Forests for Clean Water in the Huron River Watershed

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Client Organization: The Huron River Watershed Council

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Abstract

Clean water is essential for life; from drinking water to recreational opportunities, ensuring the quality of the Huron River has far-reaching impacts for all inhabitants of the watershed. To preserve the quality of these features, the Huron River Watershed Council (HRWC) has undertaken a project entitled "Forests for Clean Water" (FCW). The FCW project is focused on engaging landowners in the Huron River watershed who own or manage forest properties, as well as public education on the connections between forests and water quality. The goal is to foster a connection between forest health and drinking water quality. In support of FCW, our master's project team approached three aspects of forest property management and ecological assessments across the Huron River Watershed.

In this report, we provide background on the watershed and the most pressing issues facing water quality. We investigated nitrogen and phosphorus runoff into tributaries of the Huron River. Using the Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) model, we adapt a nutrient delivery ratio model to the Huron River watershed under multiple development scenarios. We recommend improvements to HRWC's Bioreserve map by incorporating aspects of the Mapping and Prioritizing Parcels for Resilience (MAPPR) model. Finally, we discuss strategies for engaging forest landowners with techniques derived from the Tools for Engaging Landowners Effectively (TELE) model, providing recommendations to HRWC using results from a landowner survey.

Our findings illustrate which natural areas in the Huron River watershed are most influential on water quality. We found that agricultural and highly developed areas result in the most nutrient runoff. Modeling predicts a significant increase in nutrient export into waterways if HRWC-defined Bioreserve areas are not conserved. Our updated Bioreserve map confirms high-priority locations of Bioreserve sites and offers an interactive tool to assess ecosystem quality in the watershed. The landowner survey depicts a widespread desire by landowners to engage in responsible land management practices to improve water quality. It also reveals a lack of knowledge in best land management practices, and insufficient funding and education to achieve conservation goals. Our findings highlight the highest priority Bioreserve areas for conservation that most directly impact water quality. They also provide a roadmap for working with landowners to effectively engage in forest land management to promote ecosystem health and water quality.

Acknowledgements

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Introduction

The Huron River Watershed spans over 900 square miles. The river itself stretches over 125 miles with 1,200 miles of streams and creeks flowing into the river. A map of the Huron River is shown in Figure 1. According to the Huron River Watershed Council, "The river's drainage area includes seven Michigan counties (Oakland, Livingston, Ingham, Jackson, Washtenaw, Wayne, Monroe) and 60 municipal governments, serving six hundred and fifty thousand residents" (HRWC, 2023). The watershed is of vital importance to all that reside within its reach - from farmers that rely on it for agriculture, to residents that swim in and drink from its waters. Among the most populous municipalities in the watershed, Ann Arbor draws surface water from the river for its municipal drinking water system. This is one of the few, yet largest, systems to utilize surface water for drinking water in the state of Michigan. The Bioreserve areas of the watershed, parcels defined as protected or privately owned properties with natural land cover, make up 362.34 square miles. HRWC has mapped over 1,700 Bioreserves, which have an average area of 0.21 square miles per Bioreserve area.

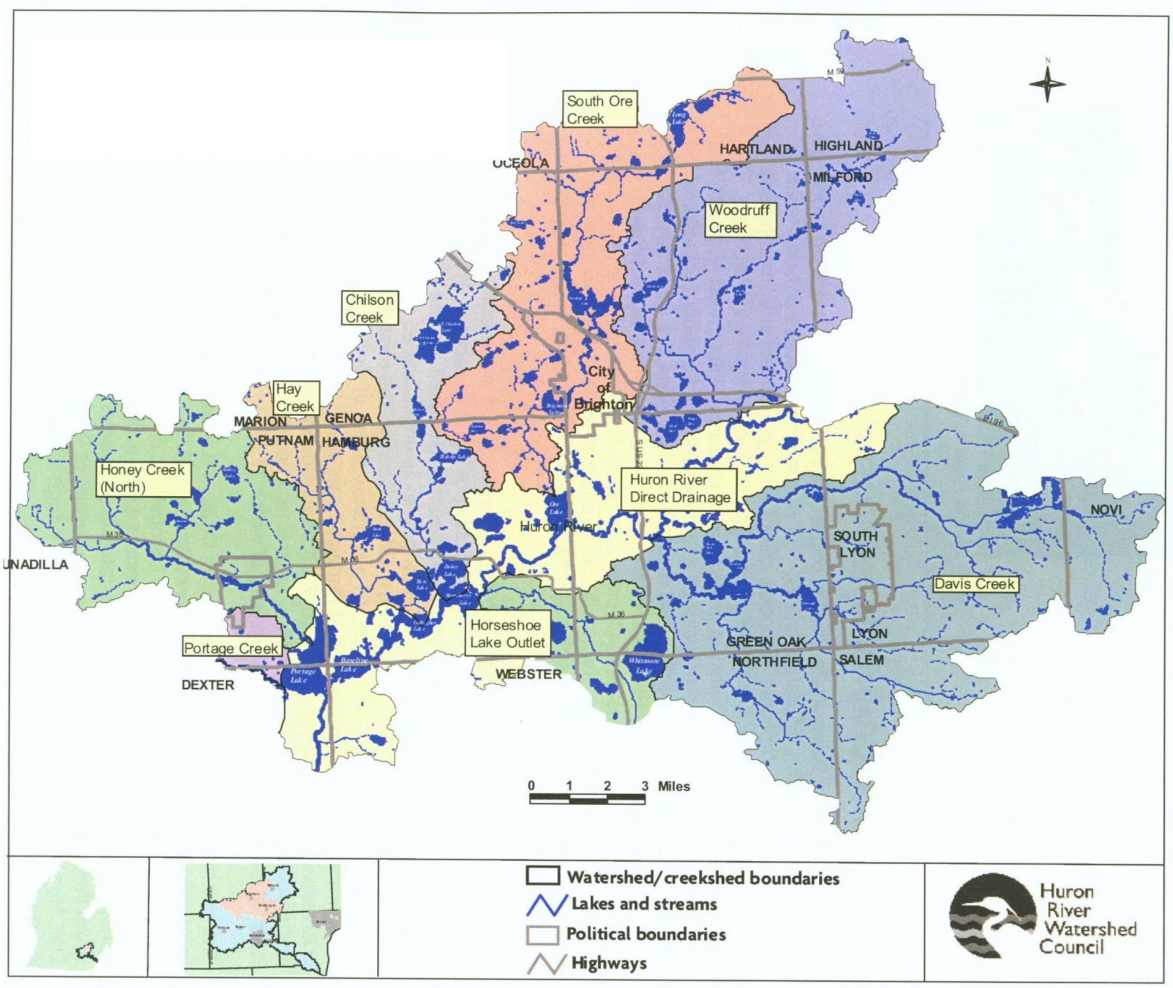

Figure 1. Map of the Huron River Watershed and Creeks

The Huron River Watershed Council (located in Ann Arbor, Michigan) is a non-profit established in 1956 as an environmental organization dedicated to the protection of the Huron River watershed. HRWC works with citizens as well as the seven counties (Ingham, Jackson, Livingston, Monroe, Oakland, Washtenaw, and Wayne) and sixty municipalities located within the watershed. HRWC monitors the quality of the watershed, advocates for its wellbeing, formulates environmental policy recommendations, and creates volunteer opportunities for citizens to become active caretakers of the Huron River. Their work has resulted in the conservation and protection of over 10,000 acres in the watershed (HRWC, 2021).

Today, HRWC focuses on reducing pollution flow (nitrogen, phosphorus, and PFAS), soil erosion, excess flows, enhancing shoreline plant buffers, working with private landowners, creating policy suggestions, and citizen volunteer opportunities. These efforts have historically ensured the quality of the watershed, increased public awareness of issues pertaining to the Huron River, and created policies that protect and fund projects to enhance the health of the watershed. Because the Huron River provides drinking water to many of southeastern Michigan's residents, the quality of the watershed is invaluable (HRWC, 2023). The efforts put forth by HRWC protect the health and well-being of not only human residents, but native wildlife and other organisms that rely on the watershed.

Non-point source pollution, or stormwater runoff, constitutes 50% of pollutants entering the Huron River watershed. These pollutants cannot be traced back to any one source or area, making them a priority for HRWC. These pollutants contaminate drinking water and degrade natural habitat quality. HRWC is especially concerned with nutrient pollutants (phosphorus and nitrogen) entering the watershed, as these stimulate algae growth. Algae create anoxic water conditions, are toxic to wildlife, impede recreation in the watershed, and are visually unappealing. 20% of nutrient pollutants enter the watershed via natural sources, while the remaining 80% enter via human activities such as fertilizer and detergents use (HRWC, 2023). Because the effects of nutrient runoff are so pervasive, HRWC has made the mitigation and treatment of these pollutants one of their highest priorities.

HRWC places great emphasis on the impact that private landowners have on the health of the Huron River watershed. HRWC offers no-cost land assessments for privately owned forests, wetlands, and prairies that are 10 or more acres in size located within their Bioreserve region. During these land assessments, information about the ecological features of the property including vegetation structure, forest and wetland types, and disturbance are recorded. This allows HRWC to gather increasingly detailed information on their Bioreserve area. HRWC also provides landowners with the findings of the assessment, helping inform them for future land management decisions (HRWC, 2021).

HRWC has created a map of natural areas within the Huron River watershed which they call their "Bioreserve Map" (Figure 2). This map details the remaining natural areas in the watershed and ranks them based on the ecosystem services they provide. The Bioreserve Map spans 237,000 acres in the watershed using aerial photography. Natural area boundaries were drawn based on woodland, wetland, or open-field designations. The map ranks remaining natural areas based on size, presence of wetlands, rivers, or lakes, potential groundwater recharge locations, high ecosystem diversity, and high-value remnant ecosystems like wetland prairies (HRWC, 2022).

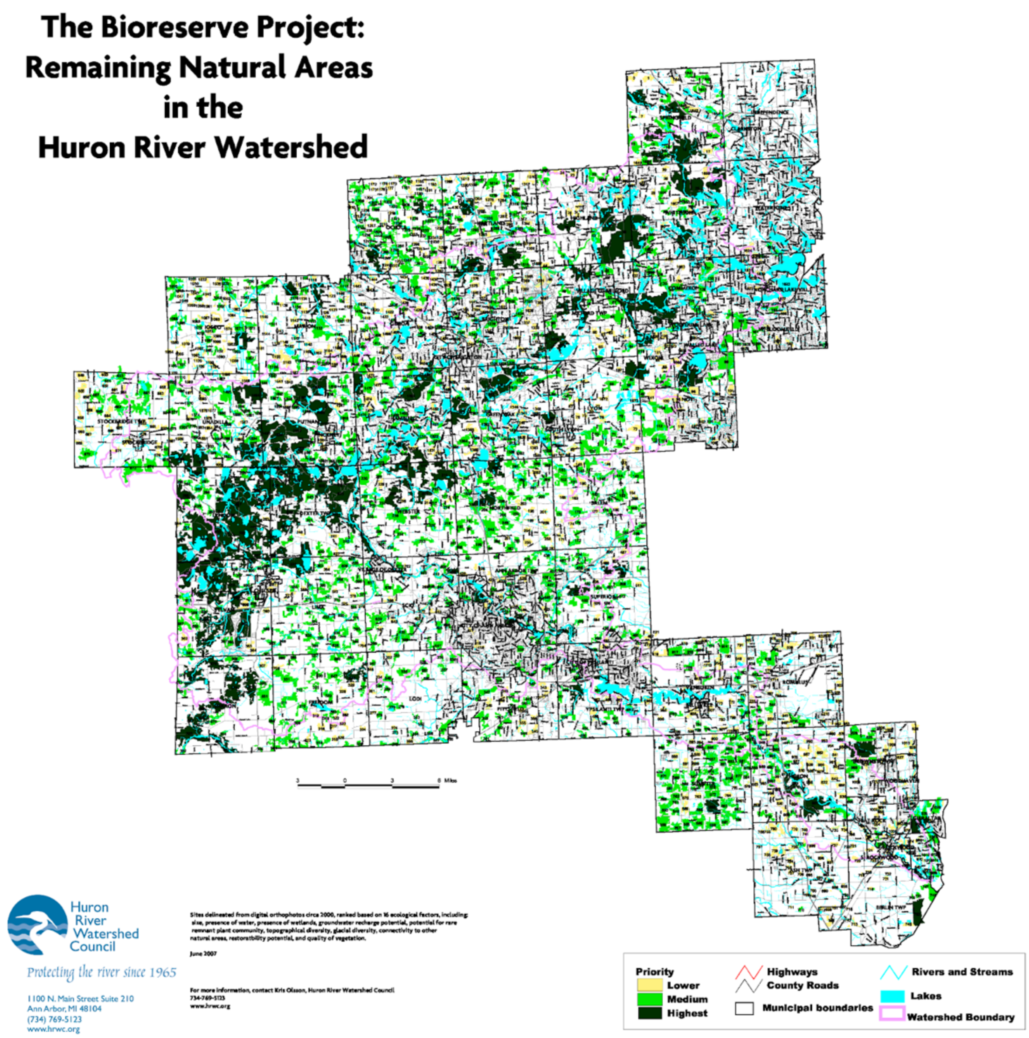

Figure 2: The Bioreserve Map created by HRWC

An ongoing project at HRWC, and the project this masters team is supporting, is titled Forests for Clean Water (FCW). This project is further supported by the Michigan Department of Natural Resources (MDNR). FCW focuses on the interactions between forested land use and drinking water quality in the Huron River watershed. During the course of FCW, HRWC is hoping to increase private forest landowner participation in managing their properties to support the health of the watershed. Other goals include public education on the connections between forests and drinking water quality, creating spatial datasets of forest cover, landowner property assessments, and workshops for forest landowners.

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Chapter 1: Nitrogen and Phosphorus Runoff

Relevant Appendices: Appendix A-E

1. Background

The Natural Capital Project's InVEST suite of models from Stanford University are used to model ecosystem services and aid in local decision making surrounding ecosystem management. The Huron River Watershed Council (HRWC) is interested in how forested property land management decisions impact drinking water quality and drinking water treatment costs as part of their Forests for Clean Water (FCW) project. Among the many models in the InVEST suite, the nutrient delivery ratio model is especially salient to the aim of this project. Ecosystem services here are defined as

The Nutrient Delivery Ratio model uses nutrient load, soil, and precipitation data to track the movement of phosphorus and nitrogen in the watershed. As InVEST states, "The retention service is of particular interest for surface water quality issues and can be valued in economic or social terms, such as avoided treatment costs or improved water security through access to clean drinking water" (Natural Capital Project). Phosphorus is able to transport via soil particles and can impact both groundwater and surface water drinking sources (Nitrogen and Water, USGS). Given that Ann Arbor is one of the largest users of surface water in the state of Michigan and its water source is independent of larger regional systems, it is imperative that its water supply remains protected from high nutrient loads (Community Water Supply).

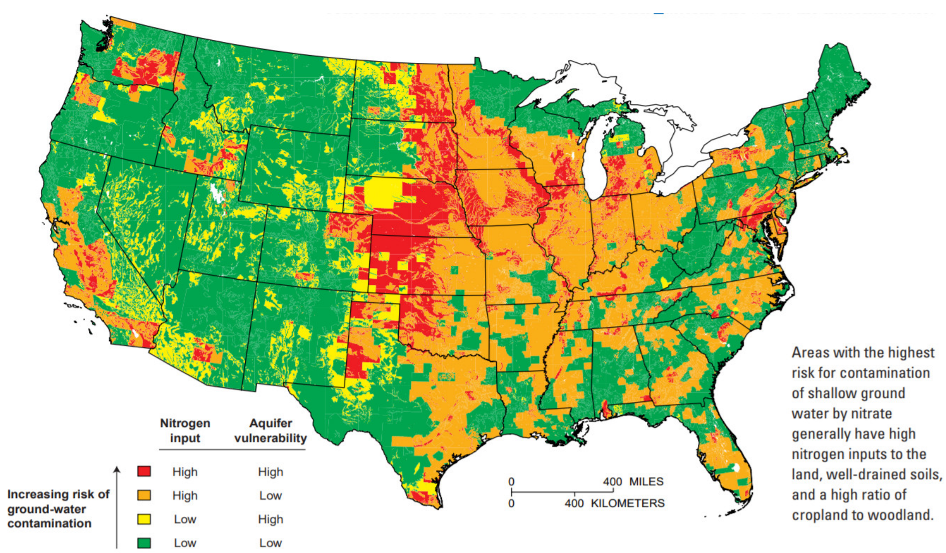

Fig. 1.1. US Geological Survey The quality of our nation's waters; nutrients and pesticides. 'The quality of our nation's waters,' designed to describe major findings of the National Water-Quality Assessment Program regarding water-quality issues of regional and national concern.

Smaller cities within the watershed use both groundwater and surface water. Additionally, all of these cities maintain agricultural land which contributes to phosphorus runoff due to the use of herbicide that may contain Glyphosate Acid (Hébert et al, 2018). Residential herbicide, pesticide, or fertilizer use can contribute to nitrogen and phosphorus runoff and enter waterways (*The Effects: Dead Zones and Harmful Algal Blooms | US EPA*, 2013).

The nutrient delivery ratio model requires a variety of geospatial inputs as well as unique tables and values. This non-spatial data includes a biophysical table which requires, among other things, soil retention estimates and a threshold flow accumulation, which is a digit the model uses to define when cells in a spatial input constitute a waterway. The nature of this input allows the model to be run under numerous soil or land use development conditions.

Nitrogen and phosphorus runoff into waterways has far reaching negative ecological and economic impacts. From harmful algal blooms, such as those seen in Lake Erie, to increased drinking water treatment costs, understanding where these nutrients are coming from and where they are going is essential for responsible management of water resources. Figure 1.1 demonstrates the importance of this knowledge in the Huron River Watershed. While most of the watershed is listed as the second highest at risk level of groundwater contamination, some of the watershed is also listed at the highest risk of contamination. Michigan's drinking water systems are at continuous risk of contamination (Community Drinking Water). The InVEST nutrient delivery ratio model provides insight into nitrogen and phosphorus runoff that can inform HRWC's decision making, especially surrounding bioreserve and natural areas in the watershed.

2. Methods

To run this model, we conducted a review of the Huron River Watershed Council's existing GIS database. While some of the required data was already maintained by HRWC, other data was found elsewhere. This chapter discusses the methodology of finding the data, the results and limitations of the model, as well as recommendations to HRWC for data that may be helpful in the future.

a. Spatial Inputs

For the nutrient retention ratio, the model requires a digital elevation model (DEM), which is a spatial dataset that represents the elevation topography of the watershed. This data was obtained in one degree section by one degree section (approximately 69x69 miles) via the United States Geological Survey (USGS) data center. The data was stitched together using ArcGIS Pro and clipped to the extent of the Huron River Watershed so that only the relevant area was analyzed. For the Land Use and Land Cover raster, which shows the land use classifications for areas in the watershed, an existing dataset that HRWC has from the USGS National Land Cover Database was used, and was similarly converted to the correct file type and clipped to the extent of the watershed using arcGIS Pro. The reference extent for the watershed is a map of the

Huron River Creek Sheds developed by HRWC so that the model can match the digital elevation model with individual creek sheds instead of the watershed as one whole. Finally, each spatial dataset was re-projected from either US feet or international feet to meters via the NAD 1983 projection using the ArcGIS Pro toolbox. The attribute table for the National Land Cover Database (NLCD) 2011 Land Cover layer in the HRWC sharepoint does not have a corresponding land use code ("lucode" in the biophysical table). Thus, we added a column in the attribute table with a numeric code that corresponds to the land use classification in the biophysical table (Table 1.1, Table 1.2). These codes were extracted from the NLCD land use classification codes legend (Dewitz).

The resolution of the NLCD download is 30 meters. Our literature review found that the resolution of the land use raster results in little variance in output quantities at resolutions less than 100 meters in the InVEST model. The literature had the same findings for the digital elevation model (Benez-Secanho and Dwivedi, 2015). Our DEM was downloaded at 1-arc second, which, at a roughly 42 degree north latitude, results in a 22.9 meter resolution.

The nutrient runoff proxy was obtained from worldclim.org, which provides historical precipitation data as monthly averages for the years 1990-2000 (Harris et al., 2014). The data downloads as 12 different .tif files, one for each month. Using RStudio, all 12 files were stacked together to create one mean precipitation raster. The extent of the raster was the entire world. While RStudio was able to reproject the rasters into the Universal Transverse Mercator projected coordinate system and stack all 12 monthly data tifs into one raster, we were unable to clip the raster to the extent of the Huron River Watershed as we did for other raster inputs. An additional attempt to reproject and clip the raster using the ArcGIS Pro extract from mask tool was successful in stacking all 12 individual datasets into one file. However, the resolution of this new precipitation raster is not as clear as the original (1 arc-second resolution) that was originally downloaded and clipped together. Despite this somewhat lower resolution, we determined that using different runoff proxy data, such as soil data maintained by HRWC and created by the Department of Agriculture's Soil Survey Geographic Database (SURGGO) , would not be as complete or fit the intention of the nutrient runoff proxy as well as the rainfall data as it did not include precipitation information. See the model limitations section of this chapter for a more detailed discussion of the rainfall data.All spatial inputs can be seen in Appendix A.

b. Unique Value Inputs

The Biophysical table (Table 1.1) for the current land use model was obtained mostly from Han et al. and cross referenced with data from the USGS and InVEST data downloads (US Geological Survey; Natural Capital Project). Other data is compiled from InVEST datasets. Nutrient loads were determined using InVEST global and regional averages (Table 1.1, Table 1.2). The columns are described below in Table 2.

Table. 1.1 - Biophysical table for the Nutrient Delivery Ratio Current Land Use Land Cover Scenario describing nitrogen and phosphorus nutrient loads, runoff ratios, and travel distances.

lucode	Description	Load_P	Eff_P	Load_N	Eff_N	crit_len_p	crit_len_n	proportion_subsurface_n
11	Open Water	0.1	0.69	2.2	0.1	0	0	0
21	Developed, Open Space	2.55	0.24	66	0.3	150	150	0
22	Developed, Low Intensity	2.55	0.24	57.8	0.2	150	150	0
23	Developed, Medium Intensity	2.55	0.24	57.8	0.2	100	100	0
24	Developed, High Intensity	2.55	0.24	50.2	0.08	30	30	0
31	Barren Land	0.18	0.24	3.7	0.3	30	30	0
41	Deciduous Forest	2.55	0.24	50.2	0.08	15	15	0
42	Evergreen Forest	2.55	0.24	50.2	0.08	15	15	0
43	Mixed Forest	2.55	0.24	50.2	0.08	15	15	0
52	Shrub/Scrub	2.55	0.24	50.2	0.08	15	15	0
71	Herbaceous	2.55	0.24	50.2	0.08	15	15	0
81	Hay/Pasture	1.5	0.8	11.5	0.45	150	150	0
82	Cultivated Crops	4.46	0.15	67.2	0.15	150	150	0
90	Woody Wetlands	2.55	0.24	50.2	0.08	15	15	0
95	Emergent Herbaceous Wetlands	2.55	0.24	50.2	0.08	15	15	0

Table 1.2 - Biophysical table for the Nutrient Delivery Ratio High Intensity Development Land Use Land Cover Scenario describing nitrogen and phosphorus nutrient loads, runoff ratios, and travel distances.

lucode	Description	Load_P	Eff_P	Load_N	Eff_N	crit_len_p	crit_len_n	proportion_subsurface_n
11	Open Water	0.1	0.69	2.2	0.1	0	0	0
21	Developed, Open Space	2.55	0.24	66	0.3	150	150	0
22	Developed, Low Intensity	2.55	0.24	57.8	0.2	150	150	0
23	Developed, Medium Intensity	2.55	0.24	57.8	0.2	100	100	0
24	Developed, High Intensity	2.55	0.24	50.2	0.08	30	30	0
31	Barren Land	0.18	0.24	3.7	0.3	30	30	0
41	Deciduous Forest	0.162	0.7	17.4	0.7	150	150	0
42	Evergreen Forest	0.162	0.7	17.4	0.7	150	150	0
43	Mixed Forest	0.162	0.7	17.4	0.7	150	150	0
52	Shrub/Scrub	0.84	0.6	20.8	0.6	150	150	0
71	Herbaceous	1.5	0.7	24.1	0.54	150	150	0
81	Hay/Pasture	1.5	0.8	11.5	0.45	150	150	0
82	Cultivated Crops	4.46	0.15	67.2	0.15	150	150	0
90	Woody Wetlands	0.25	0.38	7.3	0.85	150	150	0
95	Emergent Herbaceous Wetlands	0.25	0.35	3.9	0.72	150	150	0

Table 1.3 - description of inputs and columns for the InVEST NDR model biophysical table

Biophysical Table Input	Description
lucode	Lucode: a numeric value that relates the land use classification in the biophysical table to the same classification in the land use raster. As described earlier, this value was assigned to the raster attribute table using a python script and consistent with the NLCD database land use codes.
Description	The land use classification for which the lucode corresponds
Load_P	Load_P: the phosphorus load for each land use classification.
Eff_P	Eff_P: This is the nutrient retention efficiency for each land use classification. The InVEST user guide describes this value as "The distance after which it is assumed that this LULC type retains the nutrient at its maximum capacity… The nutrient retention capacity for a given vegetation type is expressed as a proportion of the amount of nutrients from upslope" (Natural Capital Project). Higher values mean there is more nutrient retention.
Load_N	Load_N: the nitrogen load for each land use classification.
Eff_N	Eff_N: This is the same as Eff_P but for Nitrogen retention.
crit_len_p	crit_len_p: The InVEST guide describes this value as, "The distance after which it is assumed that this LULC type retains the nutrient at its maximum capacity" (InVEST guide).
crit_len_n	crit_len_n: This is the same as crit_len_p but for nitrogen
proportion_subsurface_n	proportion_subsurface_n: while this value is

	assumed to be zero in our model iterations, the user guide describes this as “The proportion of the total amount of nitrogen that are dissolved into the subsurface” (InVEST guide).

c. Additional Input Values

Other required inputs for the model include Threshold Flow Accumulation, the Boreselli K Parameter, Subsurface critical length for nitrogen and subsurface maximum retention efficiency for phosphorus. For the threshold flow accumulation, a value of 1000, as suggested by the InVEST user guide, was used. The threshold flow accumulation is a number that the model references to determine how many pixels to count before determining that part of the spatial input constitutes a waterway. Similarly, the Boreselli K Parameter was set to the default value of 2. The K Parameter helps the model determine “the shape of the relationship between hydrologic connectivity… and the nutrient delivery ratio (percentage of nutrient that actually reaches the stream)” (InVEST User Guide). Given a lack of subsurface soil data, the subsurface critical length (referring only to nitrogen) and the subsurface maximum retention efficiency were both set to 0. This means that the model ran under the assumption that all nutrient runoff was surface runoff impacted only by the soil permeability ratios in the biophysical table.

The InVEST NDR model was run twice under different land use development conditions. The first iteration of the model was under current land use conditions and each land use classification was given a corresponding entry in the biophysical table consistent with relevant research and literature on nutrient loading and runoff for that classification (Fig. 1.1). The second iteration of the model assumed high development of all forest classifications (deciduous, evergreen, mixed forest) as well as shrub/scrub, grassland/herbaceous and woody and emergent herbaceous wetlands (Fig. 1.2). There was no actual change to the land use raster, only the Load_p, Eff_p, Load_n, Eff_n, crit_len_p, and crit_len_n column values in the biophysical table (Fig. 1.1, 1.2, described in Table 1.1)). The changes effected 38.4% of all pixels in the land use raster. Put simply, the first iteration of the model was run with the current land use data and runoff estimates for each classification while the second iteration took natural areas and assumed they became highly developed areas and thus were assigned the same nutrient load and runoff data as areas defined as highly developed.

d. Model Outputs

The model outputs include many tif files for analysis. The most relevant outputs will be discussed at greater length later in this chapter. The intermediate outputs are described in Table 1.4 below:

Table 1.4- A list of file names and descriptions of the intermediate outputs from the InVEST NDR Ratio Model. Descriptions are taken from the InVEST user guide (Natural Capital Project).

Output File Name	Description	Output File Name	Description
effective _retention_p	Effective retention provided by the downslope flow path for each pixel	Load_n	Loads (for surface transport) per pixel [units: kg/year]
Effective_retnetion_n	Effective retention provided by the downslope flow path for each pixel	Ic_factor	Index of connectivity
Eff_p	Raw per-landscape cover retention efficiency for nutrient x.	What_drains_to_stream	Map of which pixels drain to a stream. A value of 1 means that at least some of the runoff from that pixel drains to a stream in stream.tif. A value of 0 means that it does not drain at all to any stream in stream.tif.
Eff_n	Raw per-landscape cover retention efficiency for nutrient x.	Dist_to_channel	Average downslope distance from a pixel to the stream
Ndr_p	NDR values	D_dn_	Downslope factor of the index of connectivity
Crit_len_p	Retention length values, crit_len, found in the biophysical table	S_factor_inverse	Slope parameter for the IC equation found in the Nutrient Delivery

			section
Modified_load_p	Raw load scaled by the runoff proxy index. [units: kg/year]	D_up	Upslope factor of the index of connectivity
Surface_load_p	Above ground nutrient loads [units: kg/year]	S_bar	Slope parameter for the IC equation found in the Nutrient Delivery section
Load_p	Loads (for surface transport) per pixel [units: kg/year]	S_accumulation	Slope parameter for the IC equation found in the Nutrient Delivery section
Sub_ndr_n	Subsurface nitrogen NDR values	Runoff_proxy_index	Normalized values for the Runoff Proxy input to the model
Sub_load_n		Thresholded_slope	
Ndr_n	NDR values	Stream	Stream network created from the DEM, with 0 representing land pixels, and 1 representing stream pixels. Compare this layer with a real-world stream map, and adjust the Threshold Flow Accumulation so that this matches real-world streams as closely as possible.
Crit_len_n	Retention length values, crit_len, found in the biophysical table	Flow_accumulation	Flow accumulation created from the DEM (Digital Elevation Model)
Flow_direction	Flow direction created from the DEM (Digital	Sub_load_n	Nitrogen loads for subsurface transport [units:

	Elevation Model)		kg/year]
thresholded_slope	Raster with slope values thresholded for correct calculation of IC.	-	-

Additionally the model creates a geopackage (gpkg file) titled "watershed_results_ndr" that, in this case, summarizes total nutrient loading and runoff by creekshed. The attribute table for this feature class layer was downloaded from ArcGIS Pro as an excel file to run analysis. Each of these files were created for both the current land use model and the high development land use model. Other tif files created to summarize model outputs as part of the created geopackage are described in Table 1.5:

Table 1.5- A list of file names and descriptions of the outputs from the InVEST NDR Ratio Model. Descriptions are taken from the InVEST user guide (Natural Capital Project).

Output File Name	Description
- N_subsurface_export	Total phosphorus export from the watershed by surface flow.[units kg/year]
- N_surface_export	A pixel level map showing how much nitrogen from each pixel eventually reaches the stream by surface flow. [units: kg/pixel]
- N_total_export	A pixel level map showing how much nitrogen from each pixel eventually reaches the stream (the sum of n_surface_export.tif and n_subsurface_export.tif). [units: kg/pixel]
- P_surface_export	A pixel level map showing how much phosphorus from each pixel eventually reaches the stream by surface flow. [units: kg/pixel]

Analysis of the model outputs involved overlaying HRWC's bioreserve map (Figure X, Background) on top of the relevant output layers and extracting the pixel values that are contained within bioreserve areas in the watershed (Fig. 3). To do this, we used ArcGIS Pro's spatial analysis tool "zonal statistics as table" to extract pixel values from the model output layers only from the bioreserve polygons and take the mean of all of these pixels, thus creating a table that contains average nutrient runoff specifically for each biosreserve area. The join feature was used to create an attribute table with the bioreserve area specifics. Finally, this table was downloaded as an excel spreadsheet, which was used for statistical analysis. These values are then averaged at both the current land use scenario and the high development land use scenario. Thus, we can track more exact changes in specific areas to understand how future development or conservation could impact nutrient load and runoff. Given that HRWC is most interested in

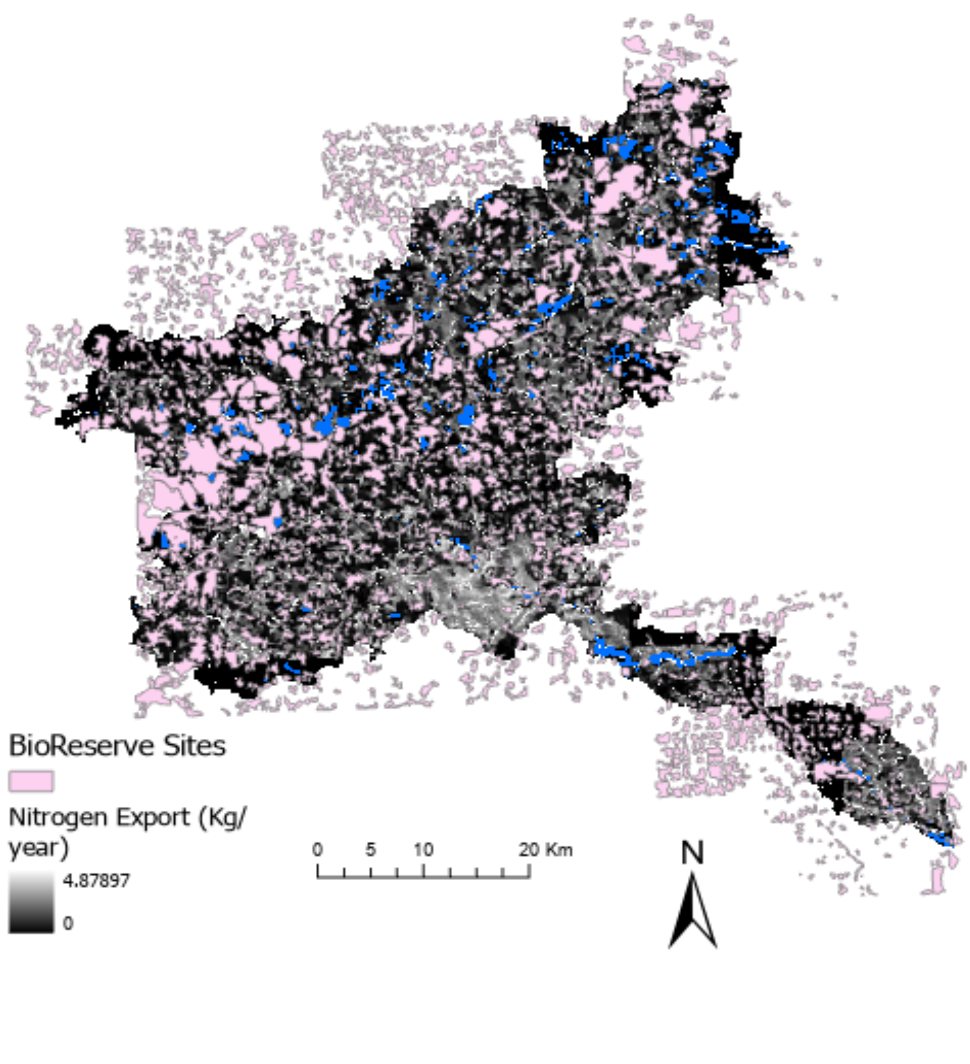

Fig. 1.2. Map of the Huron River Watershed showing both nitrogen runoff and bioreserve sites. Water is shown in blue to demonstrate where the Huron River, lakes, and creeks are located.

the ways forest properties impact drinking water, we focused our analysis on forested properties (both public and private) in a variety of areas across the watershed through the use of the bioreserve map.

3. Model Limitations

While the Nutrient Delivery Ratio Model provides valuable information that helps inform decision making, the model is limited in what can be done with the information. A few of the limitations that the Natural Capital Project list are:

- Watershed-level modeling with land use classification data is difficult to make exact, and "Calibration is therefore difficult and not recommended without in-depth analyses that would provide confidence in model process representation" (Hamel et al., 2015) (Natural Capital Project). Thus for the purposes of this project, it is difficult to dial in the exact parameters of this model. See Section "5: Conclusion and Future Research" for a more in depth discussion of how HRWC can adapt this model to more specific research needs and questions.
- InVEST suggests not using exact values from the outputs to measure ecosystem or economic impacts of nutrient runoff. Instead, to mitigate some of the effects of the model uncertainty, they suggest using percentage increases for impact analysis. As is clear in the Results section, percentage increases between model iterations are dramatic and could lend themselves to salient impact analyses.

Further, there are limitations for the models run as part of this project specifically due to our assumptions of surface export only and our spatial data inputs. These limitations include:

- The digital elevation model used in this model is stitched together from many USGS regional data downloads and clipped to the extent of the watershed. This clipping and reprojection may alter the accuracy of elevation data along the margins of the clipping extent. To remedy this, running the model with each of the spatial inputs clipped to a broader extent and then clipping only the model outputs for analysis may be helpful.
- The high development scenario assumes equal nutrient loads for all forested, wetland, and natural areas. In discussions with HRWC, they were interested in the impacts of changing these land use classifications to highly developed areas. However, given the structure of raster datasets, it is beyond the scope of this project to change individual land use classifications in specific watershed areas to highly developed. Therefore, the only way to address HRWC's question was to change all natural classifications to an equal nutrient load and extract values only from bioreserve areas.
- Nutrient loads may not be fully accurate and are from a variety of sources. While obtaining accurate nutrient data would be difficult, it would make for a much more accurate model. As discussed in the methods section, nutrient loads are pulled from a

variety of peer-reviewed sources. However, they are not specific to the Huron River watershed and assume equal nutrient loading for each land use classification. To assign more exact nutrient loads to each area of the watershed (i.e. know the exact nitrogen use of specific farms or runoff data from the Michigan Medicine campus) is beyond the scope of this project and would require very specific research.

- The accessible soil data is within a large database and takes a significant amount of time to find relevant layers. To then extract relevant information and transform it into the correct format to draw conclusions about subsurface nutrient transport would require resources beyond what is currently available.
- The land use data is from 2011 and precipitation data is from 1990-2000. While we are confident in the accuracy and source of this data, it is necessary to acknowledge that land use changes and the rising effects of climate change result in decadal changes in precipitation.
- Precipitation data resolution may not be as clear as other spatial outputs. While the nature of the data given the relatively limited geographic extent of the study area still leads to accurate results, a higher resolution precipitation raster could lead to somewhat clearer runoff data.

These limitations do not discount the outputs of this model, but provide a framework from which to conservatively analyze outputs and read through the results section of this report. Paired with the conclusions and future research section of this chapter, understanding these limitations can influence and improve future attempts at modeling and result in more accurate nutrient flow understanding.

4. Results

Analyzing the attribute tables from the “waterhsed_results_ndr” outputs in the current and high development land use scenarios can provide a general overview of the impact of extreme development of forested and natural areas in the watershed. In the current land use scenario, the model found a total nitrogen export of 4,942,133.27 kg/year. In the high development land use scenario, the model found a total nitrogen export of 10,621,253.89 kg/year. This general result shows a 114.9% increase in nitrogen export despite only a 38.4% change in pixels in the land use raster in nutrient loading and runoff ratios. Similarly with phosphorus, the entire watershed saw an increase from 240,180.50 kg/year in the current land use scenario to 445,529.12 kg/year in the high development land use scenario. This again represents a change larger than the affected percentage change of the land use raster, coming in at an 85.5% increase in phosphorus export.

Focusing on the model created layers “N_total_export” and “P_surface_export” (the phosphorus modeling assumes all above ground transport) provides a pixel level analysis of nutrient export in the watershed. By overlaying HRWC’s bioreserve map containing the spatial extent of preserved areas and forest landowners' properties in the watershed over each of these layers, we extracted the mean nutrient runoff for phosphorus and nitrogen from each bioreserve area under the current land use and the high development land use scenarios. Unsurprisingly, a paired two sample t-test (Fig. 1.4) shows a statistically significant difference in nitrogen runoff between the means of bioreserve areas in the current land use scenario (Variable 1) and the high development land use scenario (Variable 2).

Whereas the current land use model shows a mean nitrogen runoff of 0.126 kg of nitrogen per year, the high development scenario shows a 0.667 kg/year nitrogen runoff, representing a 429.37% increase in annual nitrogen runoff reaching a stream or river from bioreserve sites. Another paired two sample t-test, this time comparing the means of phosphorus runoff, similarly found a statistically significant difference in the means of phosphorus runoff between the current land use scenario and the high development land use scenario (Fig. 1.5). In the current land use scenario, there is a mean phosphorus runoff of 0.006 kg/year from bioreserve areas. In the high development scenario, there is an average of 0.028 kg of phosphorus runoff to streams and rivers from bioreserve areas annually, representing a 366.67% increase. Comparing the increase in total nitrogen and phosphorus runoff for the entire watershed and the increase only from bioreserve areas highlights the importance of these bioreserve areas for decreasing phosphorus and nitrogen runoff into streams and rivers.

t-Test: Paired Two Sample for Means		
	Variable 1	*Variable 2*
Mean	0.12602535	0.66780502
Variance	0.07660407	0.54882429
Observations	1715	1715
Pearson Correlation	0.28840662	
Hypothesized Mean Difference	0	
df	1714	
t Stat	-31.50528	
P(T<=t) one-tail	1.457E-172	
t Critical one-tail	1.64574312	
P(T<=t) two-tail	2.914E-172	
t Critical two-tail	1.961349	

Fig. 1.3 Paired two sample t-test of means for nitrogen runoff from bioreserve areas between the current and high development land use scenarios. Variable 1 is the current land use scenario and variable 2 is the high development scenario.

t-Test: Paired Two Sample for Means		
	Variable 1	*Variable 2*
Mean	0.00600939	0.02816058
Variance	0.00017476	0.00105191
Observations	1716	1716
Pearson Correlation	0.29519976	
Hypothesized Mean Difference	0	
df	1715	
t Stat	-29.409069	
P(T<=t) one-tail	1.424E-154	
t Critical one-tail	1.64574261	
P(T<=t) two-tail	2.848E-154	
t Critical two-tail	1.96134819	

Fig. 1.4 Paired two sample t-test of means for phosphorus runoff from bioreserve areas between the current and high development land use scenarios. Variable 1 is the current land use scenario and variable 2 is the high development scenario.

Appendix B shows pixel level maps of nitrogen and phosphorus runoff in the watershed under the current land use classification. There is a more intense hotspot of nitrogen runoff compared to phosphorus runoff, which is unsurprising given the difference in load quantities. These maps demonstrate where in the watershed runoff that eventually reaches a waterway originates from. There are multiple explanations for why these hotspots exist. First, looking at the digital elevation model in the spatial inputs in Appendix A, the higher elevation areas in the watershed overlap closely or are directly upstream of where the hotspots are located. It tracks that runoff would follow the natural gradient and be more intense in low areas near the river at the base of higher elevation areas where precipitation carries nutrients downhill.

Figures 1.5 and 1.6 demonstrates another reason for these high intensity runoff areas. Figure 1. 5 shows nitrogen runoff by creekshed, with higher runoff being shown in red. The map also highlights specific land use land cover classifications that are salient to the runoff analysis. Open water is shown to demonstrate waterways and lakes where nutrient runs into, along with wetlands. The brown pixels represent crop cover which, as demonstrated by the biophysical table (fig. 1.1, 1.2), have high nutrient loads. In deeper red areas, indicating greater runoff, there is also more crop cover. It logically follows that the high nutrient loading agricultural areas would result in higher runoff. This, paired with the elevation in the mid-southwestern portion of the watershed, results in the largest nutrient loading hotspot shown on the map. The below map (Fig. 1.6) shows phosphorus runoff by creekshed, also overlaid with the relevant land use

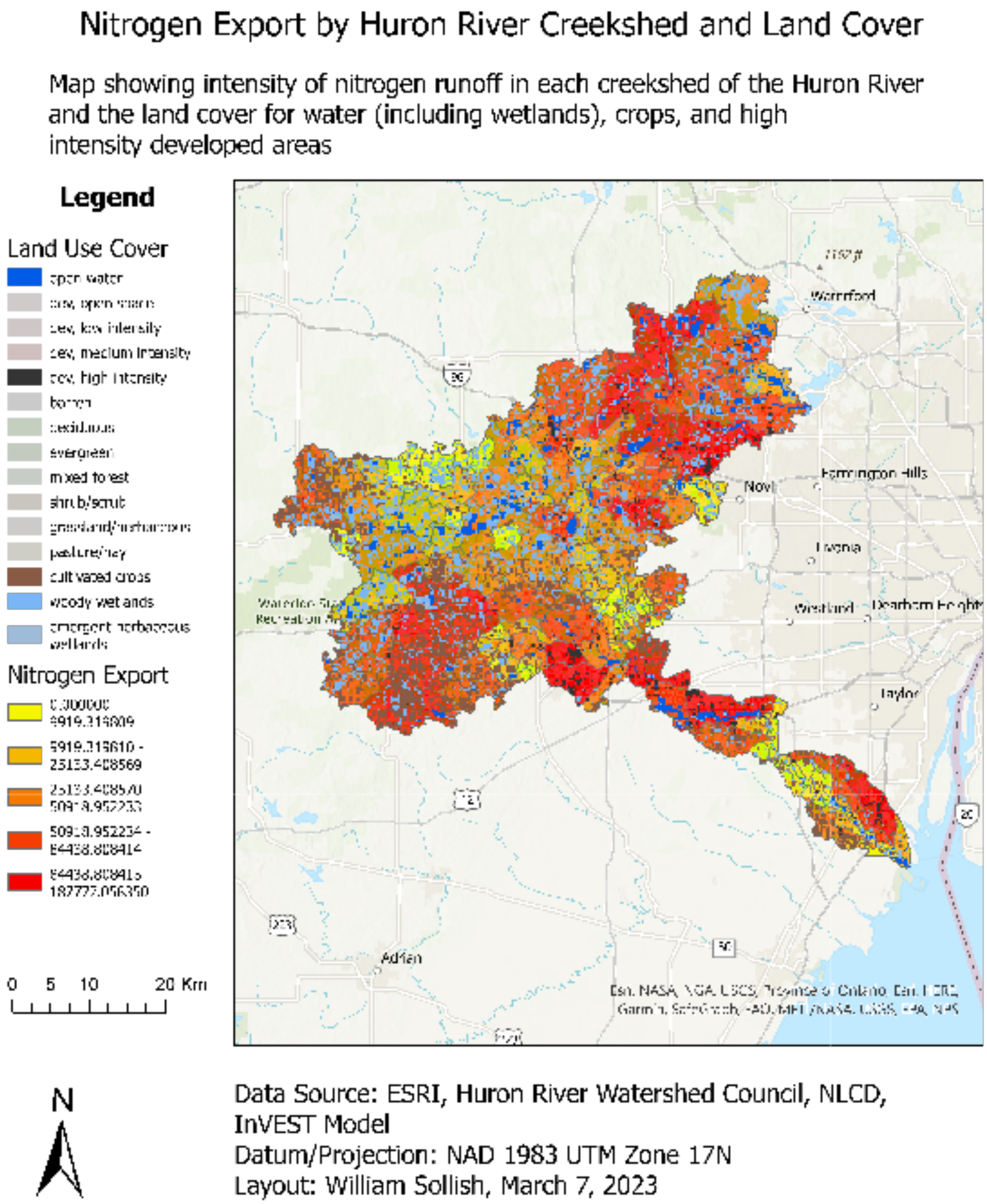

Fig. 1.5. Map of Nitrogen runoff in the Huron River Watershed by Creekshed showing land use for water and wetlands, agriculture, and highly developed areas.

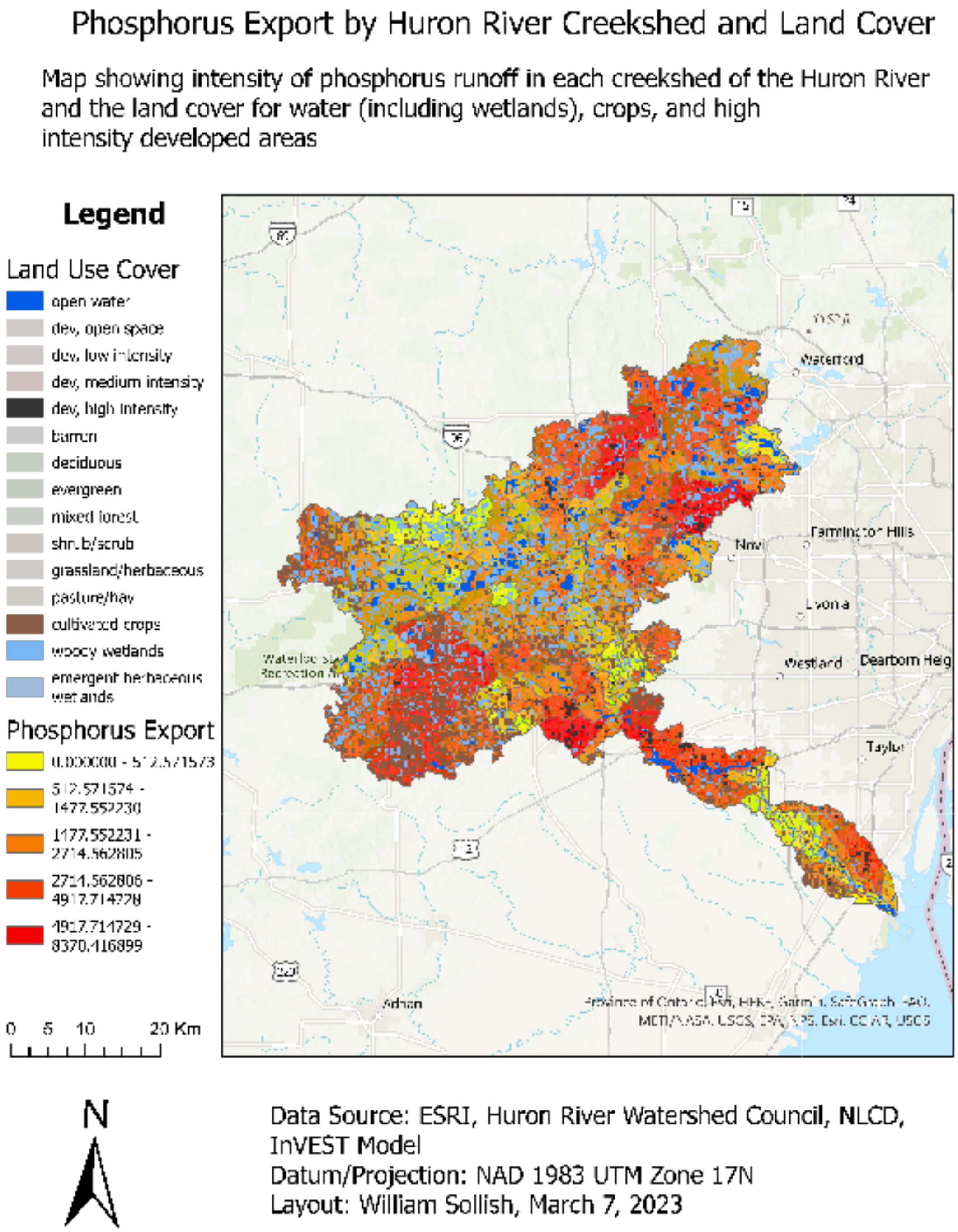

Figure 1.6. Map of Phosphorus runoff in the Huron River Watershed by Creekshed showing land use for water and wetlands, agriculture, and highly developed areas.

classifications, and similarly shows agricultural areas as higher contributors to nutrient runoff. Finally, the pixels in black show areas deemed as developed, high intensity. These are areas the the National Land Cover Database, which the land cover data comes from, defines as having greater than 80% impervious surface (Dewitz). While these areas are not abundant, where they are common also match up with higher nutrient loading areas.

Running the model through the high development iteration reveals the negative impacts of transforming forested areas into intense development. Appendix D shows two more pixel level maps of nitrogen and phosphorus runoff, this time in the high development scenario. It is clear to see that there is significantly more runoff in the high development scenario, as indicated by the total nutrient export described earlier, but it is also evident that the runoff is much more widespread across the watershed than in the current land use scenario (Appendix B). The high intensity scenario demonstrates the effects of developing forested and natural areas. Appendix E shows the percentage of each creekshed that is forested or a natural land cover. There is a higher percentage of natural land cover areas in the northern part of the watershed as well as the lower watershed area. Evidently, the areas with the highest percent of natural land cover then become the highest runoff areas in the high development scenario, while the hotspot area from the current land use scenario is lower (here shown in yellow), relative to the now-developed natural land cover areas. Appendix F, which shows the percentage of each creekshed that falls into the developed-high intensity land use classification, confirms that the highly developed areas, regardless of the model development scenario, results in high runoff even without a significant portion of the land cover being developed. Seeing how the development runoff outpaces the agricultural areas for nutrient runoff demonstrates the importance of conserving the Huron River's natural areas and bioreserve properties.

The results of this modeling make clear that agricultural and highly developed areas are the most responsible for nutrient runoff in the Huron River Watershed. As stated in the introduction to this report, the average area of a Bioreserve site in the watershed is .21 square miles. The 30 meter by 30 meter resolution of these results is much higher than the average Bioreserve site, which means we are able to see clear runoff differences, even within a singular property. This clarity allows for spatial conclusions to be drawn concerning where in the watershed the largest runoff hotspots are located. The conclusions section of this chapter and of the report as a whole explores the county and regional variations in the runoff data.

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Chapter 2: Mapping and Prioritizing Parcels for Resilience (MAPPR)

1. Background

The Bioreserve Map was created by the Huron River Watershed Council (HRWC) to measure the quality of natural areas in the Huron River watershed. A bioreserve area is defined by HRWC as an area of forest, wetland, or open field in the watershed (HRWC, 2007). The 1700 bioreserve areas are ranked by 15 metrics that indicate their ecological value, including their biological diversity and their contributions to water quality (HRWC, 2007). Areas that have not been developed can reduce runoff and prevent erosion, which is important to the health of the watershed. The Bioreserve map was created in 2007 using a combination of remote sensing and survey data. The data was compiled from various sources, including state and federal agencies, and was processed for the Huron River watershed (HRWC, 2007). The goal in creating the Bioreserve map was to inform decision making about which natural areas to prioritize when purchasing land for conservation.

As part of the HRWC FCW project, this project looked at how the Bioreserve map can be enhanced and displayed interactively. A version of the map that can be manipulated by users and members of the public could be used to guide conservation decisions. This project's goal is to include data that wasn't previously in the Bioreserve map and to add interactive elements through the use of ArcGIS Online. The work was informed by the Mapping and Prioritizing Parcels for Resilience (MAPPR) Project, a project that was carried out in Massachusetts and is in line with HRWC's goals for the Bioreserve map.

The MAPPR project was developed by Mass Audubon, The Nature Conservancy, and LandVest (Collins et al., 2017). It uses previously existing layers of conservation data for the state of Massachusetts and applies them to level 3 parcels. In Massachusetts, level 3 parcels are a standard developed by MassGIS for displaying property maps with sufficient accuracy (MassGIS, 2022). The conservation data layers come from a variety of organizations, including The Nature Conservancy and MassGIS. The project includes layers for various habitat types, including forest, wetland, and vernal pools. It also includes layers that represent habitat connectivity, resilience to climate change, farm land, and water supply protection areas.

MAPPR provides a system for ranking parcels based on their conservation value (Collins et al., 2017). The parcels are weighted according to the layers that are input into the ranking formula. The user can select layers that are in line with their conservation priorities. This allows the user to decide which data to include when running the model. The user can select an area of interest by town, county, or watershed within the state of Massachusetts. The model produces a ranking of high priority, medium priority, and lower priority for each parcel in the area of interest.

Fig. 2.1 shows a MAPPR output for Berkshire County, Massachusetts (Mass Audubon, 2023). The model was run using the layers for forest, wetland, and vernal pools. High priority parcels are displayed in red, medium in orange, and lower priority parcels are yellow.

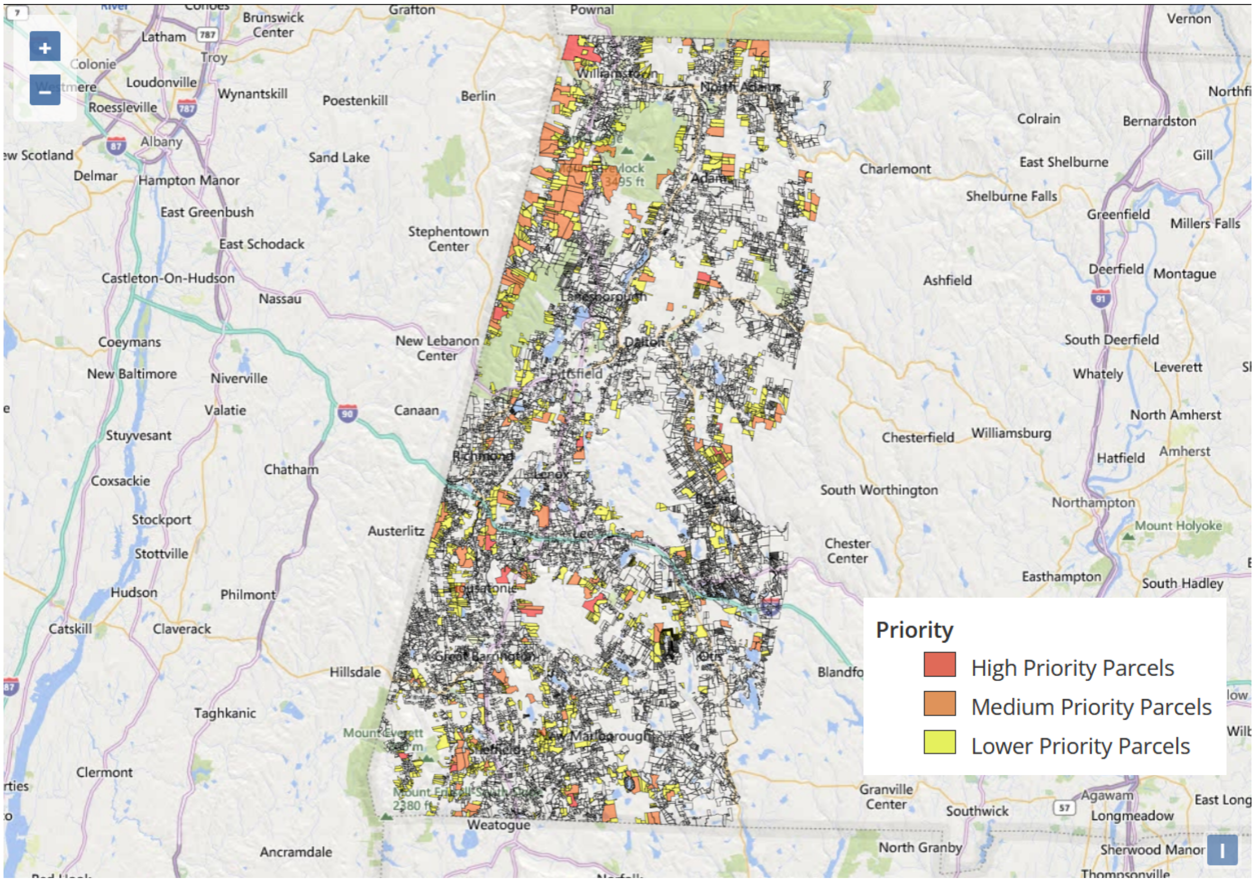

Figure 2.1: MAPPR output showing the Berkshire County, MA, based on the layers for forest, wetland, and vernal pools (Collins et al., 2017). A legend is overlaid.

The MAPPR tool can be used by conservation organizations to determine which parcels should be prioritized for environmental and conservation protection. In the output map, each parcel can be selected to learn about the factors that were included in its ranking. These factors consist of the rankings for individual metrics that were selected when creating the model, such as forest, wetland, and vernal pools.

One goal of this project was to expand HRWC's Bioreserve map to have functionalities similar to MAPPR. In comparison to MAPPR, many of the HRWC Bioreserve map's layers have similar purposes, although less data is available for the Huron River watershed as compared to the Massachusetts data. The bioreserve map has a ranking system that is similar to MAPPR's, where a variety of metrics are combined to output a value of 1, 2, or 3, indicating overall ecological quality, with 3 being high priority, 2 representing medium priority, and 1 representing low priority parcels for conservation (HRWC, 2007).

The Bioreserve map ranks by natural area polygons, while MAPPR uses parcels, which makes MAPPR a finer-scale map. Polygons are drawn manually by HRWC to represent regions in the watershed that are undeveloped, while parcels are a standardized method for defining individual properties. MAPPR is also more selective in terms of which areas are included in the ranking. Areas that are not considered high-quality habitat are excluded from the ranking. MAPPR does this by removing areas through a preliminary ranking system, so that only high-quality areas are included in the final ranking (Collins et al., 2017). Additional data can be added to the Bioreserve map to make it more similar to MAPPR, and an interactive component can be added.

As a statewide map, MAPPR is more equipped to describe the variations between and within ecosystems than the HRWC Bioreserve map. MAPPR presents the natural areas that are of highest conservation concern for a variety of ecosystem types. It includes metrics for the quality of coastal, river, and forest habitat among others, and areas that are rated as lower priority are filtered out from its analysis. HRWC's Bioreserve map covers the Huron River watershed region, which includes a narrower range of ecosystem types than MAPPR's domain. Because it covers a smaller region, the bioreserve map is less selective in the natural areas that are displayed. Any area with natural land cover is included in the analysis, and areas that are considered to be of lower quality are not filtered out.

2. Methods

For this project, the Bioreserve map was compared to MAPPR in order to determine where their functionalities are similar and whether layers can be added to the Bioreserve map to improve its ranking system. We reviewed the metrics that were used in their ranking systems and looked for additional data sources that are available for the Huron River watershed. An overview of the metrics used in MAPPR is provided in Appendix F. An overview of the metrics used in the Bioreserve Map is provided in Appendix G.

For the purposes of the comparison, we divided the metrics used by the two maps into four general categories. The first category, size of natural areas, indicates the amount of available land for different land cover types. It prioritizes continuous regions of high-quality habitat. The second category, ecological integrity, indicates the quality of the area. It ranks high integrity areas as those that are less vulnerable to disturbance.

The third category, biological diversity, indicates the amount of species diversity that the area supports. Areas with more variation are rated more highly in this category. The fourth category, groundwater, indicates the area's contribution to groundwater quality. Areas with higher levels of water flow in soils are ranked as higher priority. The metrics are described below according to the following four categories.

a. Size of Natural Areas

MAPPR includes four layers that rank natural areas according to size. These layers are from BioMap2 and are divided according to land cover type. BioMap2 is a method of prioritizing natural areas based on their conservation value, and was created by the Massachusetts Natural Heritage and Endangered Species Program (NHESP), in collaboration with The Nature

Conservancy (NHESP, 2011). The parcels are ranked according to the amount of area they include with vernal pools, forests, wetlands, and rivers or lakes. The parcels are binned into values of 1, 2, and 3, where higher values are given to parcels with a greater area for the four land cover types. The forest and wetland areas are also ranked by ecological integrity, which is discussed in the next part of this section.

The Bioreserve map's polygons are similarly ranked according to size. However, in the Bioreserve map, each polygon is assigned a rank based on its total size, rather than being divided into land cover types (HRWC, 2007). Whereas MAPPR accounts for the size of each land cover type, the bioreserve map only considers the size of the polygon as a whole. Each individual bioreserve polygon may include multiple types of natural areas. Land cover type is indicated in the Bioreserve map through a binary ranking for whether each polygon contains wetland or water. No ranking for forest or vernal pool is included.

The Bioreserve map was updated to include additional size rankings, depending on data availability. For this project, a size ranking was created for wetlands based on the percent of each polygon area that includes a wetland. A size ranking was also created for lakes and rivers, based on the area covered by lakes and the total stream length in each polygon. The process of creating the rankings is described in more detail in the New Layers section below.

b. Integrity

MAPPR ranks the integrity of natural areas using the Conservation Assessment and Prioritization System (CAPS) method, developed by the University of Massachusetts Amherst. CAPS divides the state of Massachusetts into 30m x 30m pixels, and for each cell, it calculates an index of ecological integrity (IEI) based on 18 integrity metrics. The metrics fall into five general categories, which are development, pollution, biotic alterations, hydrological alterations, and resiliency. A weighting system is applied to the metrics that prioritizes them for different ecosystem types, where a different method of weighting is used for each ecosystem type.

MAPPR applies CAPS IEI in order to rank the ecological integrity of several of its layers, including forest, wetland, and a layer that consists of landscape blocks and upland buffers. In the Bioreserve map, 6 of the 15 metrics relate to the integrity of natural areas. The connectedness of natural areas is measured in two separate metrics. First, connectedness is measured as the amount of natural area surrounding each polygon. Second, it is measured as the amount of undeveloped area surrounding each polygon. An additional metric for restorability measures the percentage of undeveloped land surrounding each polygon.

The Bioreserve map also includes two metrics for unchanged vegetation. The metrics are based on the similarity between vegetation in 1800 and 2000 (HRWC, 2007). The first metric measures the percentage of current vegetation that is potentially unchanged, which is defined as vegetation that has remained the same between 1800 and 2000. The second metric measures the area of each polygon consisting of vegetation that is potentially unchanged. In addition, a metric for remnant ecosystems measures the number of ecosystem types that were present in the bioreserve in the 1800s.

The Bioreserve map has a more limited range of integrity metrics than MAPPR. The 6 integrity metrics in the Bioreserve map all relate to resilience, whereas MAPPR has additional metrics that relate to development, pollution, biotic alterations, and hydrological alterations.

c. Diversity

MAPPR ranks biological diversity based on the presence of habitat for endangered species. Habitat was mapped for 413 species that are listed by the Massachusetts Endangered Species Act (MESA). MAPPR also includes a map of habitat for 27 species that are listed by the State Wildlife Action Plan (SWAP), but that are not listed by MESA. In addition, MAPPR includes a map of rivers and streams that are habitat for anadromous fish (Collins et al., 2017).

The Bioreserve map has 4 metrics that indicate diversity: biorarity, MNFI communities, glacial variation, and topographical variation (HRWC, 2007). The biorarity metric uses the biorarity index produced by the Michigan Natural Features Inventory (MNFI). The biorarity index ranks areas according to the likelihood that they are used for habitat by endangered species. The MNFI communities metric is based on a database maintained by MNFI that identifies areas that contain high quality plant communities. The metric used in the Bioreserve map ranks polygons by the amount of area they contain that MNFI identifies as including high quality plant communities.

The Bioreserve map ranks biodiversity based on whether protected species are likely to be found in each polygon. Data that is specific to individual species is not made available by MNFI. The MNFI only provides likelihoods of species presence, rather than providing the habitats of endangered species, due to concerns over human interference. In contrast, MAPPR uses habitat data that indicates the presence of individual species. This data is compiled from on-the-ground observations by various groups of where species are present.

The Bioreserve map uses two metrics of landscape diversity, which are not included in the layers used by MAPPR. The glacial variation metric ranks polygons by the number of glacial landforms they contain. The topographical variation metric was created by producing a triangulated irregular network (TIN), which is a method of delineating surfaces based on elevation data. The metric ranks polygons by the number of TINs they contain, where a higher number of TINs indicate that there is a greater amount of variation in slope and aspect of the landscape. These two metrics indicate the diversity of landscapes, which in turn can indicate the ecological diversity of the area.

d. Hydrology

MAPPR ranks hydrology according to two metrics: surface water supply protection areas and wellhead protection areas (Collins et al., 2017). A layer is included that shows surface water supply protection areas. These are divided into 3 zone types, according to the Massachusetts Drinking Water Regulations, which are based on the nearness of the land to a riverbank. An additional layer is used that shows wellhead protection areas. These areas are defined by the Massachusetts Department of Environmental Protection. They are divided into 3 zone types, based on the nearness of the land to a wellhead.

The Bioreserve map ranks each polygon's potential for groundwater recharge (HRWC, 2007). Darcy's law, which is an equation that describes the flow of groundwater, is used to determine the amount of groundwater flow based on soil type. MAPPR does not include a comparable metric on groundwater flow, but includes metrics that indicate areas that are important to drinking water quality.

e. New Layers

We created several additional layers to add to the Bioreserve map using data maintained by HRWC. The goal was to add metrics that were not previously available in the Bioreserve map. The addition of the metrics makes the Bioreserve map more similar to MAPPR. The process of creating the layers is described below.

A layer was created for the area of wetlands. A wetlands inventory for the state of Michigan is maintained by the Department of Environment, Great Lakes, and Energy (EGLE). The inventory is a shapefile that includes polygons that indicate the boundaries of wetlands in Michigan. The inventory was processed by HRWC so that only wetlands within the Huron River watershed were included.

We used the wetlands inventory to determine the percent of each bioreserve area polygon that contained wetlands. In ArcGIS Pro, we used the Intersect tool to create a layer of wetland polygons that occur within the bioreserves. We then used the Summarize Within tool to determine the area of wetland within each bioreserve polygon. We calculated the percent area of wetland as the proportion of wetland area to total area in each bioreserve polygon.

A layer was added for the lakes in each bioreserve site polygon. The Huron Lakes inventory is a shapefile which includes polygons that indicate the lake area within Michigan. The inventory was then processed by HRWC to demonstrate the lakes that were only included within the Huron River Watershed.

We leveraged the Huron Lakes inventory to display the percentage of each bioreserve site polygon that contains lakes. We first used the Intersect tool to create a new layer showing the intersection of bioreserve sites and the lakes. Next, we used the Calculate Geometry Attributes tool to calculate the area of each intersection part and the Summary Statistics tool to add up the area within each bioreserve site polygon. After joining the specific field of the new summary table in the original table of the bioreserve site layer, we used the Calculate Field tool then to get the percent area of lakes as the proportion of lake area to total area in each bioreserve site polygon. The new layer was displayed using the Graduated Colors as the symbology method.

A layer was added for the length of streams in each bioreserve polygon. The streams inventory is a shapefile which contains polylines that display the directions and length of streams. The inventory was processed by HRWC then to demonstrate the streams that flowed only within the Huron River Watershed.

We utilized the streams inventory to determine the total length of streams within each bioreserve polygon. We first used the Clip tool to generate a new layer which contained the streams that only flowed within each bioreserve site polygon. Next we used the Dissolve tool to aggregate the polylines and summarized the total length of streams. We then used the Spatial Join tool to join the dissolved layer and the bioreserve site layer based on the location, and determined the total length of streams within each bioreserve polygon as well. The new layer was displayed using the Graduated Colors as the symbology method.

In addition, four layers were added from TNC's Resilient and Connected Landscapes dataset. The Connectivity and Climate Flow (Wall-to-Wall) layer measures how movement of species is restricted by human activity and landscape gradients. Areas that allow more movement are rated higher, while areas that restrict movement are rated lower. In ArcGIS Pro, we used the Zonal Statistics as Table tool to determine the average connectivity ranking within each bioreserve polygon.

The Local Connectedness layer measures how human-built structures prevent the movement of species. Areas that allow more movement are rated higher, while areas that restrict movement are rated lower. We used the Zonal Statistics as Table tool to determine the average connectedness ranking within each bioreserve polygon.

The Landscape Diversity layer is a measure of the number of microclimates at each location. We used the Zonal Statistics as Table tool to determine the average diversity ranking within each bioreserve polygon.

The Terrestrial Resilience layer is a measure of how climate change will affect a site's ecological function. Areas that are likely to maintain function are rated higher, while areas that are likely to lose function are rated lower. We used the Zonal Statistics as Table tool to determine the average resilience ranking within each bioreserve polygon.

Nutrient loads for the Huron River watershed were derived from the InVEST model, which is described in Chapter 2 of this report. The resulting layers include data on phosphorus and nitrogen loads. For each layer, average values were taken for the bioreserve polygons, using the Zonal Statistics as Table tool in ArcGIS Pro.

f. ArcGIS Online Map

ArcGIS Online was used to create an interactive version of the Bioreserve map. The bioreserve polygons were displayed in the map, along with townsheds and the main branch of the Huron River. In addition, rankings were displayed according to the four groupings described above. The map includes a layer for area rank, groundwater rank, integrity rank, and biodiversity rank. These layers are selectable so that the user can view the Bioreserve map according to the rankings in the four general categories. The map can also be filtered to display only the polygons with the highest values for each of the 4 layers.

The map was created as a Web Map in ArcGIS Online, and was edited using Map Viewer Classic. We added data to the map by converting the bioreserve polygon layer to a shapefile, then zipping the shapefile folder and uploading it to the Web Map.

We used the ArcGIS Online Web AppBuilder to make the map interactive for the user. We displayed the Web Map in the app, and also used widgets that allow the user to manipulate the data displayed.

Three layers are visible on the map when it is initially opened. We displayed the outlines of the bioreserve polygons on the map in green. We displayed the main stem of the Huron River, as well as the borders of cities and townships in the Huron River watershed. When a bioreserve polygon is selected, a pop-up appears that displays its ID. Clicking the pop-up displays a new window that includes the full data available for that bioreserve polygon.

We included additional layers that can be viewed on the map if selected by the user. We added layers that display the bioreserve polygons according to various rankings. The polygons can be displayed with rankings for area, groundwater, integrity, and diversity. We grouped the bioreserve metrics into these 4 classes, and each class has values ranging from 0 to 100, where higher values are ranked higher for the corresponding metrics. We displayed the rankings in 3 separate categories, which correspond to low, medium, and high for each metric. The rankings are divided into categories of 0-33, 33-66, and 66-100. The polygons can be filtered for each data grouping. When the filter is applied, the map only displays the polygons that have a ranking greater than 50 for each chosen grouping.

3. Results

In Figure 2.2, the Bioreserve Map is displayed according to its Final Rank, which is a weighted average of all 15 metrics that were included. The polygons are grouped into values of low, medium, and high, depending on their priority ranking. The Final Rank gives an even weight to each of the 15 metrics.

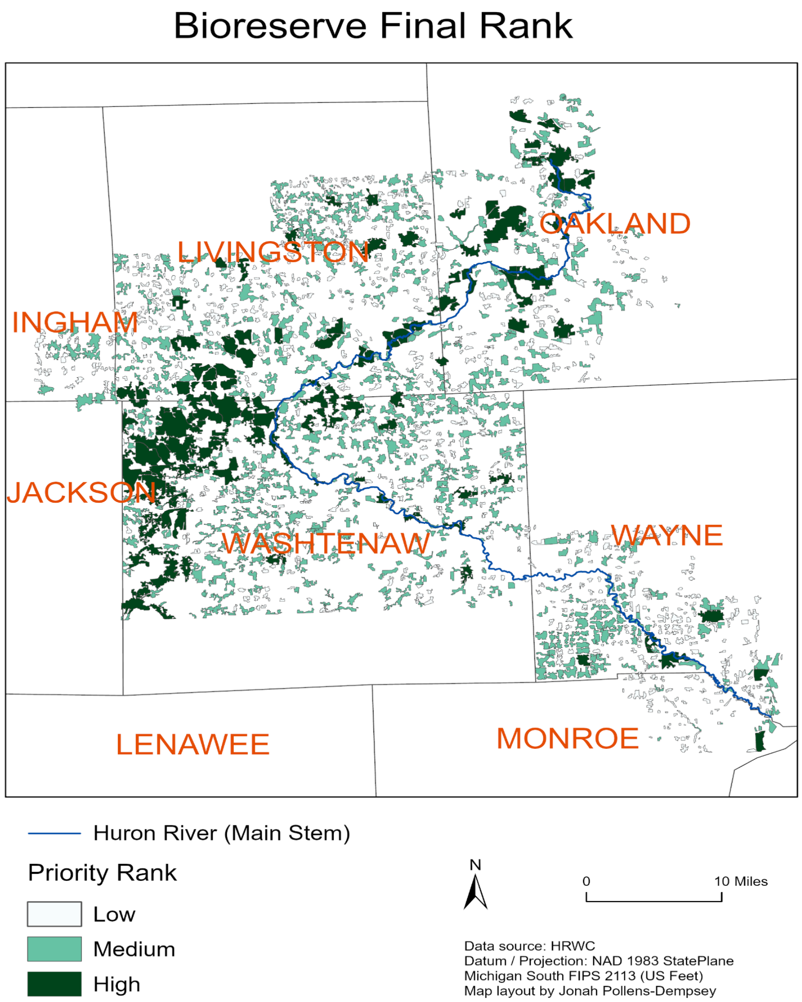

Figure 2.2- The Bioreserve Map is displayed according to its Final Rank, which is a weighted average of all 15 metrics that were included.

The bioreserves that are ranked as high priority are displayed in dark green, while the ones ranked as low priority are shown in white. The borders of the seven counties that have land within the Huron River watershed are displayed on the map. The county names are overlaid in orange.

The groups of low, medium, and high were defined by a natural breaks method, with three classes. The Jenks natural breaks method creates classes by applying an algorithm in which similar values are placed in the same group.

The figure shows that there is a large concentration of bioreserves that are ranked as high priority in southwestern portion of the map. In particular, the western part of Washtenaw County and the southwestern part of Livingston County have a number of high priority bioreserves. There are also many high priority bioreserves in the northern part of Oakland County. The areas with large numbers of high priority areas tend to correspond to areas that are rural, and where agriculture is a significant land use. These areas have less development and are set apart from cities.

High priority bioreserves are more scattered and distant from each other in Wayne County, as well as the remaining parts of Livingston County and Washtenaw County. Of these high priority bioreserves, many are near the main stem of the Huron River. This suggests that the areas that have the most impact on the watershed tend to be in close proximity to the river. Areas that are more developed and are nearer to cities tend to have fewer high priority bioreserves.

Figure 2.3 displays the bioreserve polygons according to four groups of rankings, which were defined in the Methods section of this chapter. The groupings are area, integrity, diversity, and groundwater. The groups consist of the 15 metrics in the Bioreserve Map, sorted according to the type of quality that they indicate.

The image in the top left of the figure shows area rank. Bioreserves are ranked as high priority if they consist of a large region. The image in the top right shows integrity rank. Bioreserves are ranked as high priority if they have high levels of connectedness or have little history of disturbance. The image in the bottom left shows diversity rank. Bioreserves are ranked as high

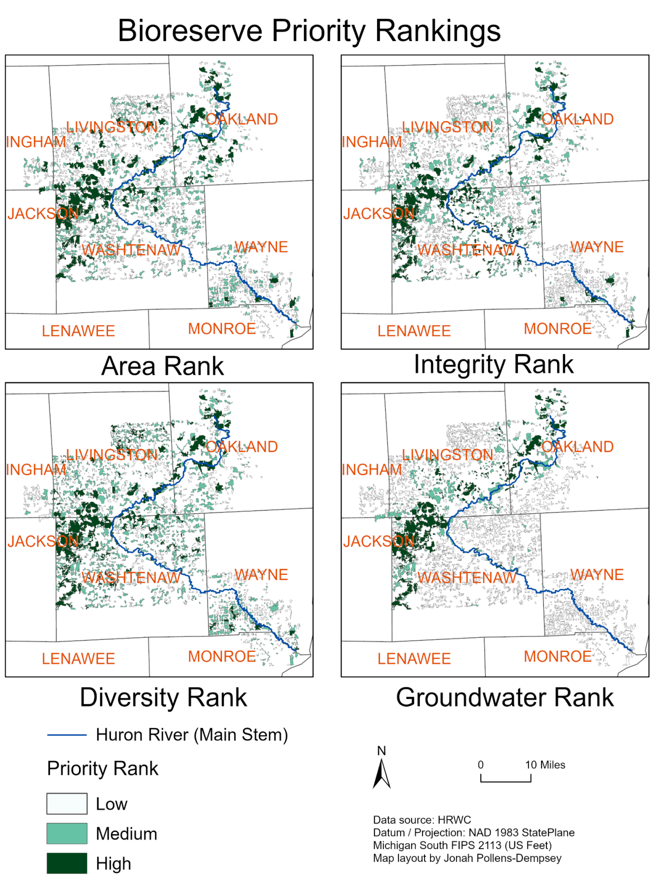

Figure 2.3: Bioreserves are displayed according to Priority Rankings, which use subsets of HRWC's Bioreserve Map metrics.

priority if they have the potential to support large amounts of biological diversity. The image in the bottom right shows groundwater rank. Bioreserves are ranked as high priority if they have high amounts of groundwater flow in soil.

The general trends are similar between the bioreserves for each of the four rankings. As in the Final Rank map, high priority bioreserves are concentrated in western Washtenaw County and southwest Livingston County, while a large number of high priority bioreserves are also located in Oakland County. For area rank and diversity rank, the high priority areas are more spread out between the counties, with a significant number spread throughout Washtenaw, Livingston, Oakland, and Wayne County. These rankings are more dependent on factors such as topography and landforms, which are factored into the diversity rank. These rankings may be less influenced by development and changes in land use. As a result, more high priority areas are present near cities.

Integrity rank has a cluster of small bioreserves that are high priority in the central part of northern Washtenaw County. This suggests that this region contains many bioreserves that are in close proximity to each other and have been protected from development. For groundwater rank, high priority areas are mostly in Livingston, Oakland, and western Washtenaw County, with few

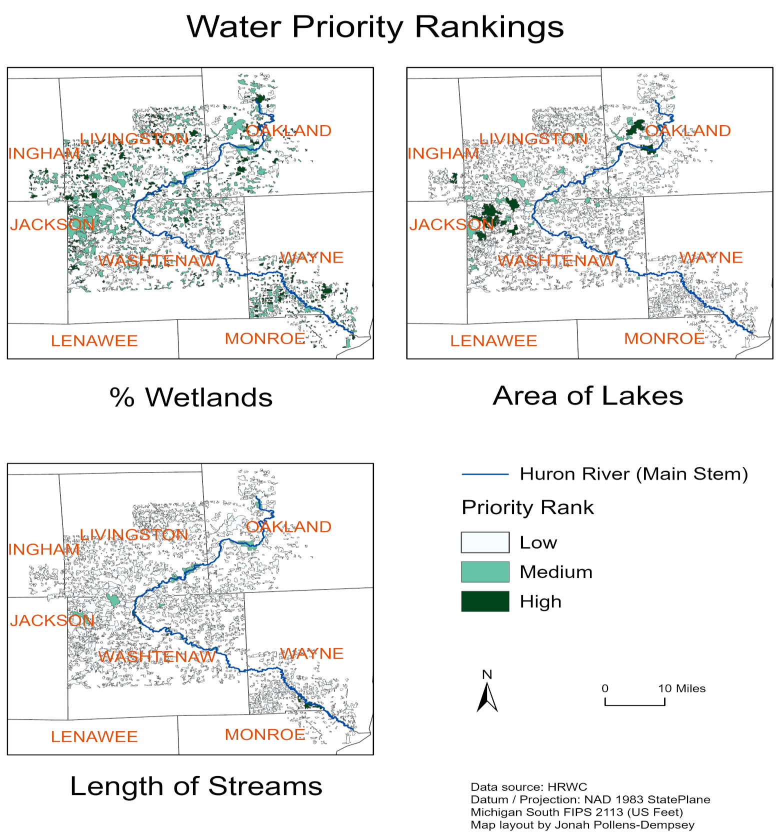

Figure 2.4 Bioreserves are displayed according to metrics for water and wetlands. These metrics were not included in the Bioreserve Map, but were added to fill a gap in data.

in other parts of the watershed. This ranking depends on elevation, because groundwater flows from higher areas to lower areas.

A metric was created for the percentage of wetlands in each bioreserve, as well as the area of lakes, and the length of streams. For the percent wetlands rank, high priority bioreserves are scattered throughout the watershed, with few areas where they occur in clusters. A large number of high priority bioreserves occur throughout Oakland and Livingston County. The presence of wetlands likely depends on the level of development in the area, where highly developed regions are less likely to have wetlands, although Wayne County has a number of small bioreserves that are high priority for this metric.

For the area of lakes metric, most of the high priority bioreserves occur in a cluster in northwest Washtenaw County and southwest Oakland County. Few high priority bioreserves occur in the remaining counties. For the length of streams metric, high priority bioreserves tend to occur along the main stem of the Huron River. These two metrics can add more precision to the Final Rank of the Bioreserve map by indicating where large amounts of water occur in natural areas in the watershed.

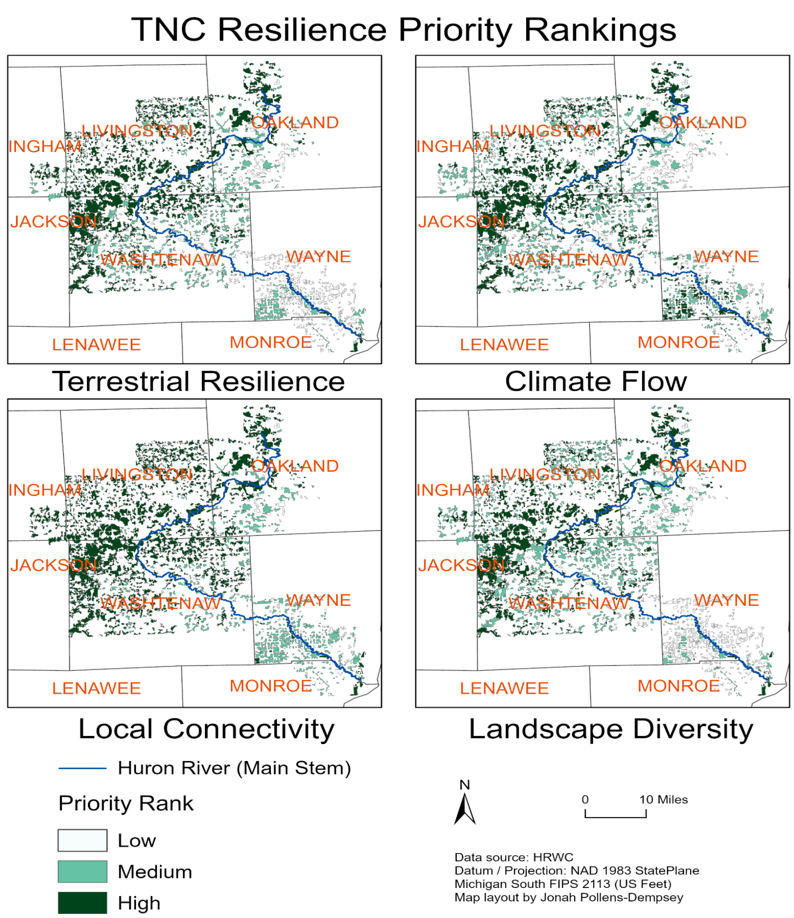

Figure 2.5: Bioreserves are displayed using data from The Nature Conservancy's resilience metrics.

Figure 2.5 shows the bioreserves displayed according to four of the TNC resilience metrics. The first metric is terrestrial resilience, which indicates an area's resilience in ecological terms of ecological function with the expected impacts of climate change. The second metric is climate flow, which indicates areas that allow for the movement of species due to climate change. The third metric is local connectivity, which indicates the ability of species to move given the presence of human-built structures. The fourth metric is landscape diversity, which indicates the number of microclimates in an area.

For each of the four metrics, a large number of high priority bioreserves are concentrated in northwest Washtenaw County and southwest Livingston County, as well as a smaller number in Oakland County. A large number of high priority bioreserves are also scattered throughout the remainder of Washtenaw and Livingston County. In Wayne County, many high priority bioreserves occur for the climate flow metric, but few occur for the other three metrics.

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Chapter 3: Tools for Effective Landowner Engagement

1. Background

As our master's team began discussing potential ways to support the Huron River Watershed Council in their Forests for Clean Water project, a guide on landowner outreach called Tools for Engaging Landowners Effectively (TELE) was suggested. This guide is helpful in accomplishing one of the main goals of the FCW project: conducting Natural Area Field Assessments for landowners with 10 or more acres of forest, wetland, or prairie property and identifying high-priority properties for management. In order to achieve this goal, HRWC must first establish relationships with the owners of these land parcels. Using TELE's eight-chapter workbook to guide the establishment of relationships, communication, and eventually working with high-priority landowners can help HRWC reach FCW objectives.

TELE methods can be utilized to engage with forest landowners whose land HRWC has not yet surveyed. HRWC offers free field assessments to landowners with 10+ acres of forest, prairie, or wetland in natural areas of the Huron River watershed as part of their Natural Area Assessment and Protection Project. This program offers landowners a no-cost opportunity to have HRWC evaluate their property's vegetative structure, plants, soil, and signs of anthropogenic disturbance (HRWC, 2023). When conducting field surveys and creating land care management suggestions for property owners, TELE methods can expand HRWC's understanding of what ecosystem services or values landowners want from their property (ex. ecological restoration, increased property value, erosion control, and increasing native species diversity). When landowners receive personalized information on how to protect their property's ecosystem, they are more likely to implement land use changes suggested by HRWC. Landowners may already be enticed to participate with HRWC in their land surveys because they are free, and they do not necessarily have to be present while the survey is taking place (HRWC, 2023). Using TELE methods, HRWC can increase the chances of landowners working with them to improve the quality of their property for the greater benefit of the entire Huron River watershed.

When creating conservation programs for privately owned forests and wetlands, stewards must be met where they are in terms of their current land management regimens. Significant participation and results from such programs are only seen when the project is interesting, engaging, and personally meaningful to stewards. By engaging with private forest and wetland owners, practitioners such as HRWC can gauge what landowners value and what programs work to improve the ecosystem services provided by private land. The vast majority of private land managers care about their land and want to take good care of it (Andrejczyk et al., 2015, p. 52). However, stewards may not fully comprehend, or may underestimate the effect that their land management methods have on the environment, particularly relating to water quality. Using a landowner outreach guide like TELE will help HRWC fill in gaps between private landowners, land management practices, and water quality in the Huron River watershed.

2. Introduction to Tools for Engaging Landowners Effectively

Tools for Engaging Landowners Effectively (TELE) is a workbook developed by the Yale School of Forestry and Environmental Studies (TELE, 2015). Structured around marketing tactics and social science research, TELE is meant to help organizations work with landowners to create outreach programs that fit into their values and needs. Families and individuals are in ownership of 36% of forestland in the United States (Butler et al., 2016, p. 638). Because such a significant percentage of forest land is privately maintained, creating outreach programs that suit landowners is important.

There is a gap in landowners receiving land management advice; 66% of landowners are not engaged in traditional forest management programs with professional forest management organizations (Butler et al., 2016, p. 638). Without this information, landowners may not be informed or empowered to make environmentally beneficial decisions with their property. Research has shown that landowners generally want to be good stewards of their properties (Chawla et al., 2008, p. 4). TELE suggests that using action-oriented stewardship decisions and working within landowners own goals and desired outcomes yield the most meaningful results.

Traditional landowner outreach involves only education, which gives people the tools for good land management, but does not necessarily motivate them to act. TELE suggests marketing stewardship to these individuals because it incites motivation and is persuasive. The marketers, in this case HRWC, provide the knowledge, tools, and support to the landowners. TELE authors suggest that those conducting outreach activities seek to learn from forest landowners in order to best engage with them, rather than the other way around.

a. Setting goals and objectives

TELE advises setting clear project objectives through defining what needs to happen to the target landscape (the landowner's property), and taking into account the organization's mission, expertise, and available funding. This includes creating project parameters informed by the best use and management of forested lands. It is essential to consider what HRWC can provide for landowners and what constraints exist. Important guiding questions include: What is the budget? How much staffing can be provided? How many volunteers? For HRWC, what does FCW project want to accomplish? This list of items should be applied to new landowner outreach and field assessments.

Different landowner segments will be interested in participating in different programs or land use change interventions. For some, reducing their use of pesticides and decreasing invasive plants may be the only feasible project for them. Other landowners may be willing to enact larger scale changes to their land, such as creating riparian buffers or changing their landscape to increase native species diversity. TELE suggests using a "Ladder of Engagement" to systematically define what HRWC needs from landowners and how best to engage them to do those actions. This "ladder" works at varying levels of stewardship involvement and outlines progressing through stewardship plans by ascending rungs of the ladder, including surveying the land, looking at management options, creating plans, assessing resource availability, implementing the activity, and monitoring the plan during and after execution (Chawla et al., 2008, p. 12). This allows landowners and HRWC to get to know each other's needs better, and determine which plan will be most likely to be successfully used.

During the field assessment process, HRWC representatives must gauge how familiar the managers are with their property and its ecosystem and ask what they hope to see done with their property. This tailored engagement allows HRWC to offer support and resources where that individual's property needs it, rather than a broad brush of resources that may not be useful to them. It is also important to be upfront with landowners with what HRWC can and cannot provide in terms of financial and logistical support.

b. Working with Partners

TELE suggests that when looking for potential partners, organizations should think about who they want to work with and why. They should consider their current relationships (ex. landowners who have already had field assessments conducted on their properties), as well as the contacts that those landowners have (Chawla et al., 2008, p. 24). In the FCW project, HRWC already has a good idea of who they want to work with: private forest or wetland owners within the Huron River watershed. While HRWC has a good general idea of who they want to work with, there are specific recommendations for making new contacts suggested by TELE.

One way to create new landowner relationships is through special events or organizational outreach programs. To initiate contact with unsurveyed landowners, an example of a new outreach program could be described in a letter addressed to landowners whose land HRWC would like to assess. This letter should include why HRWC conducts private property assessments and the potential benefits to the landowner of working with HRWC. The level of collaboration between HRWC and potential landowners should be described on a continuum (Chawla et al., 2008, p. 19) of engagement which makes it clear that the landowner can choose their level of involvement.

TELE describes three levels of professional organization contacts: field-level, executive-level, and mid-level. Field-level contacts work directly with landowners most often and can incorporate programs into their daily work. One downside of field-level individuals is that they have little decision making power. Executive-level individuals have the most decision-making power, and are more concerned with larger, organization-wide goals. The downside to landowners working with executive level contacts is that landowners are not as directly involved with the executive level contacts, and these contacts may be stretched between many different projects. Mid-level partners have some decision making power and understand more of the field-level individuals' work. While they hold some authority, there are often times when decisions are too high level for mid-level partners. Mid-level partners may need more time for decision-making because they have to check with higher-ups in their organization (Chawla et al., 2008, p. 21). HRWC must carefully consider who best represents their organization to potential private landowner partners when conducting property assessments and potentially further working with landowners to ecologically improve their land.

	LESS COLLABORATION ••••••••••••••••	••••••••••••••►	MORE COLLABORATION
	Working Alone (with ad hoc support from other organizations)	**Working Together to Implement a Project**	**Forming a Partnership to Address a Complex Issue**
Nature of the Problem	Suited to address problems that are focused and well defined, and the lead organization has the skills and capacity to deliver meaningful results.	Works when problems are focused and well defined but partner skills and resources, or cross-jurisdictional efforts, are needed. Partners must coordinate actions to deliver meaningful results.	Needed when the issue is not well defined or is a set of interrelated cross-jurisdictional problems. Many partners must take complementary actions to deliver meaningful results.
Project Objectives	The project objective is set by the lead organization and it addresses their mission.	The project objective is set by the lead organization but aligns with participating organizations' missions.	The partnership's objectives are determined jointly to address a landscape-level need.
Partners' Obligations	The lead organization requests specific help as needed, and partners provide help as they are willing and able.	Partners commit to making some contribution to the project. These contributions usually involve altering their existing activities to increase impact through coordination.	Partners commit to the objectives established by the partnership and adjust their work to meet them.
Measuring Results	The lead organization tracks results as needed for organizational or grant requirements.	Each organization tracks their own results as needed for organizational or grant requirements. Partners share tracking or summary data with each other as they are able.	The partnership tracks all actions across organizations to assess overall progress and the interactions of different activities. Results are shared with partners to direct future work.
Potential Impact	The impact of the project is limited by the lead organization's jurisdiction and resources.	The impact of the project is limited by the jurisdiction and resources of partnering organizations, with possible efficiencies from coordinated actions.	Efforts by partner organizations interact with and feed into each other, leading to impacts that would not otherwise be possible.
Example	The lead organization supports oak regeneration through landowner workshops and tree giveaways. They make requests to partners to present at events and to use their offices as distribution locations for tree giveaways.	Partners support oak regeneration through cross-boundary management actions that are coordinated to create a larger area of contiguous management. They also coordinate their landowner outreach to focus on this region.	The partnership supports the stabilization of oak habitat by changing how forests are managed in the region across all ownership types. They work to engage all relevant audiences, including landowners, loggers and policymakers, to reach their objectives.

Figure 3.1. TELE collaboration models on a continuum (Chawla et al., 2008, p. 20)

c. Understanding your audience

When marketing landowner outreach programs, TELE suggests focusing on who the landowner audience is and what interventions they are interested in (Chawla et al., 2008, p. 28). Private landowners use their property for a wide range of activities, including economic development, food production or other agriculture, ecological conservation, education, recreation, and personal use. These activities are directly tied to what kinds of programs landowners should be marketed. For example, if someone uses their property to grow corn commercially, they probably are not going to be interested in programs designed to encourage landowners to create a conservation easement on their property, as a conservation easement would impede their livelihood. If messages are tailored by specific land use demographics, marketing programs are more effective.

Understanding the target audience also involves choosing the correct language when advertising programs. TELE states that wording messages based on the landowners knowledge and interest in their land will ultimately draw more attention to your programming. Though it may not seem very inclusive to implement marketing that potentially only interests certain landowners, TELE argues that targeted language is necessary for engaging the correct audience for the program. If marketing is too general, landowners may be uninterested in or unsure of what the program entails as the information is too vague (Chawla et al., 2008, p. 29).

TELE's six points for engaging a targeting audience include: (1) geography, (2) orientation to their land, (3) ability to enhance your conservation goals, (4) likelihood of taking action, (5) previous activities, and (6) ability to act. Geography refers to choosing the physical location of the targeted landowner segment. Orientation to their land refers to how landowners use their land and how it benefits them. Ability to enhance conservation goals refers to choosing a landowner segment whose land use actions or changes will have the greatest impact on project goals. Likelihood of taking action refers to choosing a targeted landowner segment that is most likely to help achieve project goals. It is best to choose landowners who are most personally affected and most likely to act based on the issue at hand. Previous activities refers to gauging the level of known past stewardship participation, and targeting them based on previous activities. Finally, ability to act refers to knowing and understanding the capabilities, limitations, and strengths of the landowner segment (Chawla et al., 2008, p. 30). These six points for engaging a target audience will help narrow down what landowner segment is the best fit for a conservation project.

	Woodland Retreat Owners	Working the Land	Supplemental Income	Uninvolved
Orientation to Woodland	Own woodland primarily for its beauty, and conservation and recreational value Many love nature and animals and appreciate ecological benefits of woods	Tend to be pragmatic; value aesthetic and recreational benefits of woodland but also see woods as a financial asset	Tend to own land primarily for timber income and investment	Tend not to care about woods; assign low importance to their financial, recreational, and aesthetic benefits More likely than the other segments to be willing to sell their land and less likely to want to see it stay woodland
Want Information About	Land improvement (trails, ponds, streams, etc.) Keeping the woods healthy, beautiful, and good for wildlife How to find reliable loggers and other service providers Financial assistance for improving or maintaining their land	Timber market trends and rates How to choose reliable loggers and other service providers Protecting woods from natural and human threats Entrepreneurial activities, such as cultivating non-timber forest products to garner extra income How to improve wildlife habitat Financial assistance for improving or maintaining their land	Timber markets Government programs, especially tax incentives and cost-share programs How to protect their legacy; estate transfer issues How to maintain the long-term health and value of the land Emerging threats and invasive species	Ways to minimize land maintenance and management costs Estate planning and land transfer

Figure 3.2. Comparing TELE landowner segment types (Chawla et al., 2008, p. 31)

d. Designing messages

To design and create effective messages that reach target audiences, TELE recommends emphasizing the core content. The three main components of the core content are call to action, main reason to act, and attention getter. To gain audience attention, messages have to be clear, yet eye catching. TELE suggests surprising statistics, alluring visuals, or endorsements from prominent figures. The wording of messages has to convey emotion, and entice readers to respond and interact with what you are advertising. To not overwhelm the audience with too much information, only two or three main points should be used to emphasize the message. A "Because Statement" may be used to describe why landowners should care about the problem, and why obstacles to overcoming these problems are worth overcoming. This statement should invoke a call to action and give landowners a reason to participate in the program (Chawla et al., 2008, p. 40).

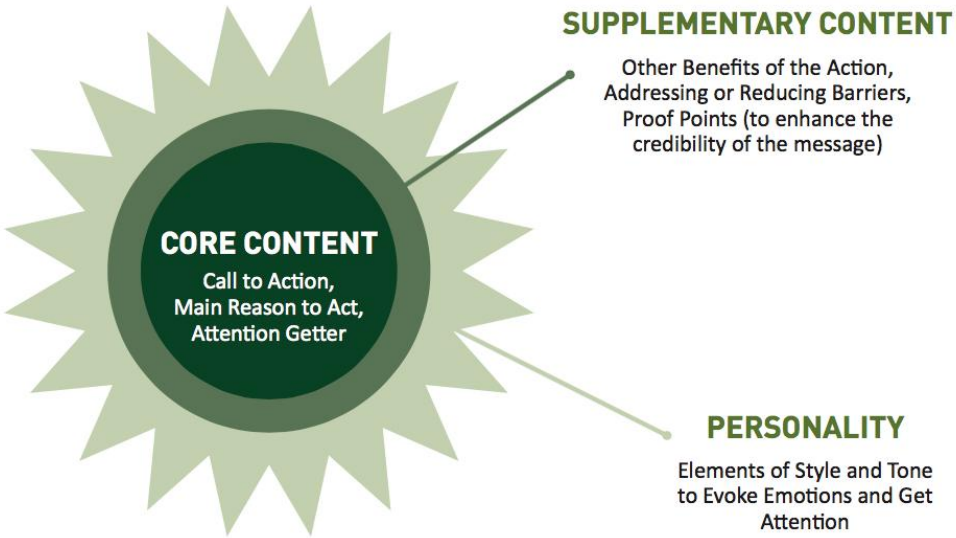


Figure 3.3. TELE's main components of an effective message to landowners (Chawla et al., 2008, p. 40)

Communicating specific problems, programs, or educational opportunities should be personalized for the target audience segment. The messages themselves should have personality so that readers consider and remember the main points. The main points must evoke emotion, whether it is happiness, fear, humor, or sadness; highlighting points that compel your audience to feel something about your advertisement incites action. Visuals and language should be carefully used to evoke the emotion organizers are trying to convey (Chawla et al., 2008, p. 42).

e. Developing materials

The design and visual layout of marketing materials are nearly as important as the messages themselves. To grab audience attention before they even comprehend what is being communicated to them, TELE recommends that materials should be (1) focused, (2) understandable, and (3) relatable (Chawla et al., 2008, p. 45). Focused messages are concise (ex. bullet points or graphs), avoid lengthy text, and do not contain unnecessary information. The communication medium has to be considered when formulating messages. For example, mailings and advertisements should be shorter than emails because they tend to be scanned over more quickly. Understandable messages use simple language that is personalized to the target audience and goal without being too complicated. Technical language used mostly by those in natural resource management should be avoided as it is not always colloquial. Complex words or phrases may come off as condescending, which would turn the audience off from engaging with the message. Good advertisements will evoke memories, emotions, and experiences that the audience have in regard to their audience segment category (Chawla et al., 2008, p. 47).

The physical layout and visuals included in outreach messages has to be intentional. Choosing clear photos that evoke emotions or memories in the audience elicit more responses. These can be images from other programs put on by the organization, or simply stock photos from the internet. Clear pictures that have peoples' faces tend to be attention grabbing (Chawla et al., 2008, p. 48). Designing the graphics and layout of messages and advertisements is important, so TELE recommends using computer tools such as Canva, Google Suite, or Adobe. An organizational style guide is a good way to ensure consistency and organization in designing advertisements (Chawla et al., 2008, p. 51). Testing the effectiveness of messages with a focus group (ideally 8-12 people) is beneficial for extra assurance that your communication is effective, though it may not always be temporally or financially feasible (Chawla et al., 2008, p. 54).

f. Getting the word out

It is unlikely that a single message, advertisement, or communication to landowners will be enough to incite action related to the organization's project. According to TELE, 4-6 interactions (touches) are needed on average to motivate a response. Touches should be made to the audience multiple times within a relatively short period so landowners are able to process and gain interest in the messages being conveyed without forgetting (Chawla et al., 2008, p. 57).

The medium used to deliver messages to the target audience is important. Different mediums will reach different audiences. For example, emailing those without computers or internet access is ineffective. The space needed for graphics and text should be considered, as different communication methods have different space limitations. The reach of the message is pertinent to choosing a medium. If messages are highly personalized to a small audience segment, phone calls or letters may be most effective. If the message is more general and meant for a wider audience, media advertisements, mass emails, or mailings may be most effective. Message designers should also keep in mind that landowners are more likely to interact with programs if they are familiar with the organization hosting them (Chawla et al., 2008, p. 59). Finally, the timing of messages should be considered. If it is a particularly busy time of year, or a time when people are spending a lot of money (ex. the holiday season), landowners likely have social obligations or budgetary constraints. Messages inciting participation or an action that costs money should not be sent during these times. If messages are inciting landowners to do some sort of work on their land, warmer months are better to send a message.

g. Evaluation and learning

Before, during, and after outreach programs, organizations should evaluate and add to the knowledge they have gained from the work they are doing with landowners; what is and is not working? Clearly defined goals for an outreach program not only helps landowners, but the program organizers as well Because resources are limited, it is important to define metrics of success by asking the following questions: What avenues of communication worked best? Who was most receptive to the message? Who acted (Chawla et al., 2008, p. 73)?

Both qualitative and quantitative metrics of project success are crucial to evaluation. The number of participants, landowner demographics, effects on natural resources, reaching land management or environmental quality goals, and the timing of action will all help gauge the effectiveness of outreach programs. This evaluation can be done digitally or through personal follow-up with landowners like surveying, phone calls, emailing, or using focus groups (Chawla et al., 2008, p. 74). This can be done by individuals within the organization, or as an organizational whole (Chawla et al., 2008, p. 76). The information gathered through evaluation informs future projects and organizational decisions and thus helps more efficiently direct resources (Chawla et al., 2008, p. 77). Knowledge gained from landowners as well as the organization in the project creates a culture of learning, which helps evolve and accomplish goals (Chawla et al., 2008, p. 79).

3. Public Survey

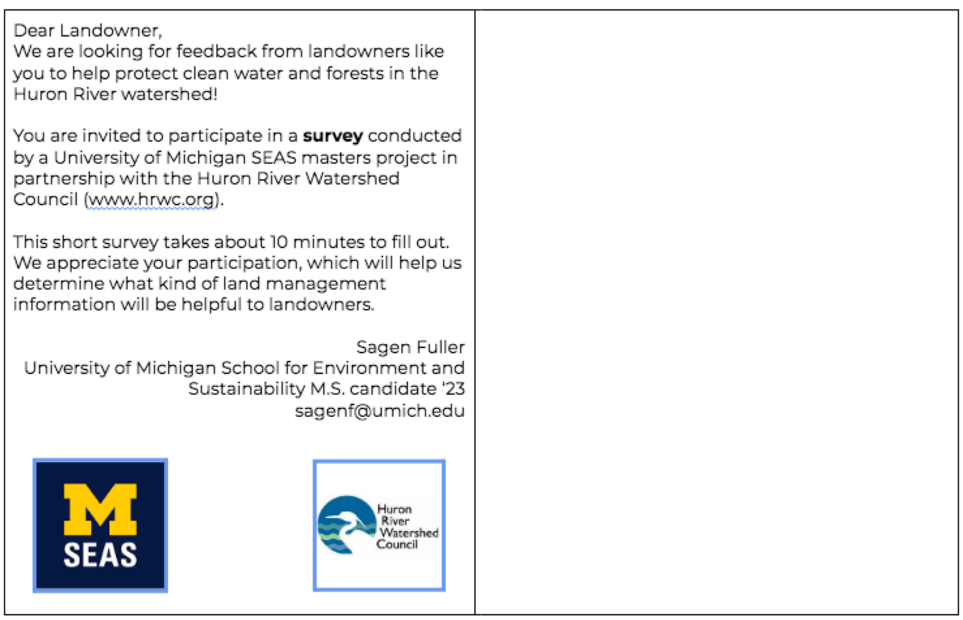
a. Method

To assess landowner demographics, land management methods, attitudes toward land stewardship, and personal willingness to utilize their land as a means to preserve the Huron River watershed, a survey was sent out to landowners in the Huron River watershed by this University of Michigan SEAS masters project team. Those managing over 10 acres of property in HRWC's Bioreserve area were the target audience. Landowners were given the option to receive additional information and support from HRWC if they are interested in creating a conservation easement on their land. The questions sent out to landowners are listed in Section 4 of this chapter.

The survey was built using Qualtrics, an online survey tool, where responses were also stored. Fourteen total questions were included in the questionnaire. The questionnaire featured a mix of qualitative and quantitative questions. No questions were required to be answered by respondents, thus not all response numbers per question are equal in the results. The solicitation to participate in the survey was sent via three postcard mailings. The postcard includes an introduction to the Forests for Clean Water project, why the survey is being conducted, and how to take the survey. Landowners were able to either scan a QR code on their phone or enter a url on any device with internet access to lead to the survey. Each mailing was sent approximately one week apart from the last. The first mailing was sent on January 22nd, 2023, the second on January 29th, 2023, and the third on February 7, 2023.

500 total landowners were solicited for this survey. Each landowner's address was mailed three times on the dates listed above. HRWC provided an ArcGIS Pro data layer containing the names and address information of 913 landowners or managers who oversee land over 10 acres in their Bioreserve area. These properties have not previously been evaluated or assessed by HRWC. The addresses included Oakland, Livingston, Washtenaw, and Wayne counties, though 82% were located in Livingston and Washtenaw county. The dataset was narrowed down to 500 landowners based on the budget of the survey. The original dataset sent from HRWC was culled for repeat addresses, publicly owned lands, addresses associated with LLC's or other businesses, and those belonging to government agencies. The demographic sampled were private landowners. In total, 72 of the 500 (14.4%) of landowners solicited to participate in this survey responded to the online questionnaire. This response rate is quite close to HRWC's marketing executive's prediction of a 15% response rate based on the solicitation method of postcard mailings.

The TELE workbook was used to guide the creation of the questions included in this survey. The survey sought to gauge landowner personal values, knowledge of their property, and how they use their property. These aspects of land ownership help determine what kind of programs landowners in the Huron River watershed are interested in, how they should be marketed to, and what will encourage HRWC program participation from this audience segment.

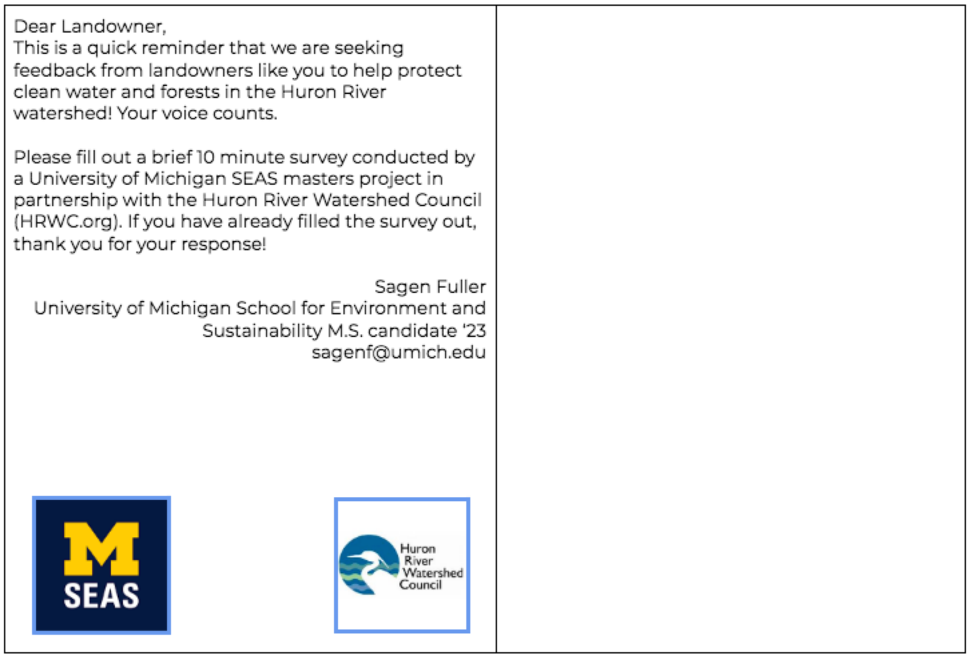

Dear Landowner,
We are looking for feedback from landowners like you to help protect clean water and forests in the Huron River watershed!

You are invited to participate in a **survey** conducted by a University of Michigan SEAS masters project in partnership with the Huron River Watershed Council (www.hrwc.org).

This short survey takes about 10 minutes to fill out. We appreciate your participation, which will help us determine what kind of land management information will be helpful to landowners.

Sagen Fuller
University of Michigan School for Environment and Sustainability M.S. candidate '23
sagenf@umich.edu

Figure 3.4 Image of the front side of the first postcard that was mailed to landowners for this survey.

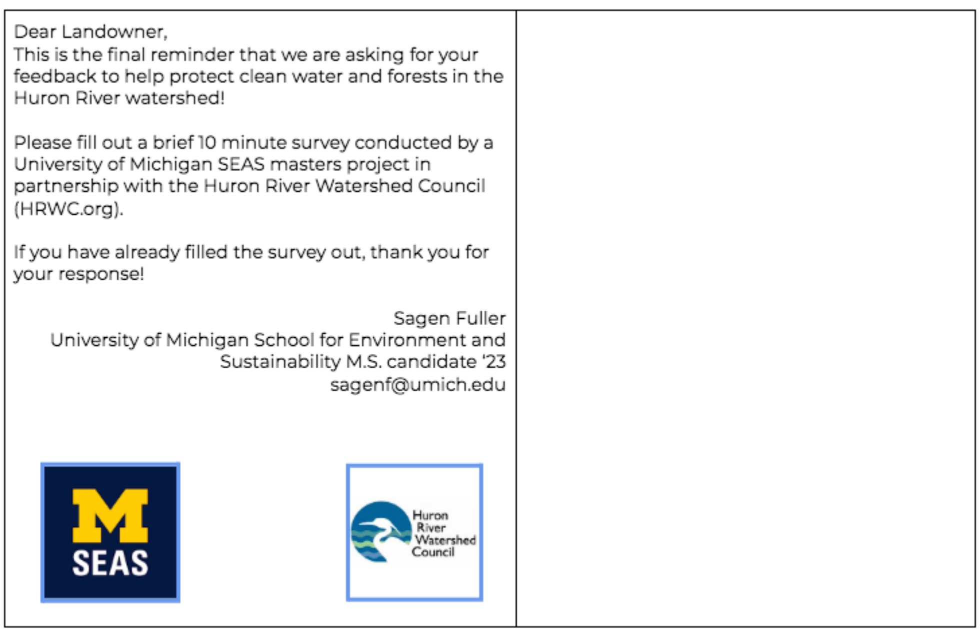


Dear Landowner,
This is a quick reminder that we are seeking feedback from landowners like you to help protect clean water and forests in the Huron River watershed! Your voice counts.

Please fill out a brief 10 minute survey conducted by a University of Michigan SEAS masters project in partnership with the Huron River Watershed Council (HRWC.org). If you have already filled the survey out, thank you for your response!

Sagen Fuller
University of Michigan School for Environment and Sustainability M.S. candidate '23
sagenf@umich.edu

Figure 3.5 Image of the front side of the second postcard that was mailed to landowners for this survey.



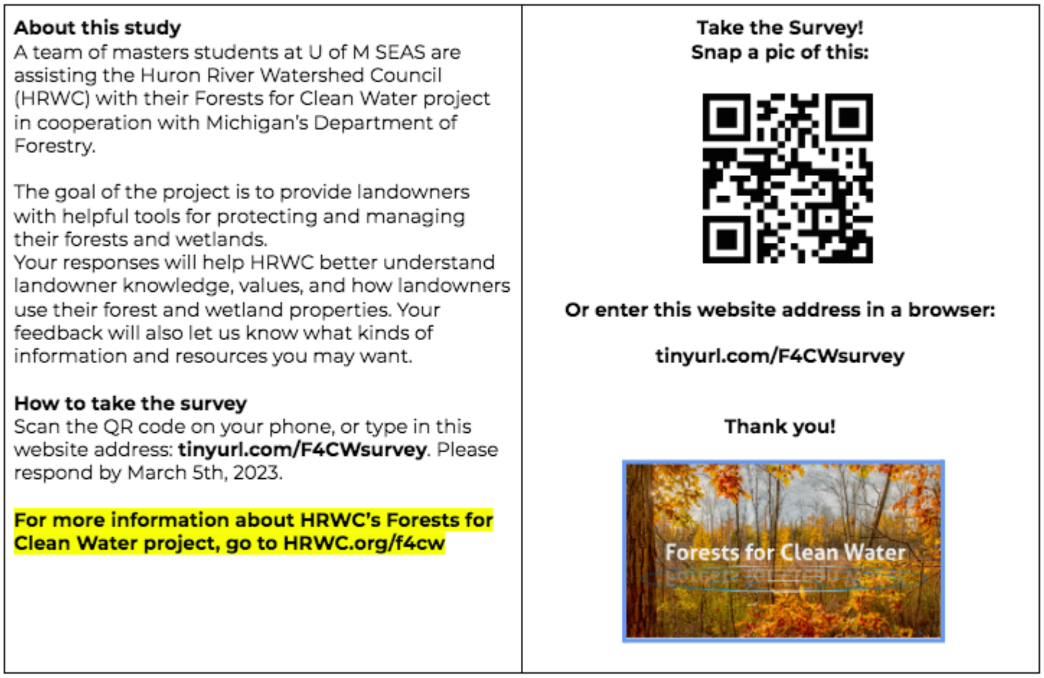
Dear Landowner,
This is the final reminder that we are asking for your feedback to help protect clean water and forests in the Huron River watershed!

Please fill out a brief 10 minute survey conducted by a University of Michigan SEAS masters project in partnership with the Huron River Watershed Council (HRWC.org).

If you have already filled the survey out, thank you for your response!

Sagen Fuller
University of Michigan School for Environment and Sustainability M.S. candidate '23
sagenf@umich.edu

Figure 3.6 Image of the front side of the third postcard that was mailed to landowners for this survey.



About this study
A team of masters students at U of M SEAS are assisting the Huron River Watershed Council (HRWC) with their Forests for Clean Water project in cooperation with Michigan's Department of Forestry.

The goal of the project is to provide landowners with helpful tools for protecting and managing their forests and wetlands.
Your responses will help HRWC better understand landowner knowledge, values, and how landowners use their forest and wetland properties. Your feedback will also let us know what kinds of information and resources you may want.

How to take the survey
Scan the QR code on your phone, or type in this website address: **tinyurl.com/F4CWsurvey**. Please respond by March 5th, 2023.

For more information about HRWC's Forests for Clean Water project, go to HRWC.org/f4cw

Take the Survey!
Snap a pic of this:

Or enter this website address in a browser:

tinyurl.com/F4CWsurvey

Thank you!

Forests for Clean Water

Figure 3.7 Image of the back side of all three postcards that were mailed to landowners for this survey.

b. Results

The results of the University of Michigan SEAS masters project landowner survey are listed below.

1. *How many acres of land do you own/manage?*

Table 3.1. Number of respondents who own or manage each category of land acreage.

Number of acres owned/managed	Number of responses	Response rate/ acreage category
10-25 acres	40	57.1%
25-50 acres	18	25.7%
50-75 acres	6	8.6%
75-100 acres	2	2.9%
100+ acres	4	5.7%
Total number of responses	**70**	

2. *How long have you owned/managed the land?*

Table 3.2. Number of respondents who have owned or managed land for each category of years.

Number of years owned/managed	Number of responses	Response rate/year category
1-5 years	5	7.1%
5-10 years	6	8.6%
10-25 years	20	28.6%
25-50 years	34	48.6%
50+ years	5	7.1%
Total number of responses	**70**	

3. *Please list the ways you manage your property's vegetation (ex. mowing, clearcutting, weeding, herbicide and fertilizer application, logging, planting). Select all that apply.*

Table 3.3. The number of respondents who reported utilizing each vegetation management method. Respondents were able to select more than one answer.

Vegetation management method	Number of responses	Response rate/vegetation management method
Mowing	43	66.1%
Clearcutting	9	13.8%
Invasive species management	35	53.8%
Herbicide and fertilizer application	12	18.5%
Logging	13	20%
Planting	30	46.1%
Controlled burning	11	16.9%
Other	18	27.7%
Total number of responses	65	

4. *If you answered 'other' to the previous question, please elaborate.*

Table 3.4. Additional vegetation management methods employed by respondents not listed in the original land management method categories.

Additional reported vegetation and land management methods
Firewood harvesting
Forest management, e.g. pruning, thinning, species selection
Planted plots for wildlife
Allow it to grow naturally
Weed wack shrubs near the house
Managed hunting activities. Manage orchard and vineyard. This is a registered organic farm and has practiced organic farming since inception beginning in the 1800's.
Small organic vegetable garden
I don't use herbicide/pesticide/fertilizer to keep it out of the wetland
Removing dead wood and composting.
Goat grazing
Selective harvesting
Cut walking trails
We pick up fallen limbs and trees and have maintained walking paths.
Nothing
Nothing
Rotationally graze grassy wetland during drought
Leave as natural space
Select clearing of dead trees for firewood
In the past, sustainable select cuts for woodlot management and firewood. Pheasants Forever seeding...Hand sowing native plants.

5. *On a scale of 1-10, how do you rate your knowledge of your property's ecosystems (ex. plants, animals, insects, soils, hydrology)*

Table 3.5 Respondents rating knowledge of their property per knowledge level category (1 being least knowledgeable, 10 being most knowledgeable).

Knowledge level	Number of responses	Response rate/knowledge level
1	3	4.3%
2	5	7.2%
3	3	4.3%
4	6	8.7%
5	15	21.7%
6	8	11.6%
7	11	15.9%
8	12	17.4%
9	3	4.3%
10	3	4.3%
Total number of responses	**69**	

6. *Are you interested in having areas of your land restored/managed in a way that protects its ecosystem?*

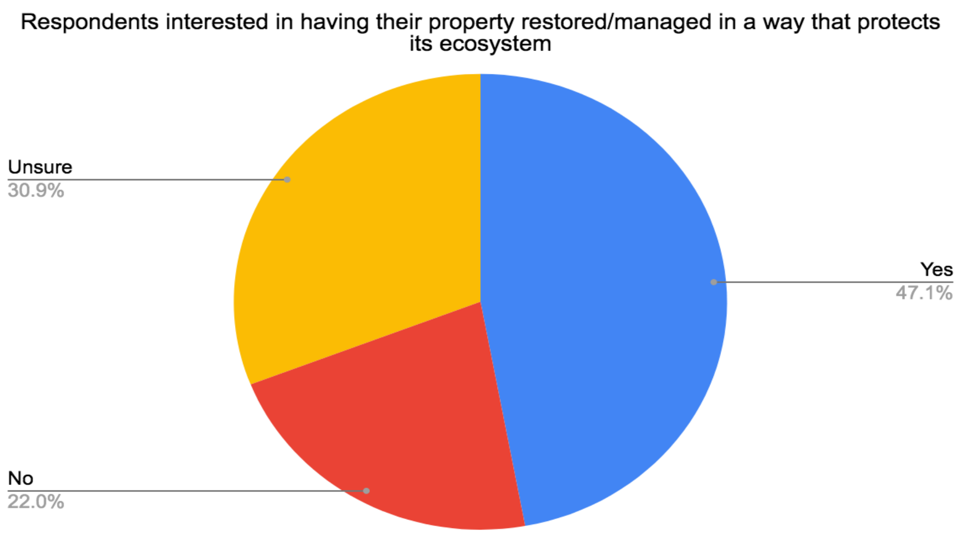


Figure 3.8. Distribution of the number of respondents who are interested, uninterested, or unsure of their interest in having areas of their land restored in a way that protects its ecosystem.

7. *If you answered yes to the previous question, what support, if any, would you need to restore/manage your land?*

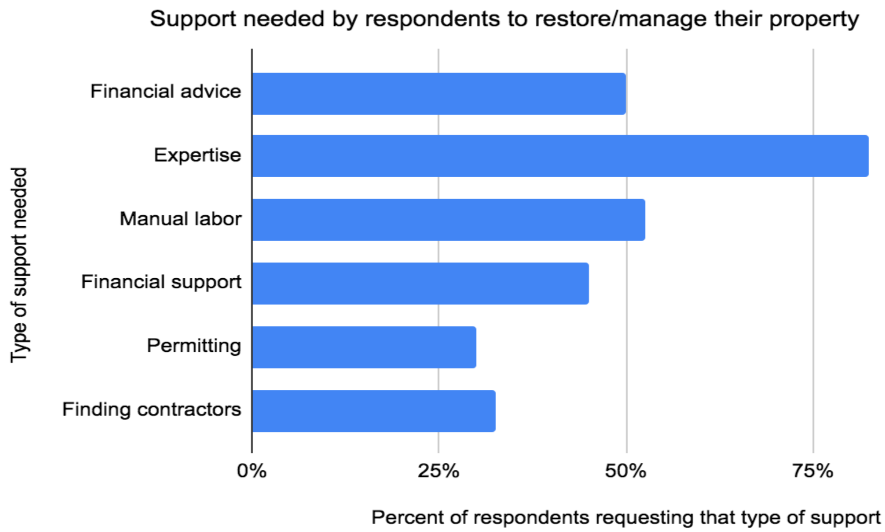


Figure 3.9. Distribution of the types of support needed by respondents who are interested in having areas of their land restored in a way that protects its ecosystem. Respondents were able to select more than one answer.

8. *Do you believe the ways you manage your forest and/or wetland property significantly affects the quality of the watershed?*

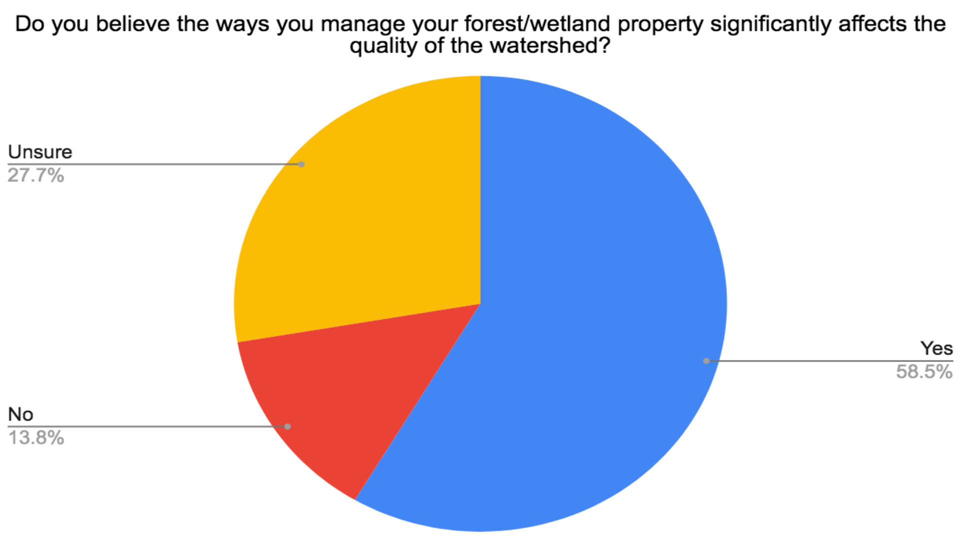


Figure 3.10. Distribution of the number of respondents who believe, do not believe, or are unsure of whether the ways they manage their property significantly affects the quality of the Huron River watershed.

9. Do you feel you have sufficient time to invest in managing your land in ways that protect and improve water quality in the Huron River watershed?

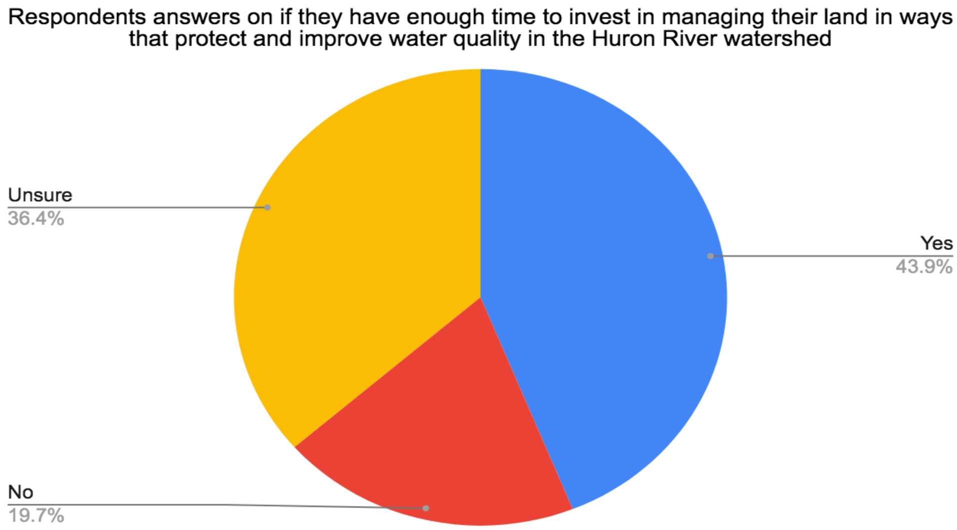


Figure 3.11. Distribution of the number of respondents who believe they do, do not, or are unsure of whether they have sufficient time to invest in managing their land in ways to protect and improve the Huron River watershed.

10. How much money would you be willing to spend annually on land stewardship activities that help protect and improve water quality in the Huron River watershed?

Table 3.6. The number of respondents willing to spend each category of money annually on land stewardship activities that help protect and improve water quality in the Huron River watershed.

Amount of money willing to be spent on land stewardship activities	**Number of responses**	**Response rate/answer**
Less than $1,000	34	64.1%
$1,000-$2,500	15	28.3%
$2,500-$5,000	1	1.9%
$5,000-$10,000	2	3.8%
More than $10,000	1	1.9%
Total number of responses	53	

11. In your opinion, please rank the following ecosystem services provided by the Huron River watershed from least to greatest importance (1 being most important, 5 being least important).

a. Recreational activities such as fishing, kayaking, hiking, and swimming

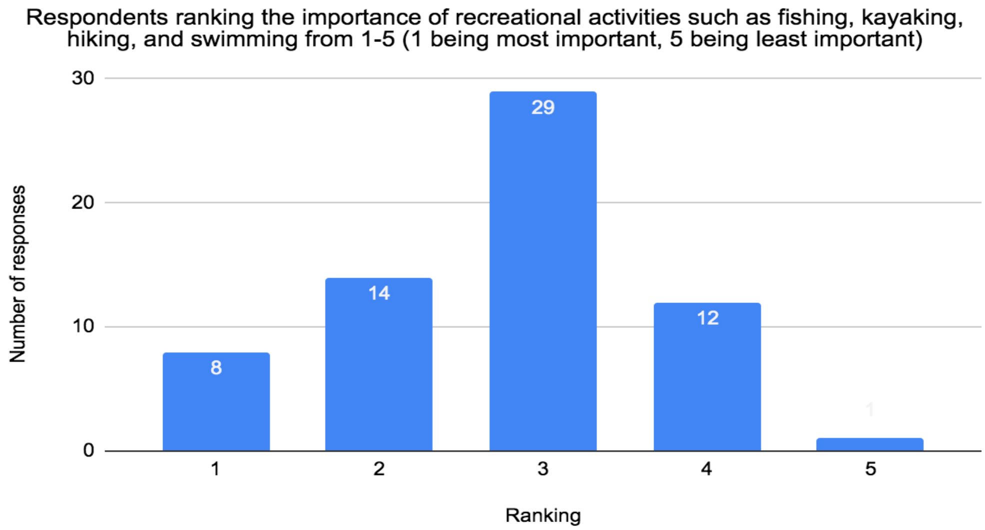


Figure 3.12. The distribution of the number of respondents ranking the importance of recreational activities from 1-5 (1 being most important, 5 being least important) provided by the Huron River watershed.

b. Clean drinking water

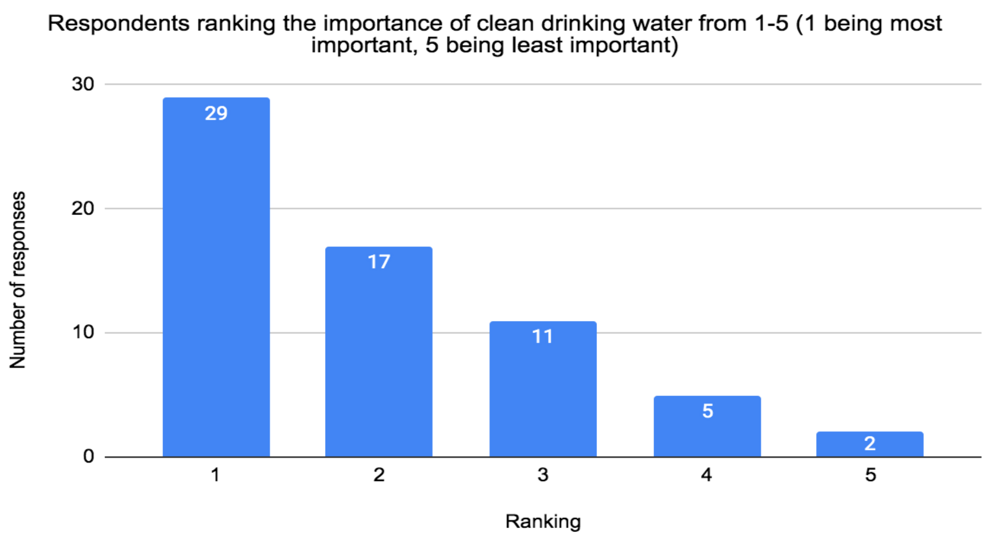


Figure 3.13. The distribution of the number of respondents ranking the importance of clean drinking water from 1-5 (1 being most important, 5 being least important) provided by the Huron River watershed.

c. Employment opportunities

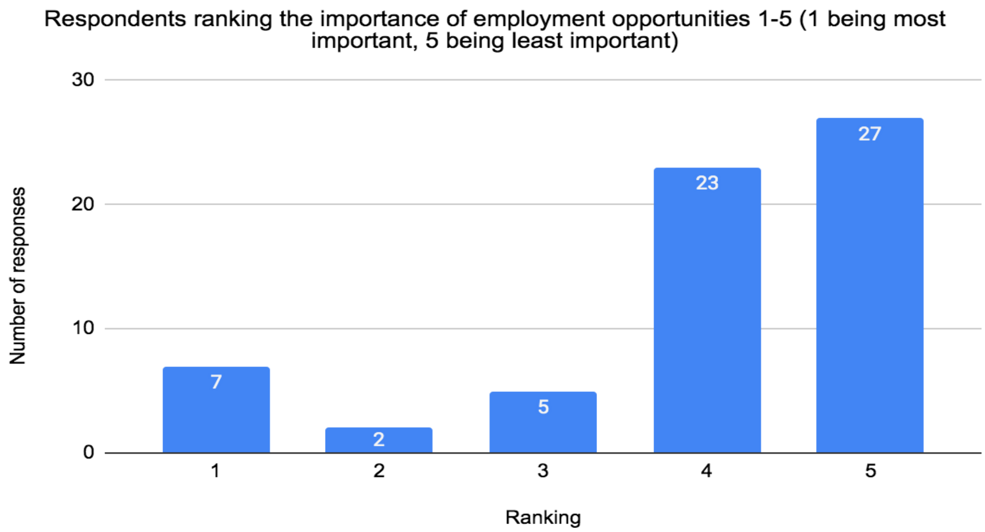


Figure 3.14. The distribution of the number of respondents ranking the importance of employment opportunities from 1-5 (1 being most important, 5 being least important) provided by the Huron River watershed.

d. Production of resources such as timber and agricultural goods

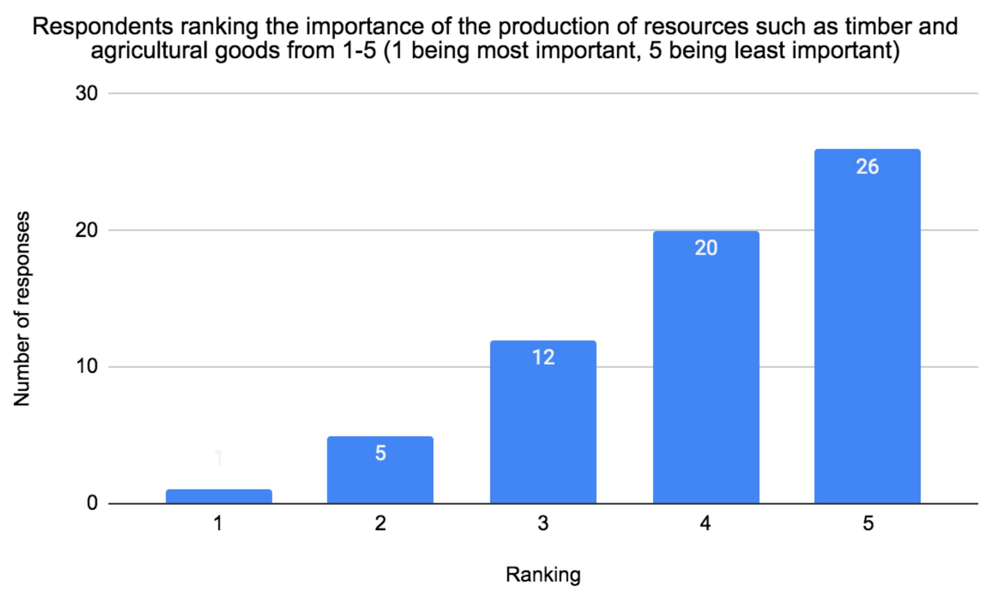


Figure 3.15. The distribution of respondents ranking the importance of the production of resources such as timber and agricultural goods from 1-5 (1 being most important, 5 being least important) provided by the Huron River watershed.

e. Natural habitat for wildlife

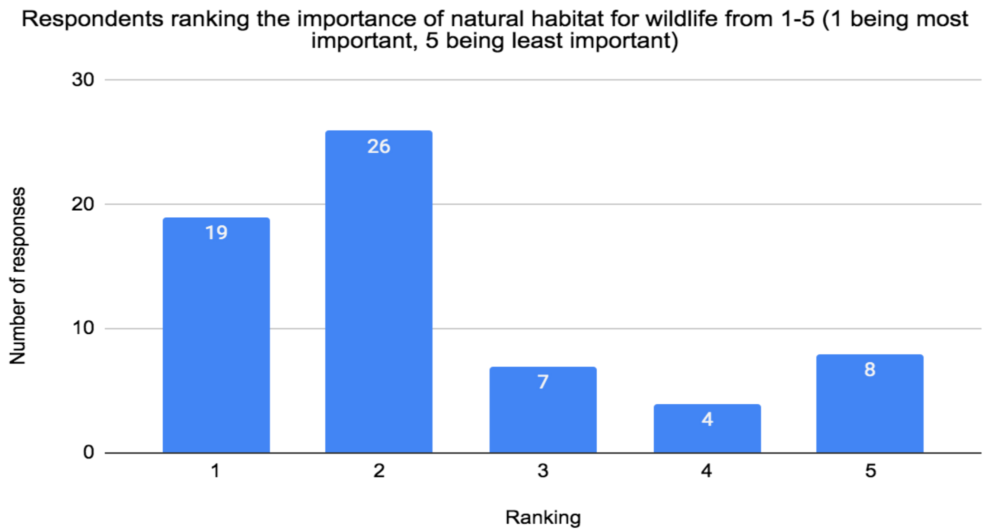


Figure 3.16. The distribution of the number of respondents ranking the importance of the natural habitat for wildlife from 1-5 (1 being most important, 5 being least important) provided by the Huron River watershed.

12. Would you be interested in learning more about permanently protecting your land? Conserving your land has many benefits, including potential federal income tax deductions.

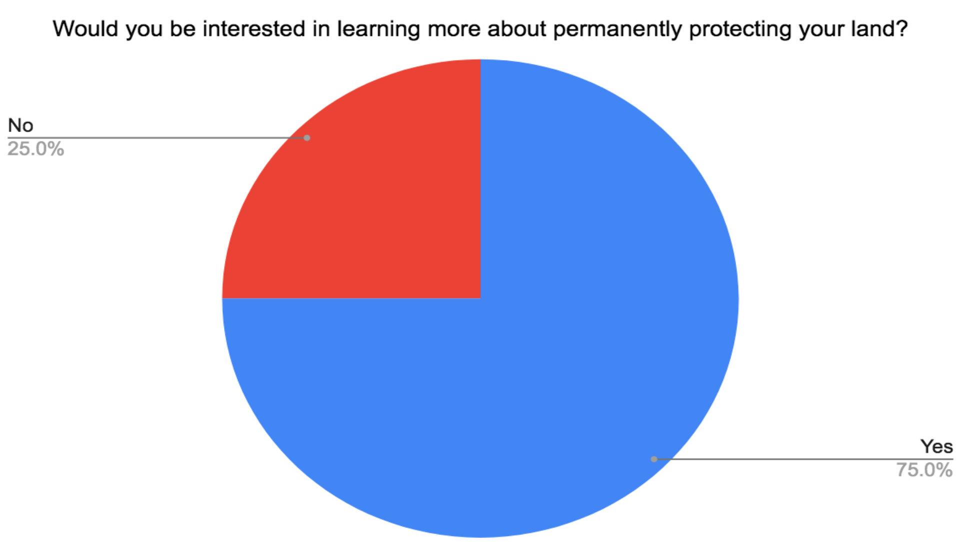


Figure 3.17. The distribution of the number of respondents who are or are not interested in learning more about permanently protecting their land located in the Huron River watershed.

13. How do you prefer to receive news and information about the Huron River watershed? Select all that apply.

Table 3.7. The number of respondents who prefer to receive news and information about the Huron River watershed per communication category type. Respondents were able to select more than one answer.

Communication type preference	Number of responses	Percent
None	4	6.2%
Mail	30	46.9%
Email	47	73.4%
Workshops/Events	11	17.2%
Internet/Web	12	18.7%
Word of mouth	4	6.2%
Social media	1	1.6%
Advertisement	0	0%
Total number of responses	64	

14. If you are interested in receiving information from the Huron River Watershed Council, please sign up for newsletters below.

Table 3.8. The number of respondents interested or uninterested in receiving newsletters from the Huron River Watershed Council.

Respondents who did or did not request additional information from HRWC	Number of responses	Response rate/information request category
Requested information from HRWC	51	72.8%
Did not request information from HRWC	19	27.1%
Total number of responses	70	

The names and contact information for those who expressed interest in receiving additional information from HRWC will be shared with HRWC separately to maintain anonymity and privacy of survey respondents.

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Conclusion

The research gathered for this project informs our recommendations related to conservation, outreach, and management. In this section, we offer a discussion of our results and recommendations that tie together the findings from each chapter of this report. We acknowledge the limitations of our research. We intend for this report to act as a guide for future researchers to expand on our findings and continue the work of making the Huron River Watershed a high-quality ecosystem.

a. InVEST

The effects of high nutrient loading on water quality and ecosystems are great. The Huron River Watershed Council can measure these impacts in ecosystem and economic terms. Future studies can use these model outputs to calculate the economic effect of an increase in nitrogen or phosphorus runoff due to development. HRWC could also look only at the extracted bioreserve area values and conduct an economic assessment of the average 0.667 kg/year nitrogen runoff and 0.028 kg/year of phosphorus runoff from bioreserve areas. However, as discussed in the model limitations, future studies should focus primarily on the percentage increases in runoff and not the exact values to account for model error. Additionally, future research could take a similar approach to the bioreserve pixel value extraction, but focus on natural areas, such as parks and recreation areas, in the watershed.

To avoid the ecological and economic effects of the high development model iteration, HRWC should consider undertaking the following recommendations, which are discussed at greater length and in broader contexts in the conclusion of this report.

- Focus conservation efforts on areas with a high percentage of natural area cover, as those areas are:
    - Often spatially close to riparian zones, making their development a greater and more direct threat to water quality.
    - Located at higher elevations in the watershed, leaving them vulnerable to higher runoff due to precipitation, especially as precipitation averages rise in Michigan because of climate change.
    - Located upstream near the headwaters of the Huron River or downstream near the Detroit River. Upstream areas impact downstream water quality and downstream areas are closer to the Detroit River. The Detroit River is already an EPA and Great Lakes Water Quality Agreement (GLWQA) Area of Concern (AOC) (*Detroit River AOC | US EPA*, 2019), meaning that it is an especially vulnerable ecosystem requiring additional care and conservation efforts.
- Target landowner outreach in agricultural areas.
    - Agricultural areas are major contributors to nutrient runoff, but can mitigate effects through more sustainable land management practices.

b. MAPPR

We recommend that HRWC collaborate with local experts, such as scientists, conservationists, and community members, to gain valuable insights into the local biodiversity and refine the map. Furthermore, other similar projects and tools could serve as useful references for the Bioreserve Map:

- The Terrestrial Ecoregions of the World (TEOW) map: It was first published by the World Wildlife Fund (WWF) in 2001 and has since undergone several revisions. This map serves as a tool to identify and delineate distinct ecological regions of the Earth's terrestrial environment and can be used in various ways to support conservation efforts (Olson et al., 2001). One way that HRWC can utilize the TEOW map is to identify priority areas for conservation within the watershed. The map can help to identify areas of high biodiversity value that may require special conservation attention, as well as areas that are under threat from development or other human activities. The TEOW map is a powerful tool that can support HRWC's efforts to protect and preserve the ecological health of the Huron River watershed.
- The Prioritization Assistance Tool for Endangered Species (PATS): Created by the U.S. Fish and Wildlife Service, PATS is a decision-support tool that assists in the prioritization of endangered species recovery actions (Puckett et al., 2019). HRWC can use PATS to identify which endangered species and populations in the Huron River watershed are most in need of conservation attention. By inputting information about the species and populations in the watershed into the tool, HRWC can generate scores that prioritize which species and populations are most important to focus on, and identify which conservation actions are most likely to result in successful outcomes (Puckett et al., 2019).
- Conservation Assessment and Prioritization System (CAPS): Developed by The Nature Conservancy, CAPS is a software tool that integrates ecological, economic, and social data to help identify conservation priorities at regional scales (Groves et al., 2012). HRWC can use CAPS to identify areas within the watershed that are of high conservation value, based on factors such as biodiversity, habitat quality, and ecological integrity, and evaluate the potential impacts of different threats to biodiversity within the watershed, such as habitat loss, pollution, and climate change (Groves et al., 2012). It can serve as a powerful tool for HRWC to support its efforts to protect and conserve biodiversity within the Huron River watershed.

We generated additional metrics to display the Bioreserve Map data, including weighted averages for the 15 metrics included in the original Bioreserve Map that present the data in separate categories that indicate types of conservation priorities. We also created new metrics that can add to the usefulness of the Bioreserve Map by displaying data that was not previously included. The metrics we produced could serve as a useful tool to identify the high priority areas for conservation.

From the spatial distribution of high priority areas described in section 3 of Chapter 2, the high priority areas are concentrated in the northwestern portion of Washtenaw County and the southwestern portion of Livingston County, which indicates the importance of preserving the connectivity of natural areas and thus provide us with the evidence of potential benefits of maintaining ecological corridors. Further investigation into the reasons why these areas were identified as high priority and the factors contributing to their importance could provide valuable insights for conservation planning.

We displayed the Bioreserve Map data according to a number of metrics, including individual metrics and weighted averages of several metrics. We compared these to the Final Rank of the original Bioreserve Map created by HRWC. The maps produced could be useful for us to identify the most important metrics for conservation. The metrics that differ from the Final Rank in terms of their spatial distribution could indicate areas that should be prioritized in order to protect ecological quality in the watershed.

c. TELE

A. Knowledge

Generally, landowners within the Huron River watershed stated that they had a moderate to moderately high level of knowledge of the forest or wetland property that they own or manage. Landowners reported that they knew some of their property's ecosystem features, such as its plants, animals, insects, and soil, and hydrology, but not all (Table 3.5). Fewer respondents put themselves into the highly knowledgeable or highly unknowledgeable categories. However, there were still respondents that stated they knew a lot or very little about their land. These results suggest that 26% of landowners in the Huron River watershed feel they could use additional information on the ecological features of their property and how to best manage them for water quality. The 41.9% of respondents who felt they are moderate to highly knowledgeable may still benefit from additional information on the ecology of their land. Understanding that these landowners may not be interested in surface level information about their land and how to protect it can guide outreach efforts as outlined by TELE (Chawla et al., 2008, p. 28).

58.5% of respondents acknowledge that the ways in which they manage their property significantly affect the quality of the watershed (Fig. 3.10). 13.8% of respondents reported that they did not believe their land management practices have any significant effect on the watershed. The remaining 27.7% of respondents stated that they were unsure of whether or not their actions significantly affected the quality of the watershed, suggesting that additional educational resources or programs on the subject may be of use to this demographic.

75% of respondents reported that they are interested in learning more about permanently protecting their land while 25% of respondents were not interested in permanently protecting their land (Fig. 3.17). This result should encourage HRWC to reach out directly to more of the landowners who participated in this survey, especially those who asked for additional information (Table 3.8). 72.8% of the respondents requested and gave their contact information to receive additional information from HRWC. This suggests that a significant portion of surveyees feel they and their land would benefit from additional resources from HRWC.

Survey participants reported a variety of communication method preferences for receiving news and updates about the Huron River watershed. Respondents were able to select more than one type of communication. Internet communication types were most preferred by respondents. Email (73.4% of respondents preferred), mail (46.9% preferred), internet/web (18.7% preferred), and workshops/events (17.2% preferred) are widely acceptable forms of communication. Respondents tended not to prefer word-of-mouth (6.2%) and social media (1.6%) communications (Table 3.7). 6.2% of respondents reported preferring no news and information at all. E-newsletters and other internet communications are the lowest-cost methods of communication for HRWC, and they are also conveniently the most commonly preferred. To keep communication and advertisement costs down, HRWC should continue to primarily use internet communications to reach landowners. 17.2% of respondents indicated that they are interested in receiving information via workshops or events, implying that there is a sizable group of landowners who feel they would attend and benefit from workshops with HRWC.

B. Values

47.1% of respondents indicated that they are interested in having areas of their land restored in a way that protects its ecosystem. 22% of respondents stated they are uninterested in this opportunity 30.9% of respondents were unsure if they wanted to participate in restoration projects (Fig. 3.8). These results indicate that there is some level of interest from surveyed landowners to learn more about their land and how they can be good stewards of the Huron River watershed. While some were simply uninterested, others were unsure. This finds that there is a need for more information from HRWC on what exactly permanently protecting their land entails, both in physical changes to their property and monetary investments needed.

When asked what support they would need in order to restore or manage their land in an ecologically beneficial way, 50% of respondents reported needing financial advice, while 45% needed financial support. 30% of respondents needed assistance getting permitting, 32.5% needed help finding contractors to assist on land management projects, and 52.5% needed help with manual labor. 82.5% of those surveyed reported needing professional expertise on how to restore or manage their property in a way that benefits the Huron River watershed (Fig. 3.9). These results show that of those who are interested in responsibly managing their property, many are in need of financial assistance, professional contacts, and clarification on what they can do for this effort. These respondents may benefit from workshops run by HRWC to help with creating private land conservation easements. These respondents feel that they do not have the tools, whether it be the funds, labor, social contacts, or knowledge, necessary for using their land to benefit the watershed. Support from HRWC will greatly increase the interest of private landowners in conserving their land.

43.9% of landowners responded that they have enough time to invest in restoring or managing their property in order to protect and improve watershed quality. 19.7% of respondents felt that they did not have enough time, and the remaining 36.4% were unsure if they had enough time to invest (Fig. 3.11). These findings show that nearly half of respondents have the time to improve their land for the good of the watershed. Other respondents were uninterested in investing time into restoring and managing their property, and others were unsure of what such a time investment may involve. Applying TELE chapter 4 principle on understanding your audience, uninterested or unsure respondents may actually have time for restoring their land but do not know it (Chawla et al., 2008). These landowners could use additional resources on what managing their land to benefit the watershed would entail, and how to do it. The uninterested or unsure segment would benefit from projects where low time and financial commitments are emphasized.

92.4% of those surveyed were unwilling to spend more than $2,500 annually on land stewardship activities on their property. 5.7% were willing to spend anywhere between $2,500 and $10,000 annually on land stewardship activities, and the remaining 1.9% were willing to spend $10,000 or more annually (Table 3.6). With this information, HRWC should focus on marketing free or low-cost land stewardship tools and programs for surveyed landowners. This is related to the sixth point of TELE's 6-points for engaging a target audience which covers a landowner's ability to act (Chawla et al., 2008, p. 30). If financial constraints in land restoration projects are a concern of landowners in the Huron River watershed, HRWC should address this and design stewardship activities that cost $2,500 or less.

For the ecosystem services provided by the Huron River watershed, respondents valued clean drinking water and high-quality natural habitat for wildlife above all other options (Figures 3.13 and 3.16). Recreational activities, employment opportunities, and production of resources were less valuable to respondents (Figures 3.12, 3.14, and 3.15). Though all these ecosystem services are undeniably important to the health of the watershed and the region's economy, survey respondents valued the usability of water and habitat for humans and wildlife above all. This implies that landowners may be more incentivized to use their land in ways or participate in activities that are geared towards improving water quality and wildlife habitats. Water quality and natural habitat are the basis of recreational activities, watershed-related employment opportunities, and production of resources. HRWC should aim towards outreach programs with landowners that amplify the positive effects on water and habitat quality to not only allow participants to feel they are contributing to the good of the watershed, but also improving the variety of other ecosystem services the watershed provides. They may do this by applying the principles listed in chapter 2 of the TELE guide that suggests gearing programs towards what landowners care about and are interested in (Chawla et al., 2008, p. 12).

C. Property use

82.8% of survey respondents own or manage between 10 and 50 acres of land, while the remaining 17.2% own or manage between 50 and 100 or more acres of land (Table 3.1). This result is significant because HRWC focuses on surveying and conserving land over 10 acres in the Huron River watershed (HRWC, 2023). Information about privately owned land over 10 acres is valuable to FCW as well for potential new Natural Areas assessments. Understanding that most of those surveyed in this study own between 10 and 50 acres of forest or wetland will help guide HRWC in landowner outreach program design. This data, paired with the number of landowners reporting their desire to learn more about protecting their land and in working directly with HRWC suggests that there is great potential for landowners to conserve or ecologically improve their properties.

77.2% of respondents reported that they have owned or managed their forest/wetland properties between 10-50 years. 15.7% of respondents stated they have owned or managed their land for 1-10 years, and the remaining 7.1% have owned or managed their land for 50 years or more (Table 3.2). It is likely that landowners who have been living or working on these properties for several decades are very familiar with their property's ecosystems. They contain a wealth of knowledge on the changes they have seen on their property and within the watershed over time, which is invaluable to HRWC's various projects. The landowners who have managed their property for decades likely have an emotional attachment to their land, motivating them to be better stewards. In chapter 5 of TELE, the authors recommend wording outreach messages to landowners that convey emotion (Chawla et al., 2008, p. 40). Respondents of this survey have a long-term familiarity and fondness for their property that may inspire them to collaborate with and learn from HRWC, and to take actions that ultimately improve habitat and water quality within the watershed. HRWC should tap into this emotional attachment and use TELE chapter 5 recommendations when advertising landowner outreach programs.

Those who participated in this survey reported applying a variety of land use management methods on their property. Among the most common methods were mowing (66.1%), invasive vegetation management (53.8%), and planting (46.1%). 18.5% of respondents reported applying herbicide and fertilizer, and 20% log. Less commonly reported management methods were controlled burns and clearcutting at 16.9% and 13.8%, respectively (Table 3.3). Though there was no "grouping" of vegetation management types based on what is or is not beneficial to the watershed, some management methods are more harmful while others can be favorable. For example, controlled burns are shown to be beneficial for forest ecosystems, and can indirectly help improve water and floristic quality within the watershed (Minnesota DNR, 2022). HRWC should encourage surveyed landowners to practice ecologically responsible land management methods.

19 respondents offered management methods outside of the seven listed in this survey. These include hunting, gardening, firewood harvesting, creating walking paths, tree maintenance, ungulate grazing, "cleaning up" unwanted vegetation, or simply leaving the land be (Table 3.4). The results from the preceding question (Table 3.3) and this follow-up question imply that landowners are generally doing a great deal of work on their land. This is an excellent opportunity for directing landowners to incorporate or increase land use activities into their arsenal that fit well into HRWC's FCW project.

The landowners and managers who participated in this survey gave valuable feedback as to how HRWC can accomplish the landowner outreach goals of their FCW project. Through participation from landowners in HRWC's Bioreserve area and implementation of the TELE engagement guide principles, HRWC has the opportunity to accomplish their project goals and ultimately protect, preserve, and improve the quality of vast swaths of the Huron River watershed.

With the information gained from this survey, HRWC should take marketing advice from TELE's "Understanding your audience" (chapter 4) and "Designing materials" (chapter 5) sections. For example, HRWC may choose to target landowners that are interested in conserving their land who feel they are knowledgeable about their property and the work they do on it, but need additional support. Workshops or seminars could be held directly addressing the concerns reported in this survey, such as the financial costs and benefits associated with creating a conservation easement. TELE recommends that messages to landowners be (1) focused, (2) understandable, and (3) relatable could be implemented to design messages to landowners addressing how HRWC can help them overcome financial concerns (and emphasize financial benefits like tax breaks) to attract participants (Chawla et al., 2008, p. 45). Many survey respondents felt they could use help finding contractors for their land. HRWC can mediate relationships between their recommended contractors and interested landowners. Volunteer opportunities with HRWC could be made out of the need for manual labor for private property maintenance. Responding to the needs of landowners will allow HRWC to meaningfully work with landowners in land conservation efforts.

TELE's "Designing messages" section can be used by HRWC to create targeted advertisements or infographics for private landowners. Choosing language and images in their communications and advertisements that evoke the values of private landowners within the Huron River watershed catches attention. This may stimulate interest in the creation of private conservation easements or simply having HRWC perform a free Land Assessment. Respondents reported valuing clean drinking water and natural habitat for wildlife above all else. Much of HRWC's FCW project is focused on these concerns, so material designs related to this project should emphasize water quality and wildlife habitat in the watershed. By directing messages that clearly state the overlap between private landowners and HRWC's values, HRWC can zero in on those most likely to participate in Land Assessments or the creation of conservation easements.

Based on the responses from this survey and TELE's "Getting the word out" section, HRWC should focus primarily on mail and email communications for their target audience.

Respondents of this survey stated that they prefer these forms of communication, so they are more likely to engage with them through these means. HRWC should not underestimate the power that their organization's name and reputation holds; TELE recommends targeting landowners who are familiar with your organization, and HRWC is a familiar environmental organization in the Huron River watershed region (Chawla et al., 2008, p. 59). HRWC has a reputation of advocating for freshwater quality, wildlife habitat, usability, and holding polluters accountable for over 50 years (HRWC, 2023). Leaning into their notoriety when communicating with target audience members would certainly benefit the goals of FCW and HRWC.

HRWC should continue to learn from and communicate with community members and private landowners in the watershed. TELE states that before, during, and after outreach programs, organizations should be learning from their participants (Chawla et al., 2008, p. 73). Utilizing their notable reputation and professional resources, HRWC should continually evaluate the attitudes of their partners, especially those whose land they find to be most valuable to conserving the watersheds natural quality. Ensuring that participants are getting what they need and expect from HRWC when working with them is crucial to the success and continuation of community participation with HRWC. Large-scale mail surveys can be quite pricey for a non-profit like HRWC, so keeping up with email, phone, mail, and social media communication with their partners will help them evaluate what is and is not working in programs like FCW.

One of the most valuable pieces of feedback provided by the landowners who participated in this survey is the gaps in respondent knowledge of their land. There was quite a bit of uncertainty in this demographic as to how to best care for forests and wetlands in a way that benefits the watershed. In question #6, 30.9% of respondents were unsure if they were interested in having their land restored or managed in a way that protects its ecosystem (Fig. 3.8). Question #8 revealed that 27.7% of respondents did not know if their land management practices affect the quality of the Huron River watershed (Fig. 3.10). In question #9, 36.4% of respondents were unsure if they have enough time to invest in managing their land in a way that protects and improves the quality of the watershed (Fig. 3.11). The gaps in knowledge highlighted by survey results provide materials for HRWC and future private landowner research.

In order to increase landowner knowledge and confidence in the best land use practices for themselves and the watershed, HRWC should look to the TELE guide. Respondents of this survey were generally interested in the health of the watershed and its natural habitats (Fig. 3.13 and 3.16) and wanted to learn more about how to protect their land (Fig. 3.17). HRWC should create outreach programs that focus on building landowner knowledge of their property, emphasize the good that they themselves can do, how to do it, and what resources HRWC can offer. This fulfills chapter 6 of TELE's recommendations to create focused, understandable, and relatable messages for landowners (Chawla et al., 2008, p. 45).

TELE's chapter 4 titled "Understanding your audience" will also help address landowner uncertainty in their land management practices (Chawla et al., 2008, p. 28). HRWC can take the results of this survey that show what landowners know about and are interested in and create programs that build on these qualities. For example, many respondents reported implementing a wide variety of vegetation management methods on their land (Tables 3.3 and 3.4). If landowners are uncertain of the effects their land management practices have, or if they are interested in restoring their land for the good of the watershed, HRWC could frame outreach programs focused solely on land management methods landowners already use. Using familiar techniques but increasing landowner knowledge on how to best implement them could create positive outcomes for FCW and the watershed.

Further, we recommend that HRWC:

1. As part of their continued outreach and surveying work, HRWC should coordinate with interested landowners to include nutrient loading measurements and other in-depth surveying methods to capture higher resolution data on their Bioreserve area. These findings can fit into MAPPR-like modeling and increase the accuracy of InVEST results. While nutrient data is difficult to gather, general surveying of land management behaviors that lead to increased nutrient loading could help HRWC more closely tailor management recommendations. This information will increase landowner knowledge of their property while also increasing the quality of HRWC Bioreserve data.

2. Prioritization for conservation should be applied in areas with a high percentage of cultivated crops and large, contiguous Bioreserve areas. Agricultural areas are associated with high nutrient runoff. Our research shows that regions in the watershed with the highest percent cover of cultivated crops and the largest nutrient runoff hotspots also correspond with the largest concentration of continuous Bioreserve areas. We found that these larger (10 acres or greater) Bioreserve areas rank higher in conservation prioritization under our new metrics. Most of these areas are located in Washtenaw and Livingston counties. HRWC should utilize the new ranking methodology for Bioreserve areas, paired with the nutrient runoff data, to prioritize conservation efforts.

3. HRWC should conduct cost-benefit analyses of private land conservation easements and assess the effectiveness of different economic incentives for conserving private land. This information will encourage landowners to participate in conservation programs on their properties. The results of our landowner survey show that a majority of landowners are willing to undertake conservation initiatives on their land but lack the social, physical, and financial resources to do so. Instead of directing conservation funds directly to these landowners, a cost-benefit analysis specific to a parcel could be used to convince landowners that undertaking conservation initiatives or easements is not as financially strenuous as first believed to be, and may actually provide economic benefits to them.
4. When making management decisions, it is important for HRWC and landowners to understand the changes in ecosystem services that will occur as a result of continuous

land use changes seen in the watershed. Bioreserve regions should be prioritized for protection if their ecological function is likely to significantly decline in the case of new development. The changes in nutrient runoff found in our InVEST model when natural areas were categorized as highly developed demonstrates the importance of tracking land cover change. Targeting areas for conservation that are at risk of high development is important to maintaining ecological integrity in the Bioreserve area.

Future Research

Future research should consider the problems discussed in the InVEST model limitations section of Chapter 1. The most salient and easily remedied limitations are updated land use and land cover as well as precipitation data. As staff and students become more familiar with the HRWC soil data, it may become possible to include a subsurface nutrient export component to the model. Additional InVEST modeling is also possible. The Sediment Delivery Ratio could be easily run when soil data becomes available and, paired with the results of this model, would provide a more whole picture of runoff effects on drinking water treatment.

There is a large body of work from which future University of Michigan SEAS master's projects and HRWC researchers can pull. The previous Ann Arbor Greenbelt project (Assessing & Communicating Climate and Water Ecosystem Services of the City of Ann Arbor Greenbelt Program) began modeling carbon storage and sequestration in the watershed, which would improve an analysis of bioreserve conservation and make future subsurface nutrient transport findings more relevant.

For the Bioreserve map, in addition to the metrics we added, there are other metrics that could be added to the ranking. A size ranking for forest could be added by using land cover classifications from remote sensing imagery. Land cover data from the National Land Cover Database (NLCD) or GAP/Landfire National Terrestrial Ecosystems could be used to estimate the total forest land cover in each bioreserve polygon.

Additional metrics could be added to the Bioreserve map to measure integrity of natural areas. MAPPR uses data on impervious surface and road crossings, which is also available for the Huron River watershed. In addition, data on nutrient runoff and hydrological alterations has been collected in order to run the InVEST model, as described in chapter two of this report. Data could also be added for wellhead protection areas in order to improve the Bioreserve map's analysis of groundwater.

The method of ranking areas by conservation priority could also be updated. Each metric was divided into classes to determine their priority ranking. In the original Bioreserve Map, these classes were defined on a case-by-case basis for each metric, using either a manual classification, a natural breaks method, or presence/absence. In the rankings we displayed, a natural breaks method was used to delineate the classes. Other methods of defining classes could also be used that are more standardized among all of the metrics and allow for statistical comparison between the metrics.

The new layers we added to the Bioreserve Map enhanced our understanding of the bioreserve areas and also showed the potential implications of targeting wetlands, lakes, and stream length for conservation efforts as well as ecosystem management within the Huron River watershed. Since the Bioreserve Map has similar functionalities to MAPPR, combining these new layers with existing metrics in MAPPR can aid in developing general conservation plans. Future research can relate the new layers and results to broader conservation goals and challenges in the Huron River watershed, such as water quality protection, biodiversity preservation, and climate change adaptation. Ranking systems for connectivity and climate flow could aid in prioritizing bioreserve areas.

The ArcGIS Online Map we developed serves as an interactive tool to engage stakeholders and promote conservation awareness in the Huron River watershed. However, ensuring that the data files are easily accessible, in the correct format, and that the options provided for displaying the layers are intuitive and reasonable is an ongoing process. The data files and layers should have good data integrity and be easy to manipulate for further analysis.

The Bioreserve Map and MAPPR varied in their scales and integrity metrics. To improve the Bioreserve Map further, HRWC can incorporate more detailed data which includes information on individual parcels and the various ecological factors that impact biodiversity. Additionally, it may be beneficial to extend the research area by including neighboring regions. Also, as the datasets become more extensive, manual analysis may not be feasible, certain advanced analytical tools such as machine learning algorithms would be necessary to identify patterns and trends over time. To further provide up-to-date information on land cover changes and inform the maps' accuracy, we suggest that advances in remote sensing such as satellite imagery be taken into use.

The Bioreserve map is divided into polygons that each cover a continuous natural area. Most polygons contain multiple parcels of land within them. A suggested future step for HRWC is to divide the Bioreserve map into individual parcels. Using a finer scale, like MAPPR does, could allow for more accurate decision making when considering which areas to conserve in the Huron River Watershed.

To update the ranking system, we could include more balanced rankings that provide specific indications of ecological quality. One way to achieve this is by combining the 15 metrics currently used. Rather than choosing bins based on each individual metric, a more standardized approach could be adopted where the weight assigned to each metric is proportionate to its importance. Furthermore, some metrics such as water presence/absence and wetland presence/absence could be replaced with new layers that provide more accurate data, such as stream length, area of lakes, and percent wetland. Additionally, new metrics could be added based on land cover data, such as area of forest, percent developed, and length of roads. These changes would help to create a more comprehensive and accurate ranking system, providing more valuable insights for HRWC into the ecological quality of different areas.

Displaying the map serves different purposes for different types of users. The general public may seek an overall ranking of ecological quality in their township or creekshed. A final ranking displaying all metrics combined would enable easy comparison of overall ecological quality and factors contributing to it. Conservancies may focus on specific metrics such as percent wetland and biological diversity. Tailoring the display to specific user interests can provide meaningful insights for informed decision-making.

Due to certain limitations, our research relied on online technology and we did not conduct any field surveys in the research areas. In light of this, we recommend that future research include field surveys to enable direct observations of local biodiversity, which would aid in validating and refining the map, and enhance the accuracy of the data.

To ensure the Bioreserve Map remains relevant and useful, regular updates are necessary to reflect changes in biodiversity. New data can be integrated, and regular field surveys conducted, with the assistance of local experts. In addition, leveraging ArcGIS Portal would be beneficial for streamlining collaboration among team members and stakeholders by providing a platform for sharing and reviewing spatial data. This platform would serve as a centralized location for managing and storing spatial data, making it easier for conservation practitioners to maintain data quality and accessibility. Customizing ArcGIS Portal to meet the specific needs of HRWC's conservation planning and management activities can include creating custom apps, tools, and workflows, ensuring HRWC can make the best use of our work. We have also included our step-by-step process to create new layers in a separate document, which can serve as a reference for future manipulation and updates to the map.

Going forward, future researchers at the University of Michigan SEAS and HRWC may be able to further bridge the gap between landowner knowledge and meaningful land use habits. While this survey provided information on landowner knowledge, values, and current land use practices, not all aspects of the intersection between private land management and HRWC project goals were found. Future work could include designing specific programs based on TELE principles and the responses from this survey. More research could be done to understand respondents' uncertainty in their ability to manage their land for the betterment of the Huron River watershed, and how to generate more knowledge. Private landowners who manage 10 or more acres in the watershed are vital stewards; without their feedback and participation in maintaining watershed quality, the ecological effects would certainly be felt. Understanding how to best engage these stewards is an ongoing goal for HRWC, and there is much potential for future engagement and learning with this demographic after the completion of our team's 2023 master’s project.

Additionally, we recommend that future researchers consider the following:

1. With more time and a more detailed survey, researchers could run an analysis on survey results to investigate whether property size and proximity to the watershed is associated with a landowner’s knowledge and action of best land management practices. This data would help inform conservation recommendations and decisions for larger (10 acres or greater) Bioreserve parcels to be targeted for conservation due to high ecological priority rank from the our newly defined bioreserve metrics.

2. To evaluate the long-term impact of HRWC's outreach and educational efforts, a study could be conducted to assess changes in landowners' knowledge, attitudes, and behaviors over time. This study should take into account the influence of other factors beyond HRWC's programs. This will explore the outreach strategies and their effectiveness to better promote sustainable land management practices in participating landowners. Through the implementation of annual landowner and land surveys, HRWC can better understand the views of landowners over time. This is especially pertinent for future climate change, development, and contemporary conservation methods, all of which are relevant to the quality of the Huron River watershed.

3. Future research should investigate and quantify the impact of runoff on drinking water treatment. In keeping with the goals of the FCW project, quantifying the effects of runoff on drinking water specifically would be salient to HRWC. Methods to assign an economic and ecological impact metric of a given quantity of nitrogen or phosphorus can be explored further. This will contribute to additional economic and environmental analysis HRWC conducts related to land management practices.

We hope that this report can be effectively used to guide HRWC in accomplishing the goals of the FCW project. It is our aspiration that this project will serve as a background for future researchers in continuing and expanding upon important social and environmental work within the Huron River watershed, one of southeastern Michigan’s most precious resources.

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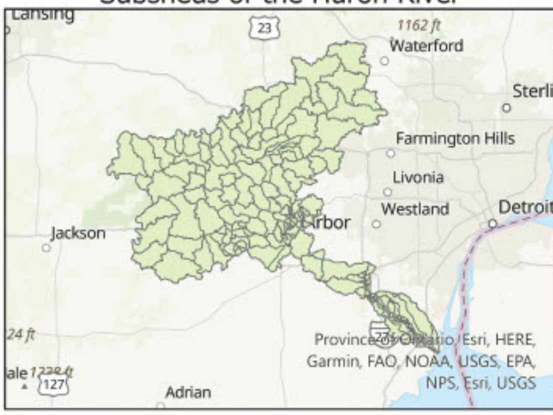
Forests For Clean Water. (2023, March 2). Retrieved March 15, 2023, from Huron River Watershed Council website: https://www.hrwc.org/what-we-do/programs/knowledge-networks-outreach/forests-for-clean-water/

Appendix A

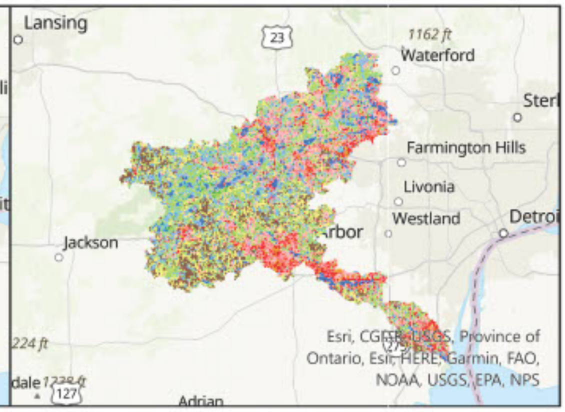
Appendix A - Model Spatial Inputs

Subsheds of the Huron River



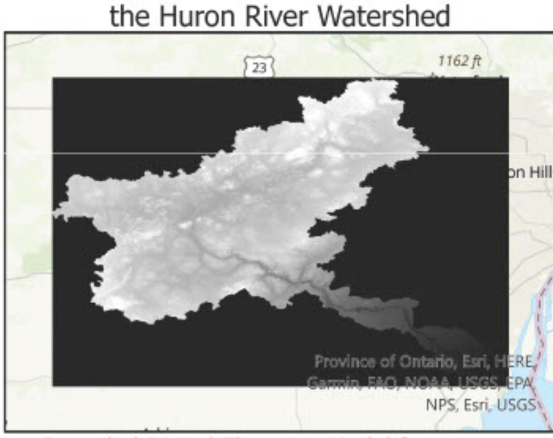
Map of the Huron River Watershed's sub and creek sheds. This map was used as the reference extent for all other input layers in the InVEST NDR model

Land Use Land Cover of the Huron River Watershed



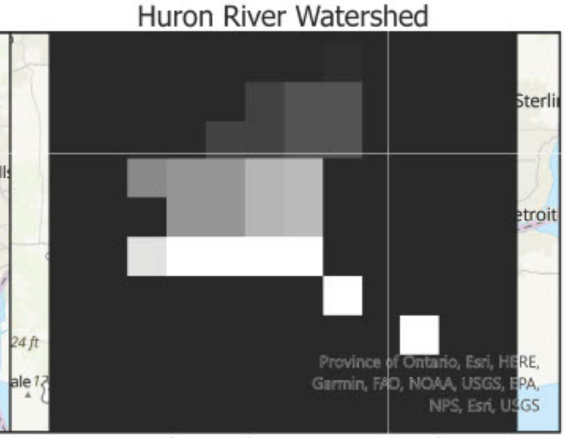
Map of the Huron River Watershed's land use and land cover. This map was clipped to the extent of the subsheds map in the InVEST NDR model

Digital Elevation Model of the Huron River Watershed

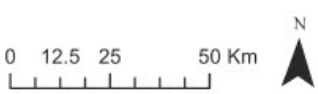


Compiled Digital Elevation Model for the Huron River Watershed. This map was clipped to the extent of the subsheds map in the InVEST NDR model

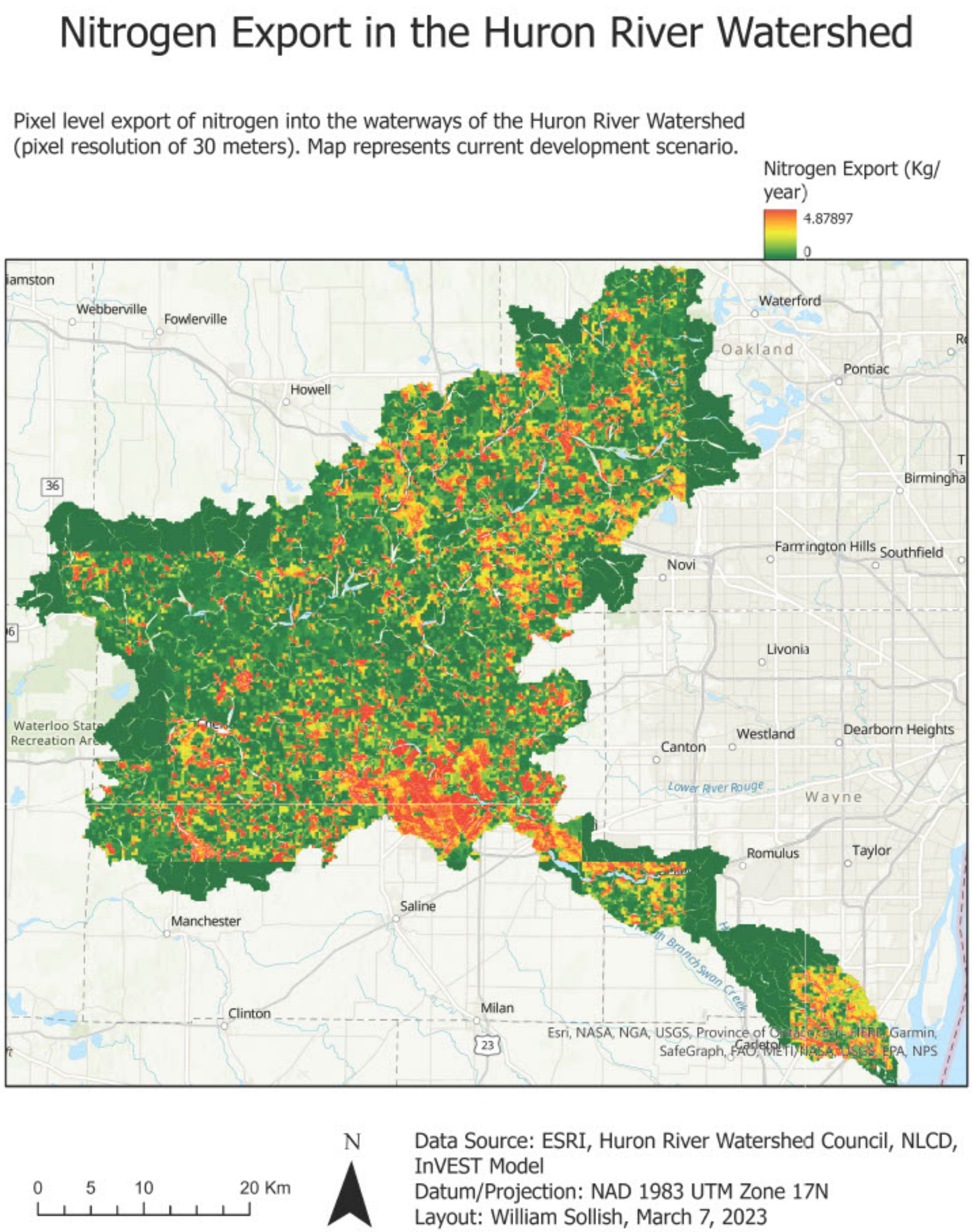
Average Precipitation in the Huron River Watershed



Map of annual precipitation in the Huron River Watershed. This map was clipped to the extent of the subsheds map in the InVEST NDR model



Appendix B

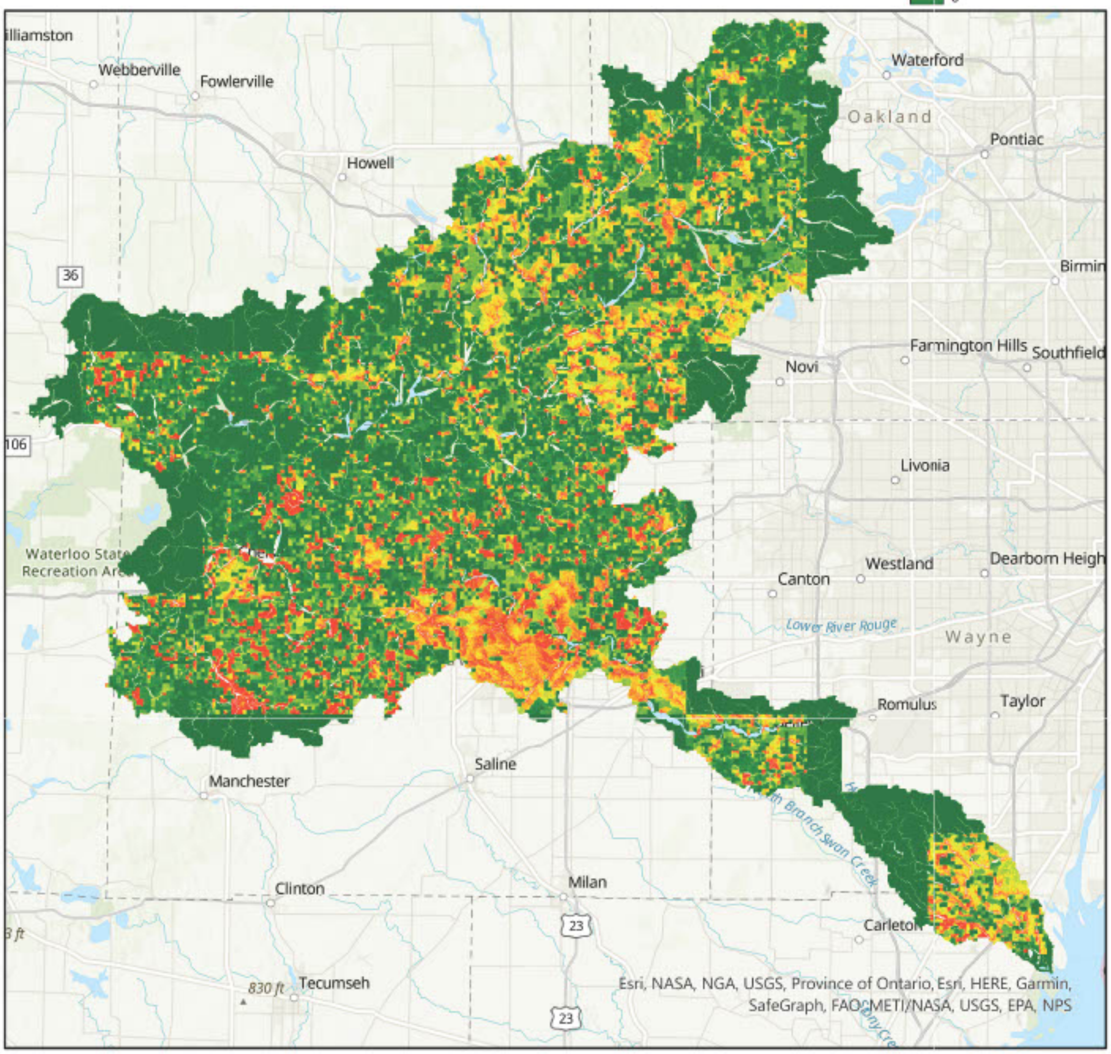


Nitrogen Export in the Huron River Watershed
Pixel level export of nitrogen into the waterways of the Huron River Watershed (pixel resolution of 30 meters). Map represents current development scenario.
Nitrogen Export (Kg/ year)
4.87897
0
Webberville
Fowlerville
Howell
Waterford
Oakland
Pontiac
Birmingha
Farmington Hills
Southfield
Novi
Livonia
Waterloo State Recreation Ar
Westland
Dearborn Heights
Canton
Lower River Rouge
Wayne
Romulus
Taylor
Saline
Manchester
Clinton
Milan
36
23
Esri, NASA, NGA, USGS, Province of Ontario, Esri, HERE, Garmin, SafeGraph, FAO, METI/NASA, USGS, EPA, NPS
0 5 10 20 Km
N
Data Source: ESRI, Huron River Watershed Council, NLCD, InVEST Model
Datum/Projection: NAD 1983 UTM Zone 17N
Layout: William Sollish, March 7, 2023

Phosphorus Export in the Huron River Watershed

Pixel level export of phosphorus into the waterways of the Huron River Watershed (pixel resolution of 30 meters). Map represents current development scenario.

Phosphorus Export
(Kg/year)
0.323813
0

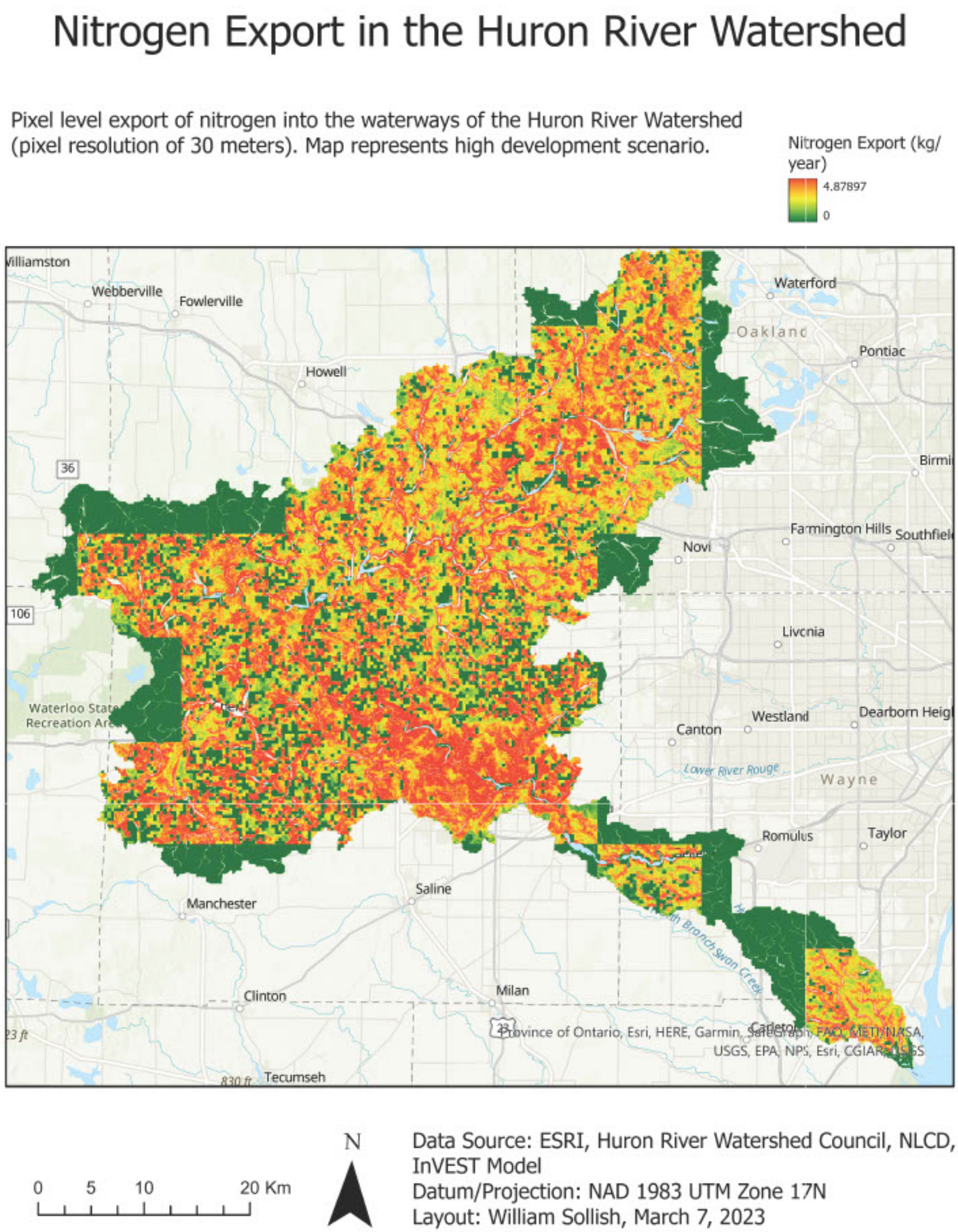


0 5 10 20 Km

N

Data Source: ESRI, Huron River Watershed Council, NLCD, InVEST Model
Datum/Projection: NAD 1983 UTM Zone 17N
Layout: William Sollish, March 7, 2023

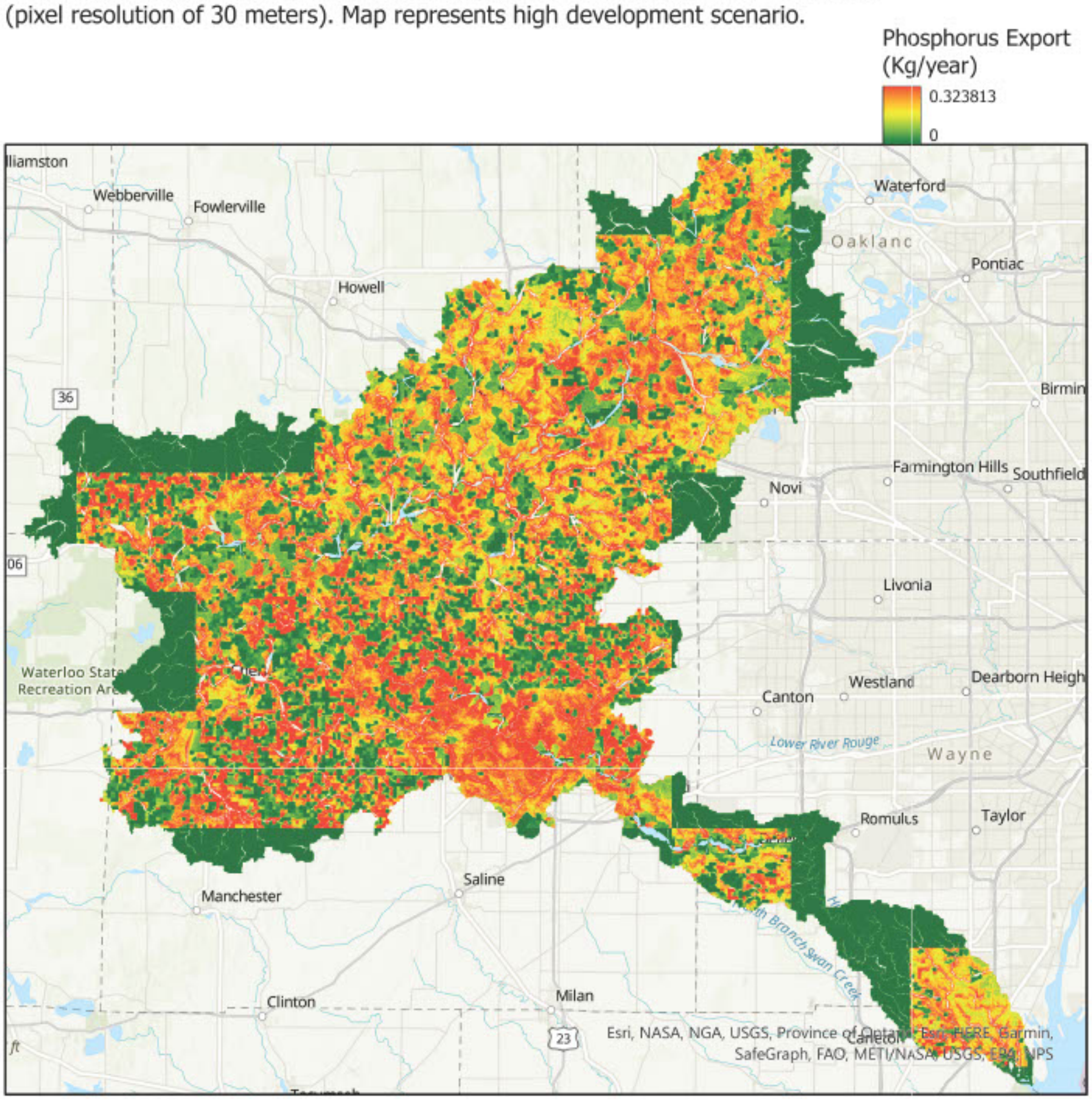
Appendix C



Nitrogen Export in the Huron River Watershed
Pixel level export of nitrogen into the waterways of the Huron River Watershed (pixel resolution of 30 meters). Map represents high development scenario.
Nitrogen Export (kg/ year)
4.87897
0
Webberville
Fowlerville
Howell
Waterford
Oakland
Pontiac
Novi
Farmington Hills
Livonia
Westland
Canton
Dearborn Heig
Lower River Rouge
Wayne
Romulus
Taylor
Saline
Manchester
Clinton
Milan
Tecumseh
36
106
Province of Ontario, Esri, HERE, Garmin, SafeGraph, FAO, METI/NASA, USGS, EPA, NPS, Esri, CGIAR, USGS
0
5
10
20 Km
N
Data Source: ESRI, Huron River Watershed Council, NLCD, InVEST Model
Datum/Projection: NAD 1983 UTM Zone 17N
Layout: William Sollish, March 7, 2023

Phosphorus Export in the Huron River Watershed

Pixel level export of phosphorus into the waterways of the Huron River Watershed (pixel resolution of 30 meters). Map represents high development scenario.



0 5 10 20 Km

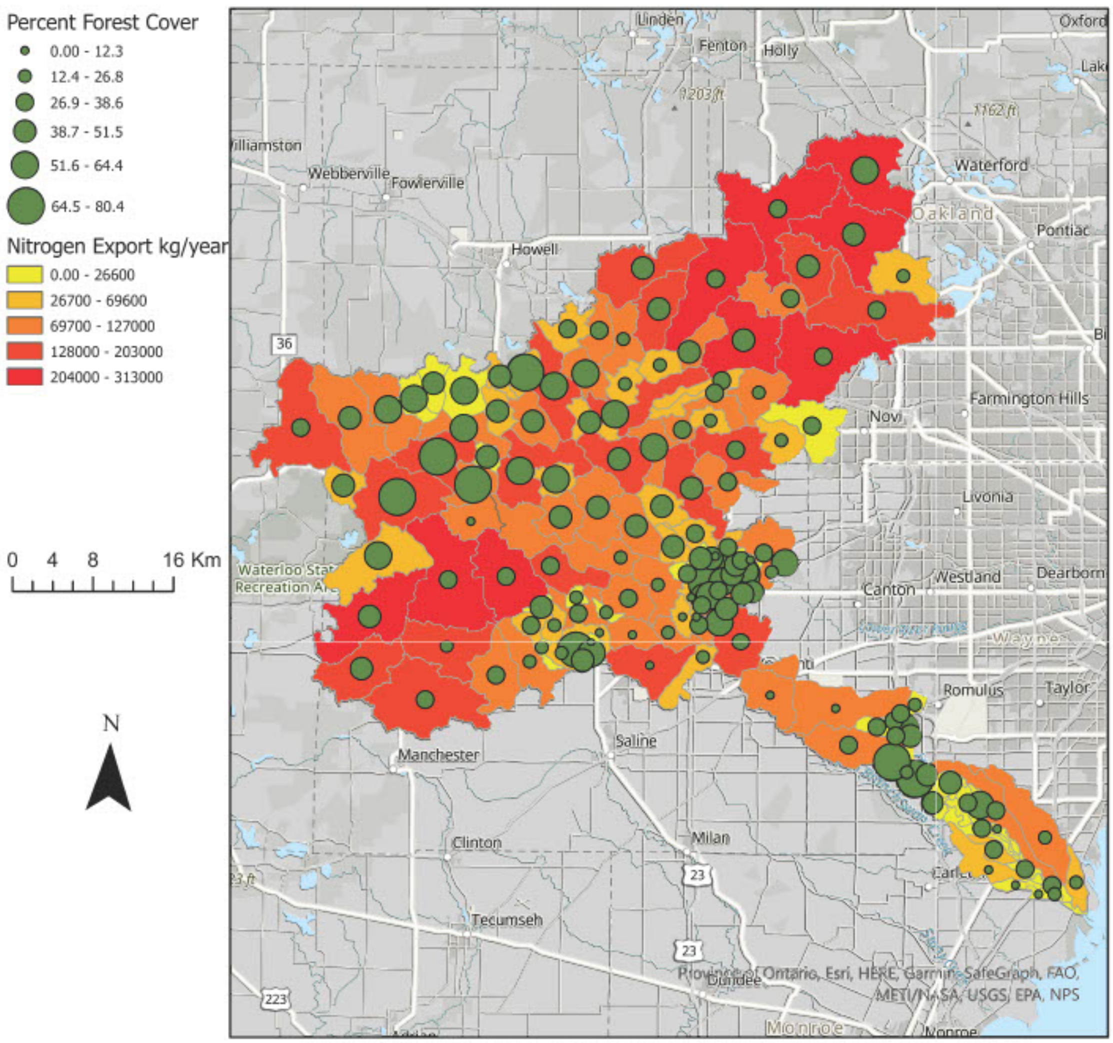
N

Data Source: ESRI, Huron River Watershed Council, NLCD, InVEST Model
Datum/Projection: NAD 1983 UTM Zone 17N
Layout: William Sollish, March 7, 2023

Appendix D

Nitrogen Export by Huron River Creekshed and Forest Cover

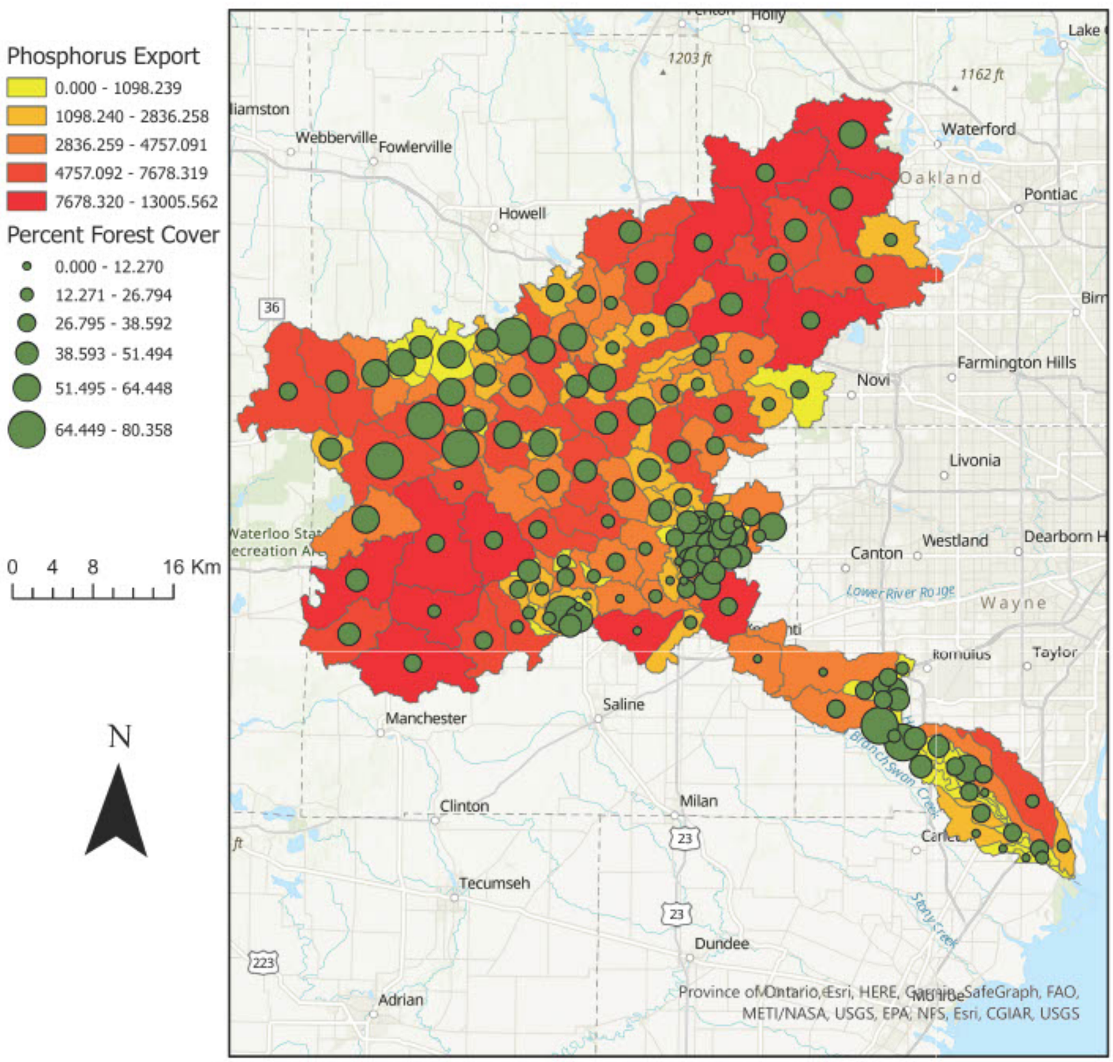
Map showing intensity of nitrogen runoff in each creekshed of the Huron River and the percent of each creekshed that is covered by forest. Forests in this model are given nutrient loads as if they are highly developed.



Data Source: ESRI, Huron River Watershed Council, NLCD, InVEST Model
Datum/Projection: NAD 1983 UTM Zone 17N
Layout: William Sollish, March 7, 2023

Phosphorus Export by Huron River Creekshed and Forest Cover

Map showing intensity of phosphorus runoff in each creekshed of the Huron River and the percent of each creekshed that is covered by forest. Forests in this model are given nutrient loads as if they are highly developed.

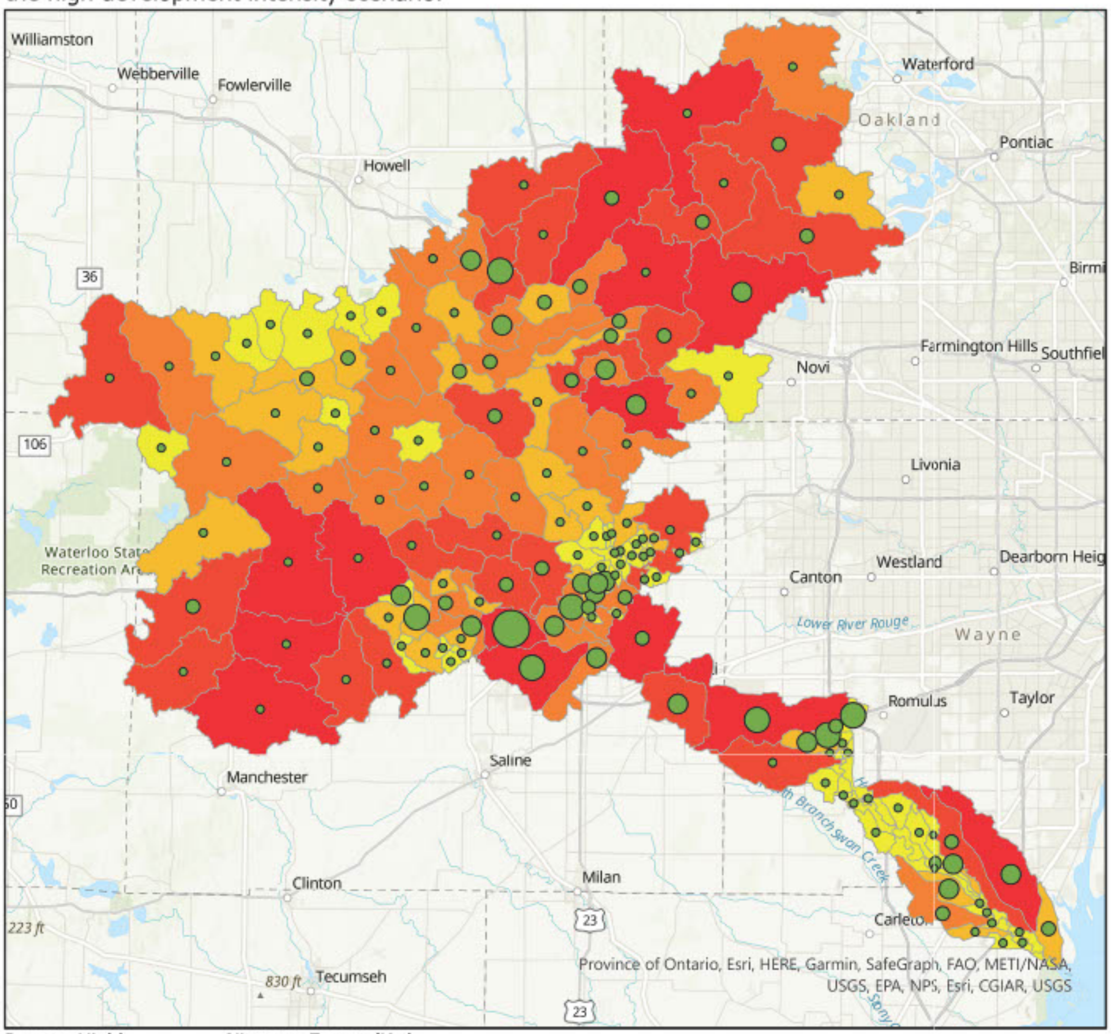


Data Source: ESRI, Huron River Watershed Council, NLCD, InVEST Model
Datum/Projection: NAD 1983 UTM Zone 17N
Layout: William Sollish, March 7, 2023

Appendix E

Percent Highly Developed Land Area and Nitrogen Runoff by Creekshed

Map shows the percent of each creekshed that is classified as high intensity development along with nitrogen export. This map is meant to be referenced, along with the percent forested areas map, to see where nutrient loading intensity shifts from the current land use model scenario to the high development intensity scenario.



Percent Highly Developed

- 0.000 - 0.978
- 0.979 - 3.017
- 3.018 - 6.604
- 6.605 - 11.697
- 11.698 - 20.175

Nitrogen Export (Kg/ year)

- 0.00 - 9919.32
- 9919.33 - 25133.41
- 25133.42 - 50918.95
- 50918.96 - 84438.81
- 84438.82 - 187777.06

0 5 10 20 Km

N

Data Source: ESRI, Huron River Watershed Council, NLCD, InVEST Model
Datum/Projection: NAD 1983 UTM Zone 17N
Layout: William Sollish, March 7, 2023

Appendix F

MAPPR Summary
MAPPR consists of a variety of conservation layers that were processed and moved into level 3 parcels, which are a standard for displaying property maps in Massachusetts. Parcels were removed from MAPPR if they were already protected or if they were less than 1 acre in area.

1: BioMap2
The first collection of layers came from BioMap2. BioMap2 was created by the Massachusetts Natural Heritage and Endangered Species Program (NHESP), in collaboration with The Nature Conservancy. It is a method of prioritizing natural areas based on their conservation value. MAPPR uses eight layers from BioMap2, which are separated into groupings referred to as Core Habitat and Critical Natural Landscape.

The Core Habitat grouping includes six layers: Species of Conservation Concern, Priority Natural Communities, Vernal Pool Core, Forest Core, Wetland Core, and Aquatic Core. All six layers are included in MAPPR. The Critical Natural Landscape grouping includes four layers, two of which are included in MAPPR: Landscape Blocks and Coastal Adaptation. The eight BioMap2 layers are described below.

1.1: Species of Conservation Concern: This layer maps habitat for endangered species in Massachusetts. 413 species listed by the Massachusetts Endangered Species Act (MESA) were mapped, and an additional 27 species listed by the State Wildlife Action Plan (SWAP) were mapped.

1.2: Priority Natural Communities: This layer is based on a database produced by NHESP that shows areas that are high-priority to conserve based on the distinctiveness of the habitats and the assemblages of species.

1.3: Vernal Pool Core: This layer includes areas where vernal pools are likely to occur, and that are considered to be high quality based on their likelihood of hosting vulnerable species.

1.4: Forest Core: This layer includes forested areas that are considered to be high quality based on their size and the IEI metric.

1.5: Wetland Core: This layer includes wetlands that are considered to be high quality based on their size and the IEI metric.

1.6: Aquatic Core: This layer includes rivers that are considered high quality habitat for fish species that are listed by MESA and SWAP.

1.7: Landscape Blocks: This layer includes areas from each ecoregion that are considered high quality based on size and the IEI metric.

1.8: Coastal Adaptation: This layer includes areas that are adjacent to salt marshes and that have not been developed.

For each of the eight BioMap2 layers included in MAPPR, parcels were binned into categories of 3, 2, and 1. The categories were assigned based on the number of acres of the layer that each parcel contained, as well as the percent of the parcel occupied by the layer. Parcels with a higher number of acres were categorized as 3, while parcels with a lower number of acres were categorized as 1.

2: Phase II Critical Linkages

A layer was created from the Phase II Critical Linkages dataset, which was produced by UMass. The layer was based on a conductance index, which is defined as the probability that an animal will pass through the region. The layer also found nodes of high quality habitat, which were based on the Core Habitat grouping of layers in BioMap2, as well as on the CAPS Index of Ecological Integrity, which is described in the CAPS IEI section.

For the Phase II Critical Linkages dataset, parcels were binned into values of 3, 2, and 1. The values were assigned based on conductance index and presence of nodes.

3: Fine Scale Resilience

A layer was created from the Resilient Sites for Conservation dataset, which was produced by The Nature Conservancy. Areas are defined as resilient sites if they are less vulnerable to the impacts of climate change.

The analysis also drew on the Geophysical Settings dataset from TNC, which divides locations into groupings based on their topology and ecology. Parcels were binned into values of 3, 2, and 1, based on the resilience scores for 20 different geophysical settings.

4: Under-Represented Settings

A layer was created from the Geophysical Settings layer, which was produced by The Nature Conservancy as part of their Resilient Sites for Conservation map, and is described in the preceding section. The parcels were binned into values of 3, 2, and 1 by the percent of unprotected area for each geophysical setting

5: Large Roadless Blocks

A GIS analysis was performed to find blocks of parcels that were uninterrupted by roads. The parcels were binned into values of 3, 2, 1 by the number of acres that are contiguous.

6: Protected and Recreational Openspace Layer

A layer containing open space areas was created by MassGIS. The layer was intersected with level 3 parcels, and the parcels were binned into values of 3, 2, and 1 by number of acres.

7: NRCS Prime Farmland

A layer of soil data was provided by MassGIS. The layer was intersected with level 3 parcels, and the parcels were binned into values of 3, 2, and 1 by number of acres.

8: Surface Water Supply Protection Areas

A layer of surface water protection areas was provided by MassGIS. The layer divided land into 3 zone types, which were land within the boundary of a riverbank, land within ½ mile of the boundary of a riverbank, and all other land. The parcels were binned into values of 3, 2, and 1, according to the percentage consisting of each zone type.

9: MassDEP Wellhead Protection Areas

A layer of wellhead protection areas was provided by MassGIS. The layer divided land into 3 zone types, which were wellhead protection areas, buffers around wellheads, and interim wellhead protection areas. The parcels were binned into values of 3, 2, and 1, according to the percentage consisting of each zone type.

Appendix G

Bioreserve Map Metrics
The following table was adapted from the definitions used by HRWC to describe the metrics used in the Bioreserve Map (HRWC, 2007).

Bioreserve Metric	**Definition**
Size	"Natural areas were sorted according to their size and divided into five categories using natural breaks."
Core Size	"Core area is defined as 'size' (see above) minus a 300-foot wide buffer measured inward from the edge of the site."
Waterways	"Natural areas containing rivers or streams received 100 points, natural areas without waterways received zero."
Wetlands	"Natural areas containing any wetlands present received 100 points while natural areas without wetlands received 0."
Groundwater Recharge	Darcy's Law "indicates areas where soil types are more likely to allow infiltration leading to groundwater discharge."
Remnant Ecosystems	"Natural areas were analyzed to see if they had formerly contained any of these presettlement vegetation types."
Glacial Variation	"Natural areas were intersected with glacial variation data to determine the number of glacial landforms within each natural area."

Topographic Variation	"Slope and aspect were identified using a digital elevation model (DEM) of the Watershed to create a triangulated irregular network (TIN) for the Huron River Watershed."
Connectedness (A)	"The proximity of the site to other bioreserve sites was measured by building a 100 foot buffer around each site and counting the other bioreserve sites in that buffer."
Connectedness (B)	"Another measure of connectedness is the percent of a ¼ mile buffer around the natural area that remains undeveloped."
Unchanged Vegetation (A)	"A vegetation change map comparing the 2000 vegetation to the circa 1800 vegetation was created."
Unchanged Vegetation (B)	"Calculating the area of potentially unchanged vegetation that falls within each bioreserve site balances the bias of small sites with high percentage of potentially unchanged vegetation by awarding points based on actual area covered."
Restorability	"We measured the percentage of undeveloped lands within a ¼ mile buffer area."
Area of MNFI Community	"Sites with larger areas of 'MNFI Communities' received 100 points; those with no areas received zero."

Biorarity	"MNFI has created a grid by section of what it calls "biorarity," a score reflecting their database of high quality plant communities, occurrences of threatened and endangered plants and animals, and other measures of potential ecological quality...Sites with a higher average biorarity score received 100 points; those with a lower score received zero."