodies are colored in blue.

Wildlife corridors are, in essence, pathways between otherwise disconnected areas of green space inhabited by animal populations. They mitigate the negative consequences of habitat fragmentation by allowing wildlife to move between different habitats without needing to enter predominantly human-developed areas. Within the scope of this project, green infrastructure will likely not establish full connections between separated habitats, but it can increase wildlife connectivity by providing stepping stones for mobile animal populations.

We identify the areas across Washtenaw County most likely to benefit from green infrastructure by first separating the county into its individual land-use types, as shown in Fig. 2. We then find the average percentage of each of these land-use types that is covered by forest. A snapshot of this analysis is shown in Fig. 14 around the Ann Arbor and Ypsilanti area, showing that “lower cost” areas (i.e. areas with less forest) are primarily concentrated in urban spaces.

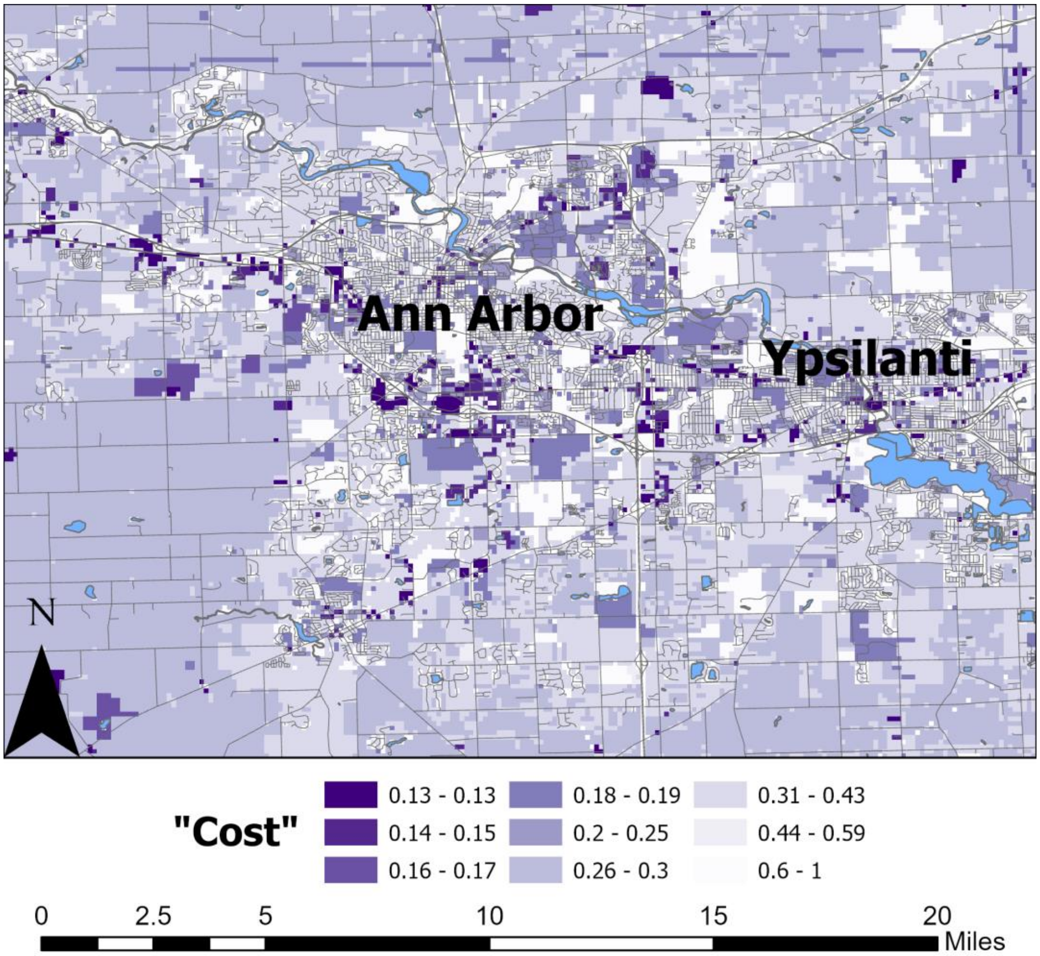

Fig. 14: Spatial snapshot of the “cost” raster used in conjunction with the Cost Connectivity ArcGIS analysis function to identify priority areas for improving wildlife population mobility.

Using this “cost” distribution, we prioritize the lowest cost pathways between areas of distinct forestland, shown without their relative cost values in Fig. 15. As expected, the highest concentration of potential wildlife corridors is in urban areas, especially in Ann Arbor, Ypsilanti, and Saline. If we zoom into southwestern Ann Arbor and southeastern Ypsilanti, as shown in Fig. 16 with the relative priority values included, we can see that these pathways have high priority values as well, making them ideal locations for the development of green infrastructure to improve wildlife connectivity. Other areas not shown with high relative priority values include the University of Michigan North Campus and around Jackson.

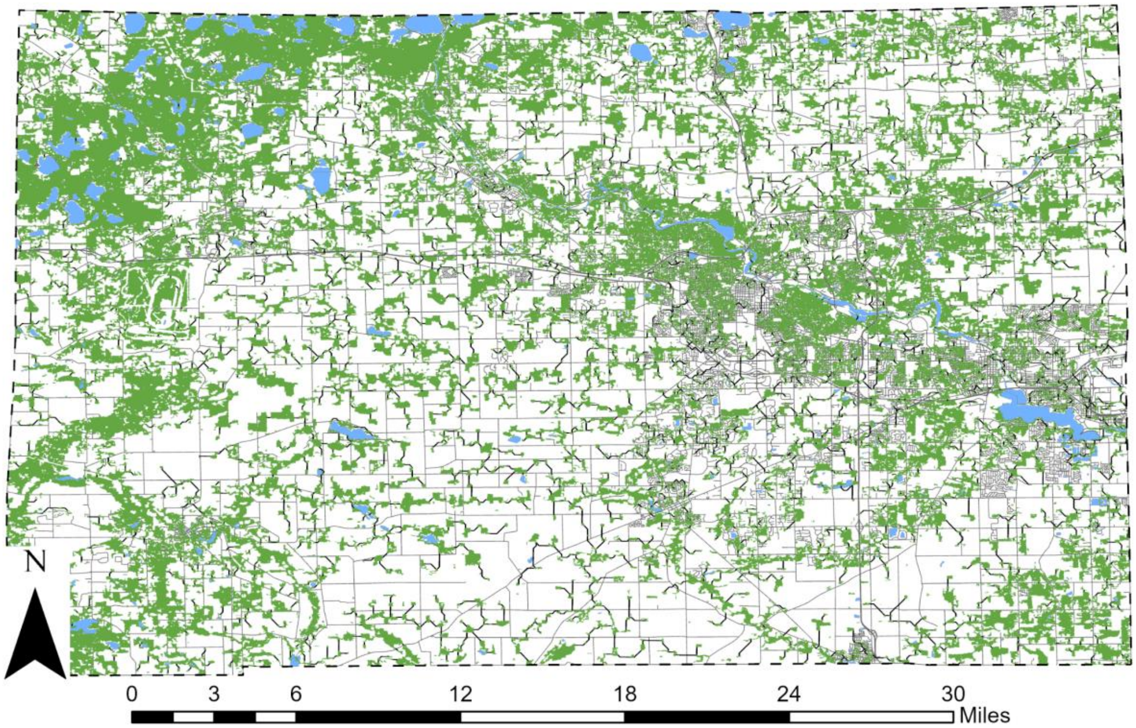

Fig. 15: Map from Fig. 13 with the computed forest area connections drawn in black. The relative cost values associated with each potential wildlife corridor are omitted.

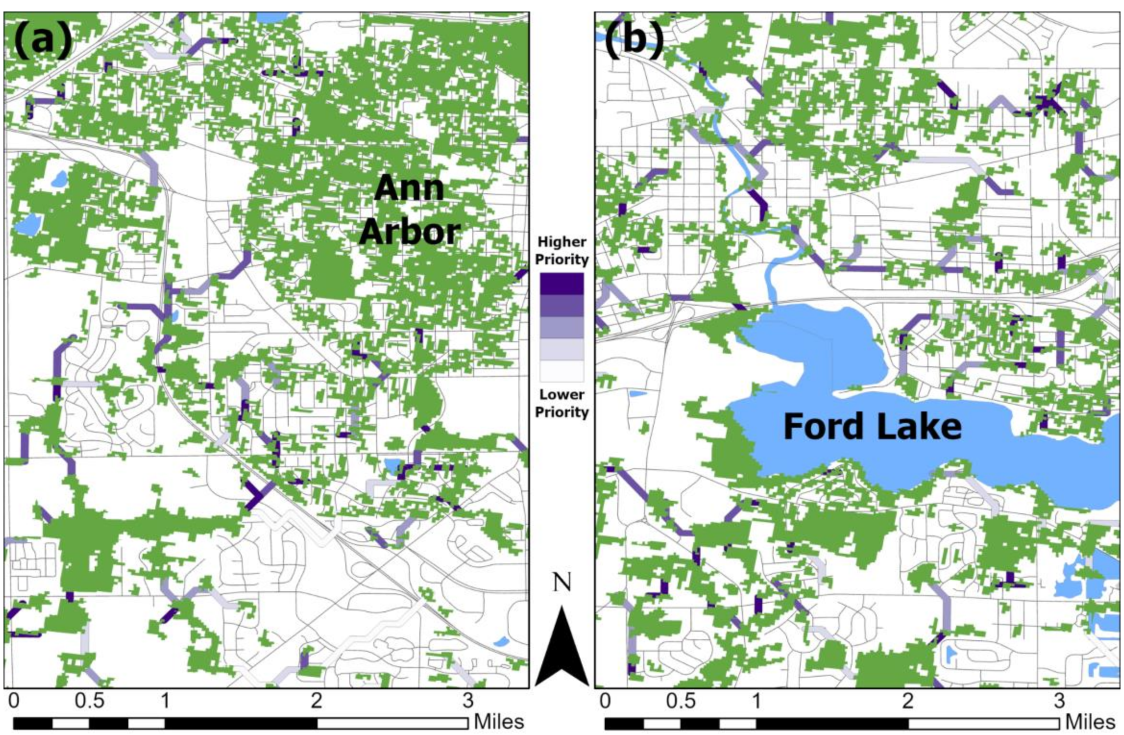

Fig. 16: Maps of the potential wildlife corridors shown in Fig. 15, zoomed-in to (a) the southwestern side of Ann Arbor, and (b) the southeastern side of Ypsilanti around Ford Lake. The relative cost values are shown as a purple color gradient.

6.1 Limitations of the Analysis

It is important to note that this analysis was performed exclusively to aid in the placement of green infrastructure, and is not designed to provide information or conclusions about any specific animal species. In order to develop corridors explicitly for serving particular wildlife populations, it would be necessary to include data about their individual spatial habitats and movements.

In addition, we focus exclusively on forests here, which are in general not the only type of green space that supports animal habitats. This may be especially relevant in the southern and northeastern parts of the county, where there are large areas of agricultural land. Our analysis partially accommodates this by producing generally low priority corridors in these areas, but we are likely still overestimating the importance of developing green infrastructure there.

Section 7) Discussion, Summary, and Conclusions

We focused on three priority criteria--water quality, socioeconomic inequality, and wildlife connectivity--for determining locations to prioritize for the installation of green infrastructure. We generated separate maps in ArcGIS Pro for each criterion. It is up to the Washtenaw County Water Resources Office to determine how to weigh these three criteria if a combined product is desired.

Across our analyses, neighborhoods in South Ann Arbor and Central Ypsilanti tend to stand out as priority areas.

We believe that the preferred locations we have identified for green infrastructure installation should remain the same in the face of climate change. We analyzed runoff in the county, and the spatial distribution was consistent across different warming scenarios. It may be beneficial to consider increasing the amount of green infrastructure installed in areas of higher runoff to account for the higher precipitation expected from a future scenario with greater warming.

The majority of our work has focused on the installation of rain gardens. We believe that other types of green infrastructure would also be beneficial in the areas we have identified, but it is outside the scope of our work to explicitly recommend types of green infrastructure or particular types of plants that would be more beneficial in different warming scenarios.

Green infrastructure has numerous environmental, social, and financial benefits. From improving air and water quality to restoring stream health, green infrastructure complements existing infrastructure while potentially reducing costs. The green space that accompanies green infrastructure additionally provides social benefits to those who can access it. Given the many varied benefits of green infrastructure beyond the scope of our project, it may be beneficial for the county to consider coordinating with SEMCOG and their green infrastructure efforts to increase resilience and avoid maladaptation.

Bibliography

1. GLISA. Projected Change in Annual Total Precipitation by Mid-Century regional map. https://glisa.umich.edu/wp-content/uploads/2021/03/Regional-Change-in-Annual-Precip-by-Mid-Century.png
2. Robert Goodspeed, Rosie Liu, Dimitris Gounaridisb, Camilla Lizundiaa, Joshua Newell. Personal communication.
3. Sara Meerow, Joshua P. Newell,Spatial planning for multifunctional green infrastructure: Growing resilience in Detroit,Landscape and Urban Planning,Volume 159, 2017, Pages 62-75, ISSN 0169-2046, https://doi.org/10.1016/j.landurbplan.2016.10.005.
4. Ibes, D.C., 2015. A multi-dimensional classification and equity analysis of an urban park system: A novel methodology and case study application. *Landscape and Urban Planning*, *137*, pp.122-137.
5. Luber, G. and McGeehin, M., 2008. Climate change and extreme heat events. *American journal of preventive medicine*, *35*(5), pp.429-435.
6. World Wildlife Foundation. Forest Habitat. https://www.worldwildlife.org/habitats/forest-habitat.
7. Food and Agriculture Organization of the United Nations, Forestry Department. Global Forest Resources Assessment 2010, United States of America Country Report. http://www.fao.org/forest-resources-assessment/past-assessments/fra-2010/en/.
8. Indiana Department of Natural Resources, Division of Fish and Wildlife. Habitat Management Fact Sheet: Wildlife Corridors. December 2004. https://www.in.gov/dnr/fish-and-wildlife/files/HMFSCorridors.pdf.
9. Huron River Watershed Council. Creek Reports. https://www.hrwc.org/our-watershed/features/.
10. Huron River Watershed Council. Maps. https://www.hrwc.org/our-watershed/maps/.
11. Miranda Gleason, Importance of Wildlife Corridors. ESRI. https://www.arcgis.com/apps/Cascade/index.html?appid=6b87112414f84c8392c842dabab9f9a1.

Appendix: Layers Included in Final ArcGIS Layer Package

The following lists our layer packages to be opened in ArcGIS Pro, uploaded at this site. We list the layer packages and the name of each layer with a short description:

water_quality_final.lpkx

- runoff_hist (raster): runoff calculated with DayMet precipitation data, for the recent time (2011-2020)
- runoff_tc0 (raster): runoff calculated with TerraClimate precipitation data, for the recent (1981-2010) scenario
- runoff_tc2 (raster): runoff calculated with TerraClimate precipitation data, for the scenario of a future with 2°C warming above pre-industrial levels
- runoff_tc4 (raster): runoff calculated with TerraClimate precipitation data, for the scenario of a future with 4°C warming above pre-industrial levels
- HUCs (polygon): hydrologic units clipped to Washtenaw County with an additional attribute, “impervious,” which denotes prioritized/degraded creeksheds with a value of 1, while all others are 0
- reclass_run19 (raster): priority map based on degraded creeksheds and runoff, weighted 1:9

Social_Inequality_Final.lpkx

- Priority_Final (raster): A total combined priority score that sums up priority scores from Tract Poverty, Distance to Parks and Urban Heat Island Effect.
- Reclass_Housing_Poverty_Child_Final (raster): Priority scores assigned by % of children living below the poverty line using American Community Survey Poverty Status data for 2015 - 2019.
- Reclass_Urbanheat_Coarse_Final (raster): Priority scores assigned by the intensity of the urban heat island effect. The coarsened data is interpolated to 1 x 1 km. grids. The data is from NASA’s LandSat thermal sensor for the summers of 2018 and 2019.
- Reclass_UrbanHeat_High_Resolution (raster): The same as the above dataset but in its native 30 x 30 m. grid resolution.
- Land_Use_Housing_Clip_Poverty_Child (polygon): This layer shows housing land use from SEMCOG which have been assigned % of child poverty values depending on the tract each housing vector is in. % of child poverty is assigned into 4 distinct groups and is reflected by the color scheme of the houses.
- Washtenaw_Tract_Clip_Population_Child (raster): This layer shows the population of children that live in each tract. This layer may be helpful to understand whether there are any pixels that have been skewed by the tract poverty analysis with respect to the population size.
- Parks_Clip_Buffer (vector): This layer shows the 0.3 mile buffer zones that have been made around parks to help visualize what we mean by ‘walking distance’ in our analysis.

wildlife_corridors_final.lpkx

- Forests (polygon): Forest areas identified by isolating tracts 0.5 hectares or larger with tree heights taller than 5 meters and tree canopy covers of at least 10%. Created using the USFS “Cartographic” Tree Canopy Cover dataset and the GLAD 2019 Global Forest Canopy Height dataset.

- Land_Use_Cost_Raster (raster): Cost raster for the ArcGIS Cost Connectivity function, calculated by finding the average percentage by area of each SEMCOG land use type that is covered by forests across Washtenaw County.
- Priority_Wildlife_Corridors (polygon): The final priority pathways between forests for improving wildlife habitat connectivity, calculated by the Cost Connectivity function and given 200-foot widths. Note that the absolute magnitudes of the PATHCOST variable are not meaningful here, as they are not a 1:1 comparison to the values in the cost raster, but the relative magnitudes are useful for prioritizing specific corridors.