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Utilizing GIS and Open-Source Data for River Restoration Prioritization

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GEOG591: GIS in Water Resources

Table of Contents

Table of Figures

Table of Tables

Introduction.

River restoration is a major point of consternation in the environmental remediation community. With over one third of the rivers in the United States listed as impaired or polluted, there is significant focus on how to return these rivers to their original, pristine state (Bernhardt et al. 2005). However, much of the focus of river restoration is reactionary, focused a limited reach of stream and aimed to restore that stream with a rather specific set of guidelines (Rohde et al. 2006, White and Fennessy 2005). Investment in restoration projects has exceed $1 billion per year on average, further increasing

The aim of this project is to begin the development of a methodology to prioritize watersheds for restoration. By looking at a larger scale than the stream reach or catchment, areas can be prioritized across a county, state, or even country and then targeted with more specific management practices. This strategy will become increasingly important as the number of restoration projects continues to grow. With at least 37,000 restoration projects on record as of 2005, and many of these projects cherry-picking the most degraded or most in-need rivers for restoration, prioritizing areas for restoration based on sustainability and overall ecological impact should become a priority (Bernhardt et al. 2005).

The growth of GIS use and extensive public data repositories from the USGS, USFWS, and USFS have made it easier than ever to build models and prioritization databases for exactly this purpose. In 1997, Russell et al. provided a rudimentary approach to selecting sites for wetland remediation. Even with the comparatively juvenile state of GIS and the relative dearth of public data in the mid-1990's, the group was able to combine a topographic wetness index derived from digital elevation models (DEM) with land cover data from Landsat to definitively classify ~4% of their study watershed as priority areas for wetland restoration or preservation.

They noted the relative simplicity of their approach, but still stressed the importance of this style of analysis to lower costs and expedite the overall restoration process, especially with the growing availability of GIS data (Russell et al. 1997). A decade later, Rohde et al. (2006) made use of the vastly expanded facilities of GIS data along with multiple criteria decision analysis to create an ecological restoration suitability index. By utilizing knowledge of the underlying process behind river restoration, weights were developed for the individual data layers and helped to build a suitability score for each catchment in the study area. The group went as far as to combine socio-economic data, including public attitudes towards restoration, with their ecological suitability score to help determine the longevity and sustainability of the possible projects (Rohde et al. 2006). White and Fennessy (2005) also used a criterion-weighting scheme and the restoration suitability index concept to develop a wetland restoration potential model for the entire Cuyahoga River watershed in Ohio. The "likelihood of success" was analyzed for each pixel in the watershed in order to provide a map of all suitable sites to managers and practitioners. Similar work has also been conducted in an exploratory sense. Wasson et al. (2010) followed similar geospatial methods to analyze the connectivity between landscape processes and the ecological status of multiple rivers. In establishing this connectivity, this and similar studies can then contribute this information back to the restoration suitability research. As river restoration research continues to grow, these studies can provide context and background for projects tackling expanded spatial and temporal scales.

Methods.

Study Area.

This work focuses on the Upper Neuse and Upper Tar watersheds as delineated by the National Hydrography Dataset (NHD) 8-digit hydrologic unit (HUC8) (*Figure 1*). These watersheds fall in the northern, central region of North Carolina and contain the urban areas of Raleigh and Cary, NC as well as parts of the cities of Durham and Rocky Mount, NC. The Upper Neuse watershed has 74 HUC12 watersheds and the Upper Tar basin has 43 HUC12 watersheds. The area covers approximately 9,611 km^2 , which is dominated by forest and cropland based on the 2011 National Land Cover Database (NLCD 2011).

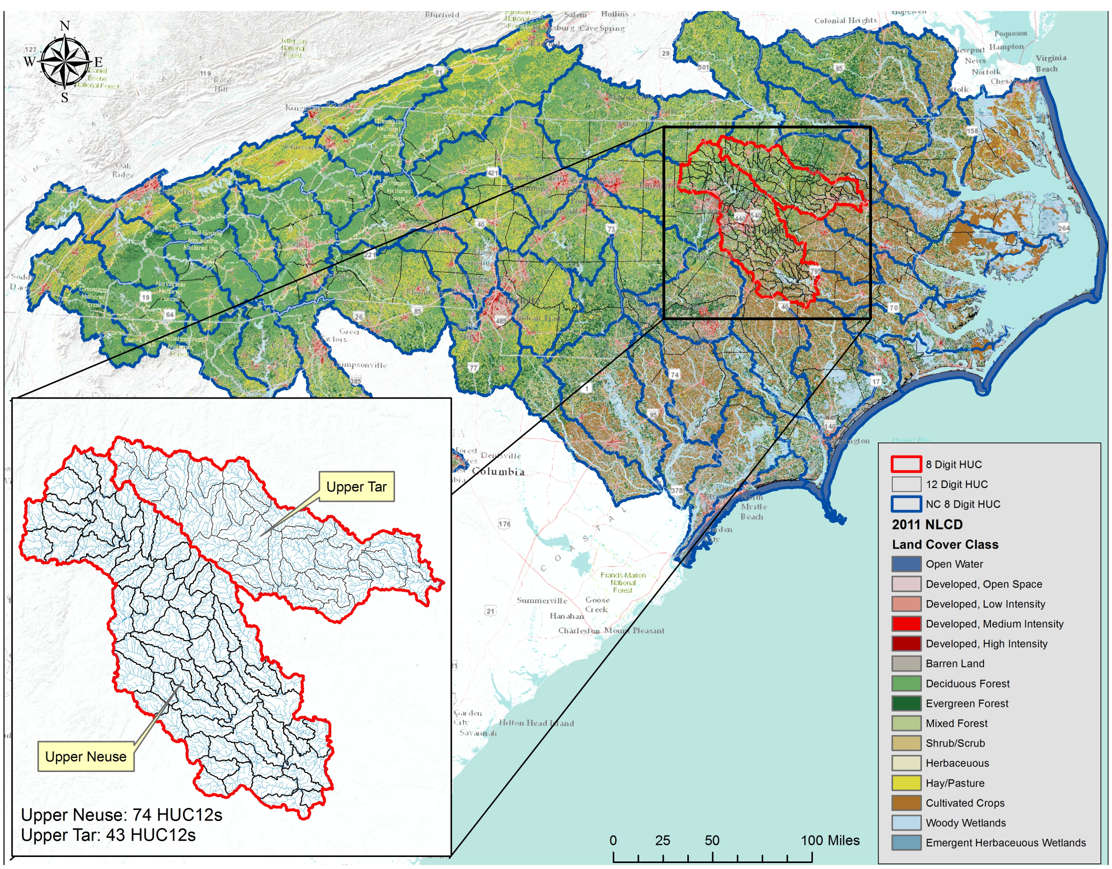

Figure 1. Study Area: Upper Neuse and Upper Tar watersheds in North Carolina

Data Collection and Manipulation.

One of the goals of this work was to utilize data sources that are readily available to any interested party and relatively simple to use. The focus of this work at the HUC12 scale also helped to direct the data collection process. Three data sources were used to collect the data for this work: NLCD, NHD, and EnviroAtlas. NLCD provided land cover data at 30m resolution for the entirety of the study area, as well as a percent impervious area layer for each pixel within the two watersheds. The NHD holds blue lines for all rivers and streams digitized at the 1:24,000 map scale. Attached to these blue lines is a wealth of data including mean annual flow and potential evapotranspiration for the catchment. EnviroAtlas is a database supported by the EPA with a variety of data layers relating to environmental benefits and ecosystem services for the entire United States, aggregated to the HUC12 scale. The database provides all of its information in tabular form and can be easily joined to any HUC12 polygon layer. Each of these databases was queried for data within the Upper Neuse and Upper Tar watersheds. Data that was not already aggregated to the HUC12 scale (NLCD and NHD) were summarized to each subwatershed to provide uniform spatial coverage for all input data.

The NLCD layer was reclassified in order to aggregate the land use categories into more general categories with similar restoration functions (*Table 1*). The reclassification process created a new NLCD layer (R-NLCD) that was used for all further analyses regarding land cover within the watersheds (*Figure 2*).

NLCD Reclassification			
NLCD 2011		R-NLCD	
11	Open Water	1	Water
21	Developed Open Space	6	Open/Barren
22	Developed, Low Intensity	7	Urban
23	Developed, Medium Intensity	7	Urban
24	Developed, High Intensity	7	Urban
31	Barren Land	6	Open/Barren
41	Deciduous Forest	4	Forest
42	Evergreen Forest	4	Forest
43	Mixed Forest	4	Forest
52	Shrub/Scrub	3	Shrub/Scrub/Herb
71	Herbaceuous	3	Shrub/Scrub/Herb
81	Pasture/Hay	5	Agriculture
82	Cultivated Crops	5	Agriculture
90	Woody Wetlands	2	Wetland
95	Emergent Herbaceous Wetlands	2	Wetland

Table 1. NLCD 2011 reclassification scheme

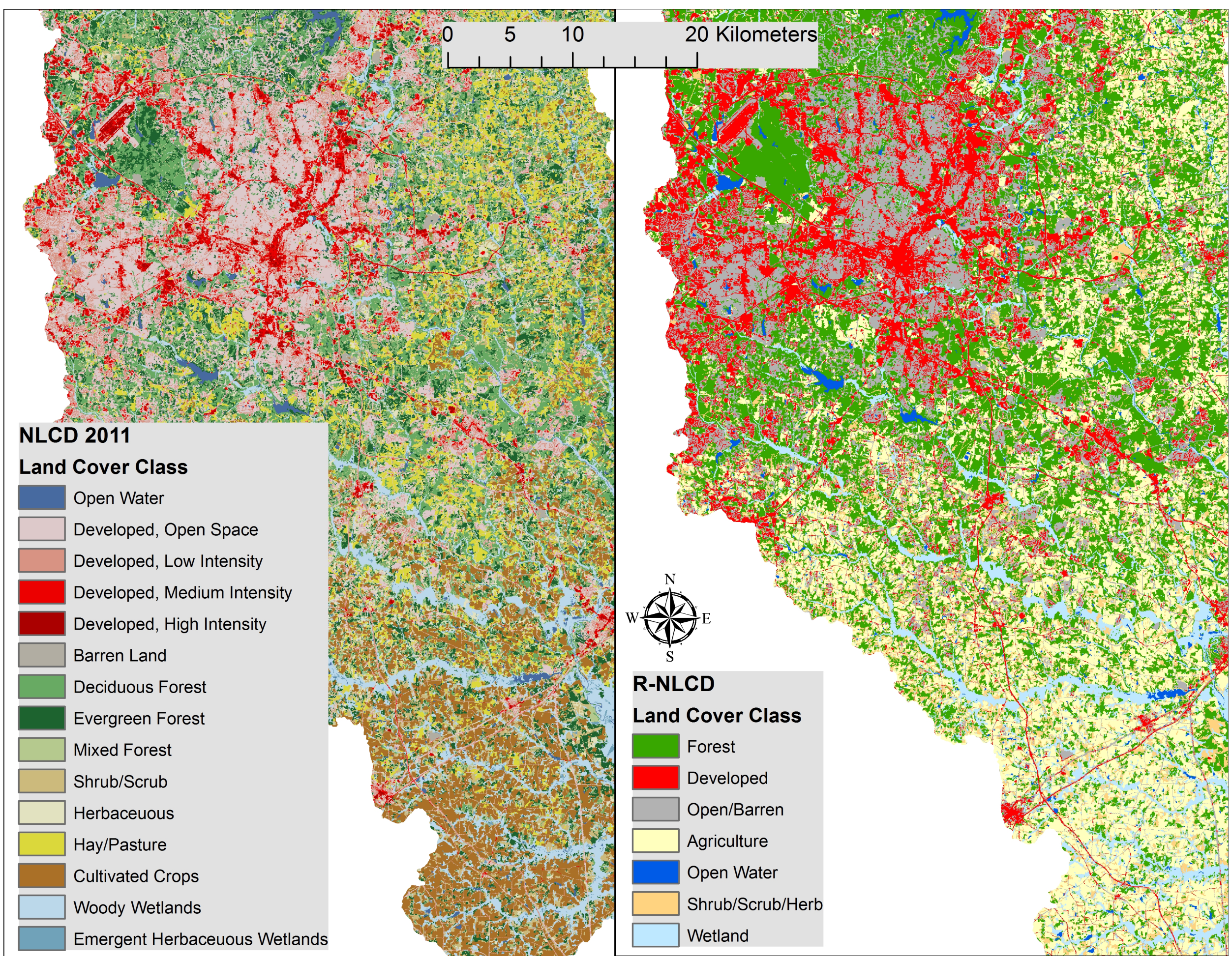

Figure 2. NLCD 2011 reclassification scheme

The importance of land use proximity to each stream and river was noted during the literature review. In order to account for this, buffers were created along each blue line at 30, 150, and 500 meters. The R-NLCD layer was then extracted to each of these buffer polygons and again summarized at the HUC12 level to give the percent coverage of each land cover type within the buffer area in each subwatershed (*Figure 3*). The 30, 150, and 500 m buffers accounted for 5%, 26%, and 74% of the total watershed area respectively.

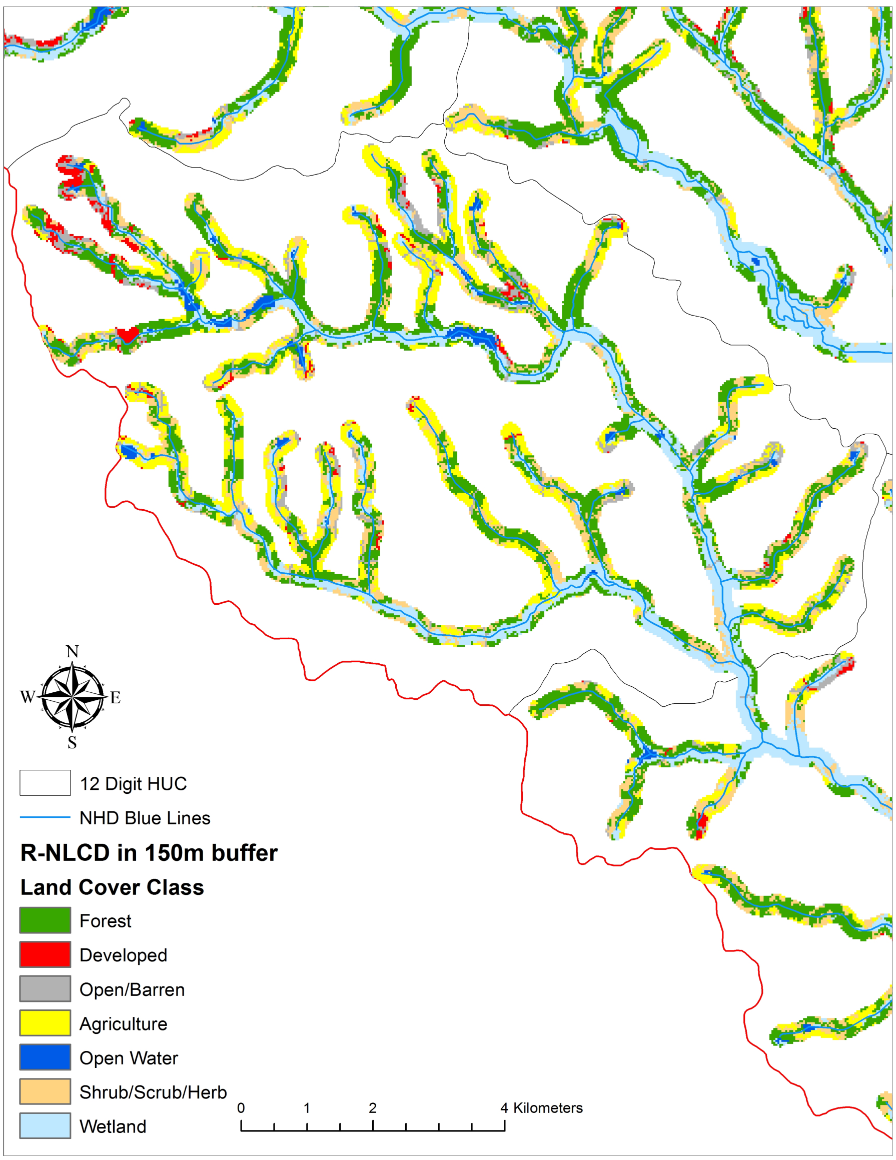

Figure 3. R-NLCD within the 150m stream line buffer

Restoration Suitability Model.

With the abundance of data that was available for each 12-digit HUC, it was important to parse out which layers were pertinent and useful for developing the restoration suitability model. The data was divided in to two groups in order to build two separate model inputs: restoration need, and restoration ability (*Table 2* and *Table 3*). The data layers incorporated into each of these groups were chosen based on the similar studies mentioned above. All data layers were normalized within themselves, creating a relative comparison between each HUC12. Two different weighting schemes were then used for the need and ability tables. The first weighted all layers equally, and the second accounted for some variation in layer impact on the stream and for distance relations to the streams, especially in the case of the buffered land cover layers. This created four separate layers: equally weighted need, variably weighted need, equally weighted ability, and variably weighted ability. Finally, two final restoration suitability score were calculated for each HUC12 using the two equally weighted layers and the two variably weighted layers separately. In order to appropriately visualize the data, natural breaks that provided relatively equal distribution of values were used to separate each set of subwatersheds into a five category scheme ranging from "Very Poor" to "Very Good". (See Appendix 1. for brief description of all data layers used)

Restoration Need			
Variable	Impact	Equal Weighting	Variable Weighting
Number of dams	pos	1	1
perc_ag	pos	1	0.25
percent_urb	pos	1	0.25
perc_ag_30m	pos	1	1
perc_openurb_30m	pos	1	1
perc_urb_30m	pos	1	1
perc_ag_150m	pos	1	0.66
perc_openurb_150m	pos	1	0.66
perc_devel_150m	pos	1	0.66
perc_ag_500m	pos	1	0.33
perc_openurb_500m	pos	1	0.33
perc_devel_500m	pos	1	0.33
TotImpLen	pos	1	1

Table 2. Restoration Need layer inputs and weighting

Restoration Ability			
Variable	Impact	Equal Weighting	Variable Weighting
max_MAF_areanorm	neg	1	0.5
drainage_density	neg	1	0.75
perc_ag_30m	pos	1	1
perc_wetland_30m	pos	1	1
perc_scrub_30m	pos	1	0.75
perc_forest_30m	pos	1	0.75
perc_openurb_30m	neg	1	0.25
perc_devel_30m	neg	1	0.25
TE_AVG_I	pos	1	0.75
Percent_of_HUC_Rare	pos	1	0.5
Percent_Rare_Area_Protected	pos	1	0.5
SMALL	pos	1	0.25
MEDIUM	pos	1	0.25
Percent agriculture on hydric soil	pos	1	1
WET_AG	pos	1	1
WET_FOR	pos	1	1
WET_WETL	pos	1	1

Table 3. Restoration Ability layer inputs and weighting

Results and Discussion.

Restoration Need.

The restoration need model accounted for detrimental environmental conditions that would lead to reduced ecosystem services from the streams and rivers in the study area. With the equal weighting model (*Figure 4*), the highest restoration need is found around the urban ares in the watersheds due to high values found with the percent urban coverage in close proximity to the streams. When shifting the weights to the variable weighting model, the areas of high need remain the same (still containing high urban coverage in close proximity to the streams), but many other watersheds show a relative increase in need. The HUC12s that showed a relative increase are largely located in suburban areas with larger percentages of agriculture.

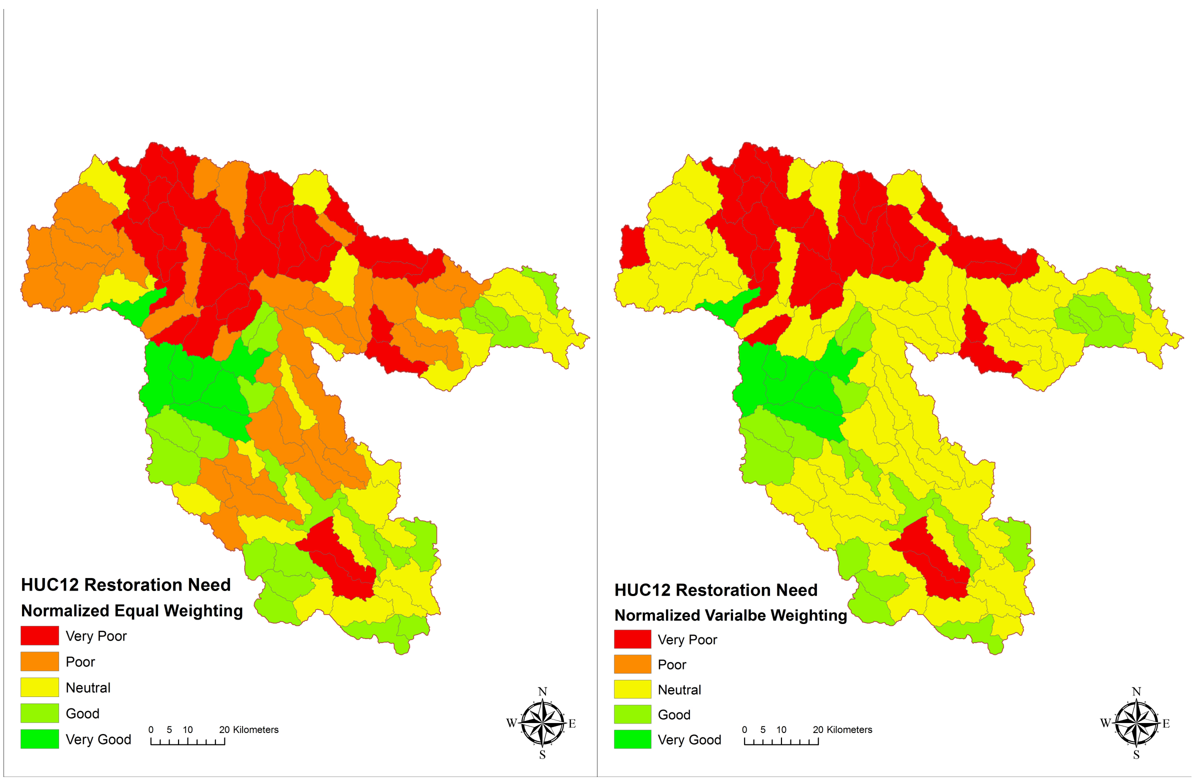

Figure 4. Restoration Need by HUC12 - normal and variable weighting

Restoration Ability.

As one may expect based on the input layers, the restoration ability analysis identified largely opposite HUC12s as highly suitable for restoration. These areas exhibited a large percentage of easily restorable land cover types (agriculture, wetland, shrub/scrub, etc) within cloe proximity to the stream, as well as low urban density at the same scale. Areas with high restoration ability also had larger ares within the HUC12 that were identified as natural or rare ecosystems, thus increasing their relative ecosystem services. Finally, all of these areas also exhibited relatively high percentages of land cover classes on soils with higher wetness index, thus increasing the long-term sustainability of a restoration project. With the equal weighting model and the variable weighting model, the urban areas were all identified as relatively poor areas for restoration (*Figure* 5). In the variable weighting model the HUC12s furthest from the headwaters in both watersheds showed higher ability, most likely due to higher percentages of wet soils.

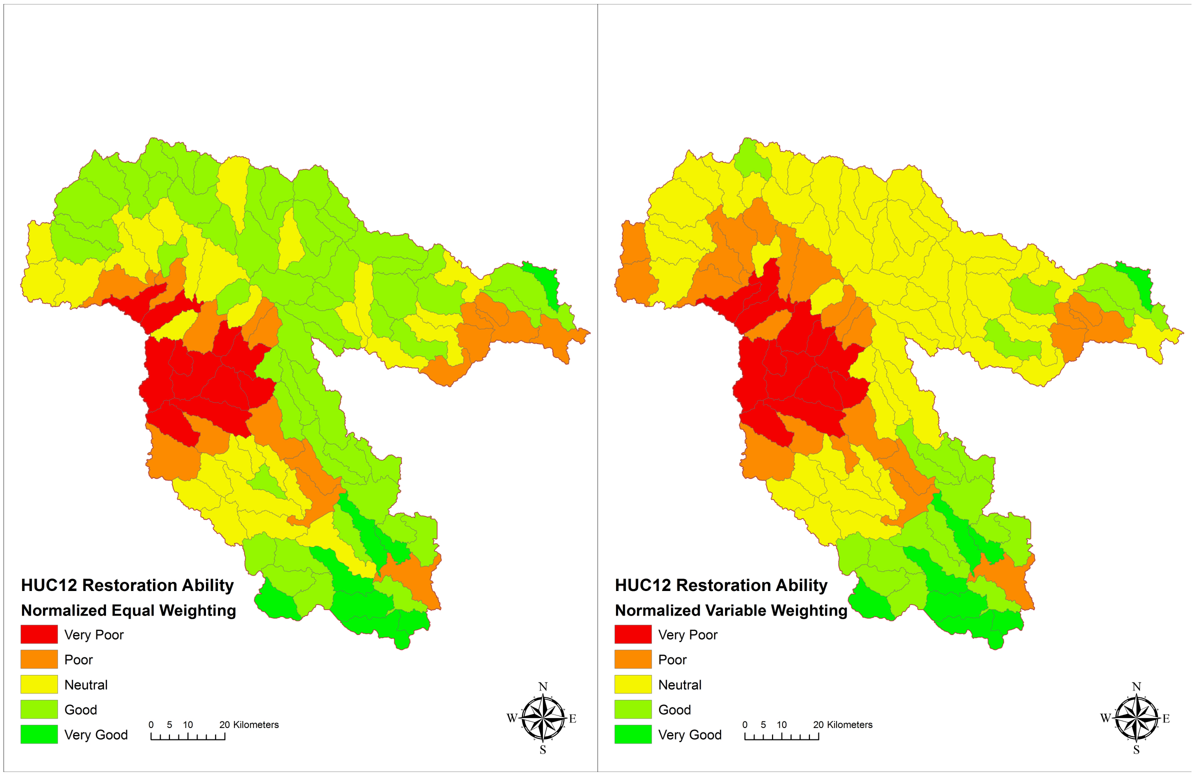

Figure 5. Restoration Ability by HUC12 - normal and variable weighting

Final Restoration suitability.

When combining the need and ability layers, many of the same patterns emerge in the final restoration suitability model (*Figure 6*). With equal weighting, the downstream HUC12s dominate the "Very Good" restorability model, showing a dominance of low urban coverage and easily restorable soil types in the model. The variable weighting model identified more of the urban watersheds with higher restoration need as those to target for restoration. However, in both models, the area north of Raleigh, NC was determined to have "Very Poor" restoration ability due to a combination of both low need (relatively healthy) and low ability (little restorable area). This area is dominated by suburban land use and industrial areas like Research Triangle Park, therefore removing a majority of the potential restoration areas (agriculture and wetlands), while maintaining relatively low urban land coverage.

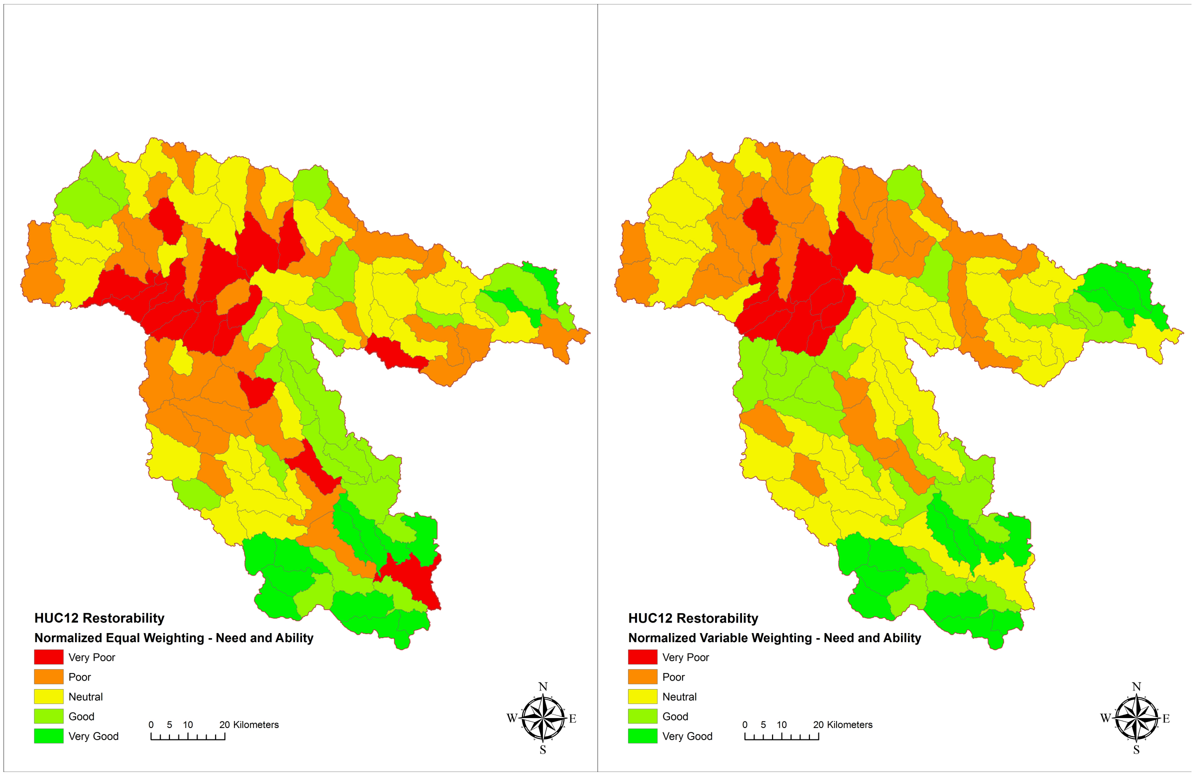

Figure 6. Restorability by HUC12 - equal and variable weighting

Conclusion and Future Work.

This work expands on the ability to create suitability models, like the one presented here, in order to improve communication between those carrying out restoration projects and the research community identifying sites of need. By focusing at the HUC12 scale, broader landscape impacts on river quality and health can be assessed while still allowing practitioners to determine the areas in each HUC12 that is most economically feasible and practical for restoration. At the same time, this work provides much more of an exploration of methods rather than a robust final analysis. Because the work only focused on two watersheds and used a comparative analysis within them, the results themselves are not easily translatable to other locations or regions. However, by collecting the necessary data and providing a rudimentary methodology, this analysis can act as guidelines for future work in this field. Based on the work done here, with large storage and computing capacity this or a similar analysis could theoretically be run for the entire state, region, or even country. In doing so, one would need to dig much deeper into the variable effects of each data layer on stream health and ecosystem services, but the data is all readily available and not very difficult to manipulate.

I hope to continue to address this work moving forward. By increasing the database and consulting with experts in the fields of restoration ecology, fluvial geomorphology, and hydrology, more robust weighting methodologies can continue to be developed. With this sort of input, this work can one day become extremely useful in bridging the researcher-practitioner gap in river restoration and hopefully increase the effectiveness and efficiency in every restoration project moving forward.

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Appendix 1.

Description of data layers and sources used in models.

Variable	Description	Source
max_MAF_areanorm	maximum Mean Annual Flow normalized by watershed area	NHD
drainage_density	Drainage density of the HUC12	NHD
perc_ag_30m	Percent of 30m buffer area covered by agriculture	NLCD
perc_wetland_30m	Percent of 30m buffer area covered by wetland	NLCD
perc_scrub_30m	Percent of 30m buffer are covered by scrub/shrub/herb	NLCD
perc_forest_30m	Percent of 30m buffer area covered by forest	NLCD
perc_openurb_30m	Percent of 30m buffer area covered by open urban/barren	NLCD
perc_devel_30m	Percent of 30m buffer area covered by developed land	NLCD
TE_AVG_I	Total threatened or endangered species	EnviroAtlas
Percent_of_HUC_Rare	Percentage of HUC designated rare from USGS GAP Analysis Program	EnviroAtlas
Percent_Rare_Area_Protected	Percentage of HUC rare area protected from USGS GAP Analysis Program	EnviroAtlas
SMALL	Total area of small (<500 acres) natural areas in HUC	EnviroAtlas
MEDIUM	Total area of medium (500-25,000 acres) natural areas in HUC	EnviroAtlas
Percent agriculture on hydric soil	Percent of agriculture on hydric soils (defined by SSURGO)	EnviroAtlas
WET_AG	Percentage of agriculture on land with >550 wetness index	EnviroAtlas
WET_FOR	Percentage of forest on land with >550 wetness index	EnviroAtlas
WET_WETL	Percentage of wetland on land with >550 wetness index	EnviroAtlas
Number of dams	Number of dams in the HUC12	EnviroAtlas
perc_ag	Percent of agriculture in total HUC12	NLCD
percent_urb	Percent of urban area in total HUC12	NLCD
perc_ag_150m	Percent of 150m buffer area covered by agriculture	NLCD
perc_openurb_150m	Percent of 150m buffer area covered by open urban/barren	NLCD
perc_devel_150m	Percent of 150m buffer area covered by developed land	NLCD
perc_ag_500m	Percent of 500m buffer area covered by agriculture	NLCD
perc_openurb_500m	Percent of 500m buffer area covered by open urban/barren	NLCD
perc_devel_500m	Percent of 500m buffer area covered by developed land	NLCD
TotImpLen	Total Imparied Length of stream normalized by total stream length	EnviroAtlas