Evaluation of Socioeconomic Vulnerability and Flood Risk in New Orleans, Louisiana

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INTRODUCTION AND PROBLEM FORMATION

As climate change intensifies globally, impacts such as increased temperatures and flooding can be felt especially acutely in cities, and research shows that these impacts are not shared equally across varying socioeconomic groups (United Nations, 2011). Given that different socioeconomic groups do not experience climate change-related hazards in the same way, there has been a push to incorporate social vulnerability and adaptive capacity into flood risk management (Koks et al., 2014). Cities around the world that are working to become more resilient and equitable must therefore also build frameworks for incorporating existing inequalities and vulnerabilities into the ways in which they address flooding hazards. New Orleans, Louisiana is one city with a long history of flooding hazards and socioeconomic inequality, and climate change is likely to increase the frequency and intensity of flooding events. Understanding where climate and socioeconomic risks are greatest is therefore a critical step in improving preparedness and resiliency in New Orleans.

Bixler and Yang (2020) performed a study in which they combined climate hazards and the Social Vulnerability Index (SoVI®) to produce composite risk maps of Austin, Texas. The goal of this study is to apply the methods used by Bixler and Yang in their 2020 Austin Area Sustainability Indicators report to New Orleans, Louisiana, another city with considerable climate-change related threats. This study will examine flood hazards and socioeconomic vulnerability in New Orleans using US Census Bureau and FEMA flood hazard data. This study aims to answer two main questions: 1) What parts of the New Orleans area are most vulnerable to flood hazards based on the neighborhood's socioeconomic vulnerability and flood zone designation, and 2) Do we see a correlation between high socioeconomic vulnerability and hazardous flood zone designation? The result is a spatial analysis which shows quantitative estimates of vulnerability to flooding hazards on a census block group-level.

METHODS

Data collection

Data was collected from three sources: United States Census Bureau, FEMA, and USGS. Figure 1 shows the online database interfaces of each source; Table 1 shows detailed information for the data used. For the census data, the 2018 American Community Survey data was downloaded in a geodatabase format for the state of Louisiana. The geodatabase contained a polygon feature class with census block group boundaries and ID's. All associated socioeconomic and demographic data was contained in database tables (Figure 2).

The FEMA data used was the National Flood Hazard Layer geodatabase for the state of Louisiana, which consisted of a polygon feature class containing flood zones hazard types. As described in the feature class metadata:

> "The National Flood Hazard Layer (NFHL) data incorporates all Flood Insurance Rate Map (FIRM) databases published by the Federal Emergency Management Agency (FEMA), and any Letters of Map Revision (LOMRs) that have been issued against those databases since their publication date. It is updated on a monthly basis. The FIRM Database is the digital, geospatial version of the flood hazard information shown on the published paper FIRMs."

In order to accurately show surface water features on the final map products, hydrography data from the USGS National Hydrography dataset was also downloaded. This data was contained in a geodatabase which included a large amount of hydrographic data for the study area shown in orange in Figure 1. For the purpose of this study, only two polygon feature classes were added to the map: NHDArea and NHDWaterbody.

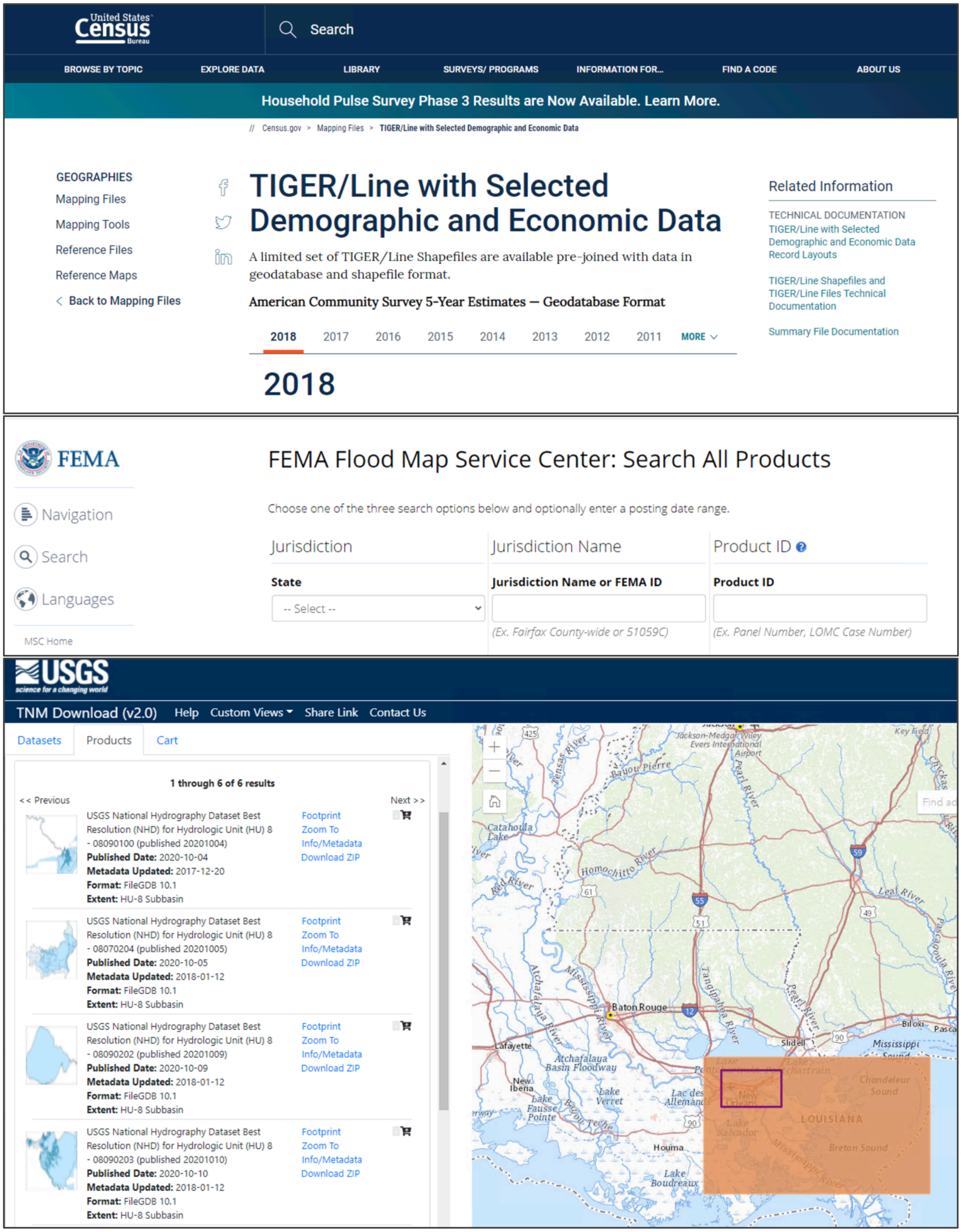


Figure 1: *US Census, FEMA, and USGS online database interfaces*

Table 1: *Data used in analysis*

	US Census	**Flood Hazard Map**	**Hydrography**
Source:	United States Census Bureau	FEMA	USGS
Format:	geodatabase	geodatabase	geodatabase
Names of files used:	Polygon feature class: ACS_2018_5YR_BG_22_LOUISIANA Database tables: X01_AGE_AND_SEX X17_POVERTY X19_INCOME X25_HOUSING_CHARACTERISTICS	Polygon feature class: S_FLD_HAZ_AR	Polygon feature classes: NHDArea NHDWaterbody
Datum:	GCS NAD 1983	GCS NAD 1983	GCS NAD 1983

Data and ArcGIS Processing

No pre-processing was required for the data used in this study. Once data had been downloaded from all three sources, data was viewed in ArcMap using ArcCatalog and added to the map document to be processed as needed. The hydrographic data required very little processing. The census and FEMA required substantial processing before additional analysis combining the two datasets could be conducted. Because the census and FEMA data contained data for the entire state, a simple polygon layer of the study area was constructed against which these larger data sets could be clipped to reduce file size and processing times.

Census Data

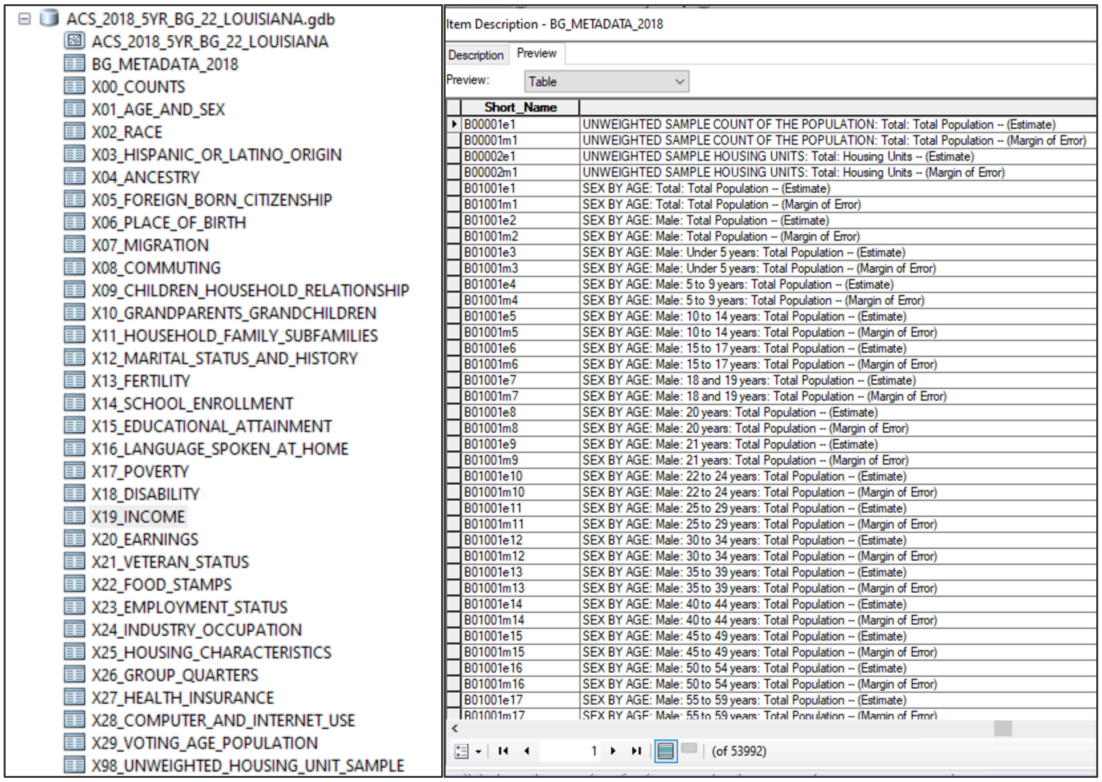
In order to work with the census data, it was necessary to join the polygon feature class of census block group boundaries and IDs with the attributes of interest from the database tables. However, each database table contained several thousand attributes. The steps completed were as follows:

Step 1. View the index database table (Figure 2, right) with definitions of all attributes contained in the database.

Step 2. Determine which attributes should be included in analysis (see Vulnerability Index section for discussion of which attributes were selected).

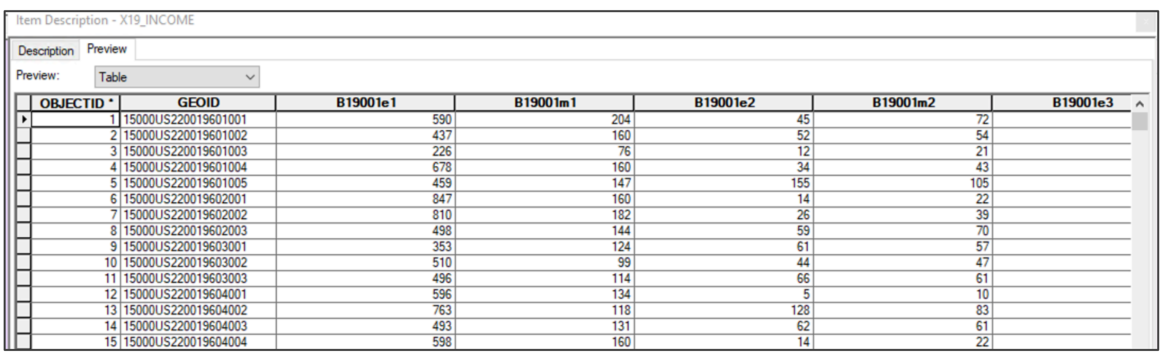
Step 3. Determine which database table contains attribute data. Import database table into map document using ArcCatalog (Figure 2, left).

Step 4. From Table of Contents, view attribute table (Figure 3) and then open properties window for database table (Figure 4). Unselect all attributes except the attributes needed for analysis.



Short_Name	
B00001e1	UNWEIGHTED SAMPLE COUNT OF THE POPULATION: Total: Total Population -- (Estimate)
B00001m1	UNWEIGHTED SAMPLE COUNT OF THE POPULATION: Total: Total Population -- (Margin of Error)
B00002e1	UNWEIGHTED SAMPLE HOUSING UNITS: Total: Housing Units -- (Estimate)
B00002m1	UNWEIGHTED SAMPLE HOUSING UNITS: Total: Housing Units -- (Margin of Error)
B01001e1	SEX BY AGE: Total: Total Population -- (Estimate)
B01001m1	SEX BY AGE: Total: Total Population -- (Margin of Error)
B01001e2	SEX BY AGE: Male: Total Population -- (Estimate)
B01001m2	SEX BY AGE: Male: Total Population -- (Margin of Error)
B01001e3	SEX BY AGE: Male: Under 5 years: Total Population -- (Estimate)
B01001m3	SEX BY AGE: Male: Under 5 years: Total Population -- (Margin of Error)
B01001e4	SEX BY AGE: Male: 5 to 9 years: Total Population -- (Estimate)
B01001m4	SEX BY AGE: Male: 5 to 9 years: Total Population -- (Margin of Error)
B01001e5	SEX BY AGE: Male: 10 to 14 years: Total Population -- (Estimate)
B01001m5	SEX BY AGE: Male: 10 to 14 years: Total Population -- (Margin of Error)
B01001e6	SEX BY AGE: Male: 15 to 17 years: Total Population -- (Estimate)
B01001m6	SEX BY AGE: Male: 15 to 17 years: Total Population -- (Margin of Error)
B01001e7	SEX BY AGE: Male: 18 and 19 years: Total Population -- (Estimate)
B01001m7	SEX BY AGE: Male: 18 and 19 years: Total Population -- (Margin of Error)
B01001e8	SEX BY AGE: Male: 20 years: Total Population -- (Estimate)
B01001m8	SEX BY AGE: Male: 20 years: Total Population -- (Margin of Error)
B01001e9	SEX BY AGE: Male: 21 years: Total Population -- (Estimate)
B01001m9	SEX BY AGE: Male: 21 years: Total Population -- (Margin of Error)
B01001e10	SEX BY AGE: Male: 22 to 24 years: Total Population -- (Estimate)
B01001m10	SEX BY AGE: Male: 22 to 24 years: Total Population -- (Margin of Error)
B01001e11	SEX BY AGE: Male: 25 to 29 years: Total Population -- (Estimate)
B01001m11	SEX BY AGE: Male: 25 to 29 years: Total Population -- (Margin of Error)
B01001e12	SEX BY AGE: Male: 30 to 34 years: Total Population -- (Estimate)
B01001m12	SEX BY AGE: Male: 30 to 34 years: Total Population -- (Margin of Error)
B01001e13	SEX BY AGE: Male: 35 to 39 years: Total Population -- (Estimate)
B01001m13	SEX BY AGE: Male: 35 to 39 years: Total Population -- (Margin of Error)
B01001e14	SEX BY AGE: Male: 40 to 44 years: Total Population -- (Estimate)
B01001m14	SEX BY AGE: Male: 40 to 44 years: Total Population -- (Margin of Error)
B01001e15	SEX BY AGE: Male: 45 to 49 years: Total Population -- (Estimate)
B01001m15	SEX BY AGE: Male: 45 to 49 years: Total Population -- (Margin of Error)
B01001e16	SEX BY AGE: Male: 50 to 54 years: Total Population -- (Estimate)
B01001m16	SEX BY AGE: Male: 50 to 54 years: Total Population -- (Margin of Error)
B01001e17	SEX BY AGE: Male: 55 to 59 years: Total Population -- (Estimate)
B01001m17	SEX BY AGE: Male: 55 to 59 years: Total Population -- (Margin of Error)

Figure 2: *Database tables included in census geodatabase (left) and index table with definitions of all census categories (right)*



OBJECTID *	GEOID	B19001e1	B19001m1	B19001e2	B19001m2	B19001e3
1	15000US220019601001	590	204	45	72	
2	15000US220019601002	437	160	52	54	
3	15000US220019601003	226	76	12	21	
4	15000US220019601004	678	160	34	43	
5	15000US220019601005	459	147	155	105	
6	15000US220019602001	847	160	14	22	
7	15000US220019602002	810	182	26	39	
8	15000US220019602003	498	144	59	70	
9	15000US220019603001	353	124	61	57	
10	15000US220019603002	510	99	44	47	
11	15000US220019603003	496	114	66	61	
12	15000US220019604001	596	134	5	10	
13	15000US220019604002	763	118	128	83	
14	15000US220019604003	493	131	62	61	
15	15000US220019604004	598	160	14	22	

Figure 3: *Database table for the income category shown as an example. The GEOID number is the ID of the census block group; each column name beginning with "B" corresponds to a census category listed in the index table in Figure 2.*

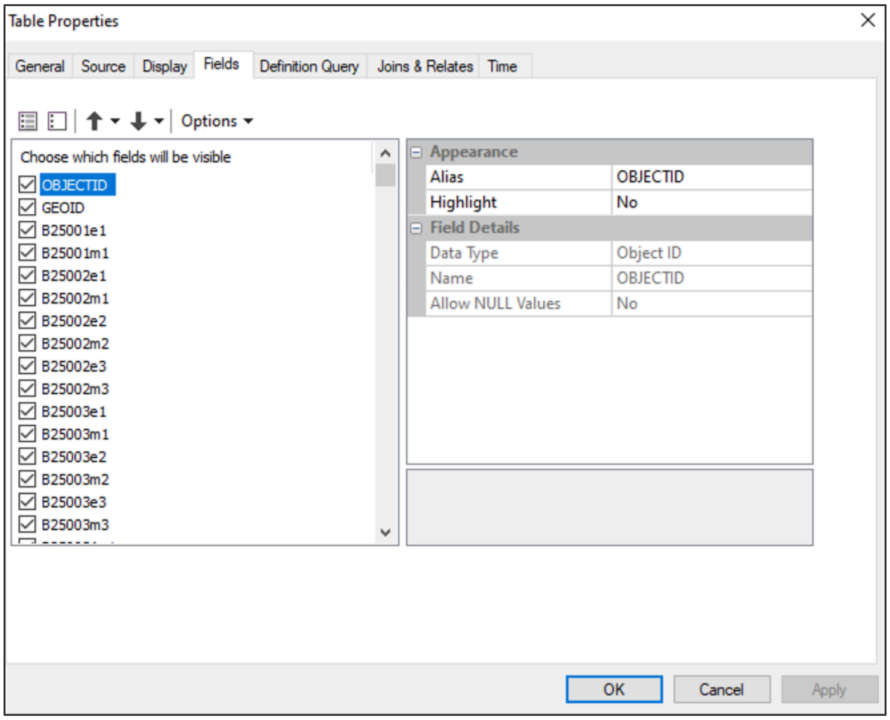
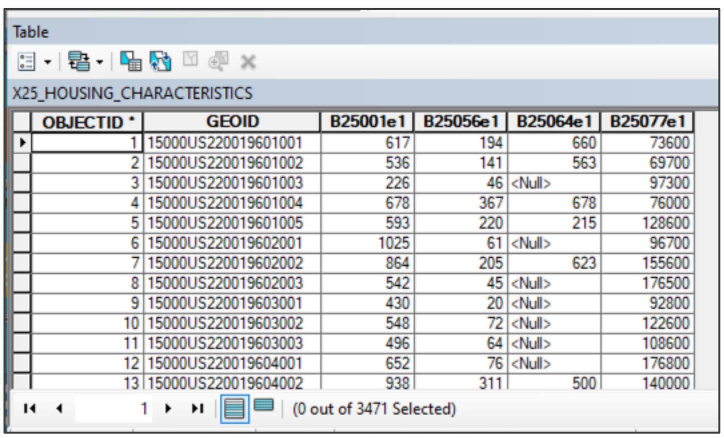


Figure 4: *Database table properties window*



Table

X25_HOUSING_CHARACTERISTICS

OBJECTID *	GEOID	B25001e1	B25056e1	B25064e1	B25077e1
1	15000US220019601001	617	194	660	73600
2	15000US220019601002	536	141	563	69700
3	15000US220019601003	226	46	<Null>	97300
4	15000US220019601004	678	367	678	76000
5	15000US220019601005	593	220	215	128600
6	15000US220019602001	1025	61	<Null>	96700
7	15000US220019602002	864	205	623	155600
8	15000US220019602003	542	45	<Null>	176500
9	15000US220019603001	430	20	<Null>	92800
10	15000US220019603002	548	72	<Null>	122600
11	15000US220019603003	496	64	<Null>	108600
12	15000US220019604001	652	76	<Null>	176800
13	15000US220019604002	938	311	500	140000

(0 out of 3471 Selected)

Figure 5: *Attribute table for Housing Characteristics database table after all unnecessary attributes have been turned off.*

Step 5. Reopen attribute table (Figure 5) to confirm only the attributes needed for the analysis appear.

Step 6. From Table of Contents, right click on database table, click Data > Export. Save/export the database table under a new name. This table will only contain the selected attributes.

Step 7. Repeat steps 3-6 for required attributes located in other database tables.

Step 8. Once all new tables containing only the attributes of interest have been created and added to the map, join each one of these tables to the polygon feature class by right clicking on the polygon feature in the Table of Contents > Join. Join by "GEOID_Data” in the polygon feature and “GEOID” in the database tables.

Step 9. Once all attributes have been added to the polygon feature's attribute table via "Join," open the feature's properties, go to "Fields" tab, and add an alias for each of the attributes (Figure 6).

Step 10. Use Clip (Analysis) tool to clip the polygon feature to the study area polygon.

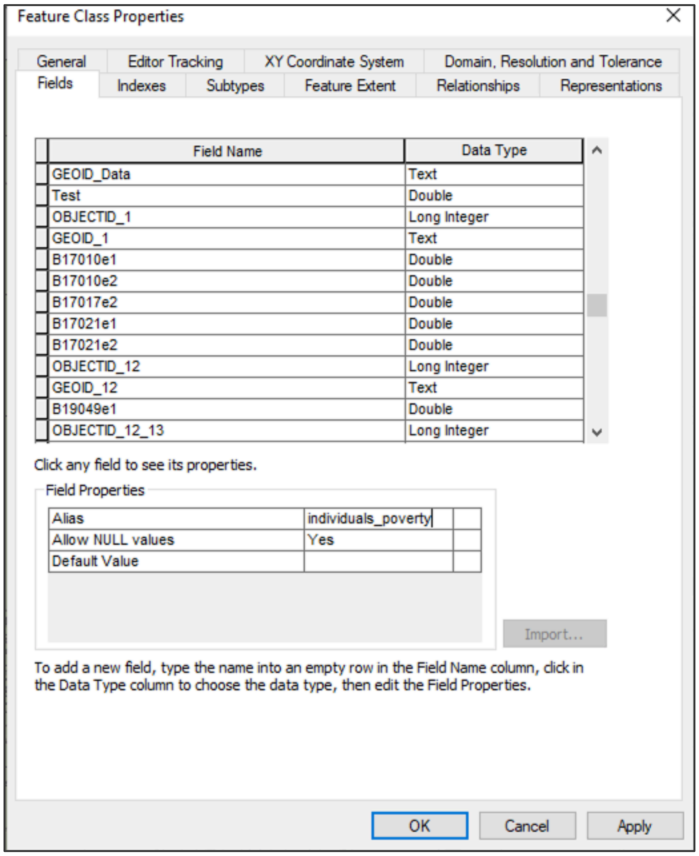


Figure 6: *Fields tab of properties window history after all attributes have been added to polygon feature.*

Importantly, as is common with census data, many of the census block groups were missing data. To fill in the missing data, it was desired to replace a block group's null value with the average value of all its neighboring polygons (Bixler and Yang, 2020). Fortunately, the Fill Missing Values tool in ArcGIS Pro can quickly perform this task, and the author had access to ArcGIS Pro through their research position. The newly created polygon feature class was imported into ArcGIS Pro. Figure 7 shows the tool and the three attributes for which missing values were filled. Once the operation was complete, the polygon feature class was saved and exported and then readded to the map document in ArcMap.

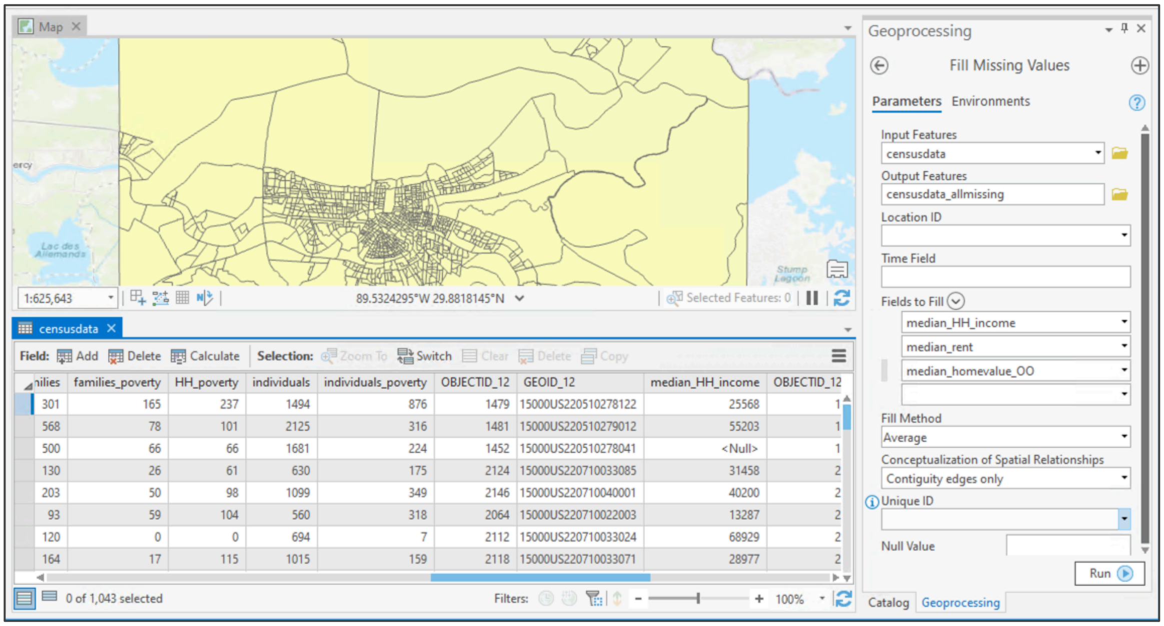


Figure 7: *Fill Missing Values tool in ArcGIS Pro used to fill null values in the census dataset.*

Vulnerability Index

The Austin Area Sustainability Indicators report that inspired this study (Bixler and Yang, 2020) employs the Social Vulnerability Index (SoVI® 2010-2014), developed by Cutter, Boruff and Shirley (2003) at the Hazards and Vulnerability Research Institute at the University of South Carolina. The SoVI® 2010-2014 contains 29 variables that can be found in US census data. For the purpose of this study, a highly simplified version of a socioeconomic vulnerability index was developed containing the five parameters shown in Table 2. Attributes were converted to percentages or normalized to bring all attributes to the same scale using the field calculator in the attribute table (Figure 8). Normalization was done using the following equation:

$$x_n = \frac{x - x_{min}}{x_{max} - x_{min}}$$

It is important to note that the data were normalized using the clipped dataset. Therefore, the normalized data values are in relation to the greater New Orleans study area (not the full statewide dataset). The five attributes were then added together to get the socioeconomic vulnerability index using the following equation:

$$Vulnerability = poverty + renter - home\ value - rent - income$$

Attributes that are positively correlated with higher vulnerability (poverty rate and percentage of renters) are added to the index; attributes that are negatively correlated with higher vulnerability (home value, rent, income) were subtracted.

Table 2: *Attributes used in vulnerability index*

Attribute	Description	Additional Processing
Poverty	Number of individuals under federal poverty level	Divided by total population to get %
Renter	Number of housing units that are renter-occupied	Divided by total number of housing units to get %
Home value	Dollar value of median home value of owner-occupied housing units	Normalized
Rent	Dollar value of median rent in renter-occupied housing units	Normalized
Income	Dollar value of median household income	Normalized

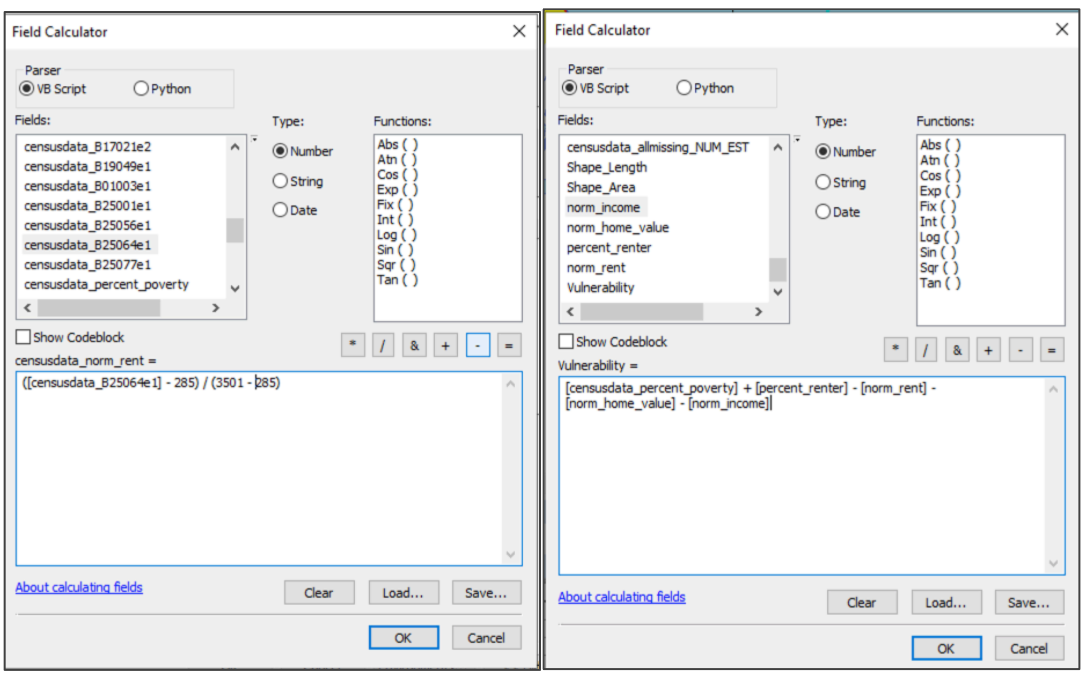


Figure 8: *Field Calculator showing equations for normalization of rent (left) and computation of socioeconomic vulnerability index (right).*

Flood Hazard Data

The flood data required less processing than the census data. However, in order to incorporate the flood data into the combined vulnerability, it needed to be reclassified from categorical zone types (X, AE, VE) to numerical values. To examine the impact of levees on the total vulnerability, the flood zones were reclassified twice using the field calculator: first considering all X zones the same, then separating out the X flood zones by subtype. Table 3 shows the values assigned based on flood zone as well as the code used. It is important to note that the proportions of these categories are not necessarily fully accurate. For example, the difference between X and AE may not be the same and the difference between AE and V, and therefore assigning values of 1, 2, 3, etc. may not accurately represent the magnitude of risk. However, for the purpose of this study it is assumed that this method will roughly capture the differences in risk, as V is riskier than AE, and AE is riskier than X. Like the census data, the flood risk data was also clipped to the study area polygon.

Table 2: *Reclassification of Flood Data*

	Assigned Value	
Flood Zone Type/Subtype	**X Subtypes Grouped Together**	**X Subtypes Differentiated**
X: 0.2% annual chance of flood hazard	1	1
X: area with reduced risk of flood hazard due to levee	1	1.5
AE: 1% annual change of flood hazard	2	2
VE: coastal area with >1% annual change of flood hazard	3	3

Code used in Field Calculator:	if [FLD_ZONE] = "X" then
	x = 1
	elseif [FLD_ZONE] ="AE" or [FLD_ZONE] = "A" then
	x = 2
	elseif [FLD_ZONE] ="VE" or [FLD_ZONE] = "V" then
	x = 3
	else
	x=0
	end if
		if [FLD_ZONE] = "X" and [ZONE_SUBTY] = "0.2 PCT ANNUAL CHANCE FLOOD HAZARD" then
		x = 1
		elseif [FLD_ZONE] = "X" and [ZONE_SUBTY] = "AREA WITH REDUCED FLOOD RISK DUE TO LEVEE" then
		x = 1.5
		elseif [FLD_ZONE] ="AE" or [FLD_ZONE] = "A" then
		x = 2
		elseif [FLD_ZONE] ="VE" or [FLD_ZONE] = "V" then
		x = 3
		else
		x=0
		end if

Combining Datasets

The Union (Analysis) tool was used to combine the flood polygon feature class with the census data polygon feature class into a new polygon feature class. Each polygon in this new feature class now contained a value for flood risk and a value for socioeconomic vulnerability. The field calculator was then used to simply add the flood risk and socioeconomic risk together into a "combined vulnerability" attribute. The vulnerability index and both versions of the combined flood and vulnerability and flood index were all symbolized using equal interval classification with 10 intervals.

While the "combined vulnerability" attribute is a useful tool to understand the total vulnerability from these two sources, it was also desired to understand the specific areas where both types of hazard are high. Once again, the field calculator was used to reclassify the two types of risk into high or low. For flood risk, if the zone type was AE or VE, it was categorized as high risk and given a value of 1. For vulnerability, if the index value was higher than the mean value for the entire dataset, it was categorized as high risk and given a value of 2. All other values were assigned 0. The two attributes were then added together, and the map symbolized to show areas with high flood risk (1), high socioeconomic risk (2), or both (3).

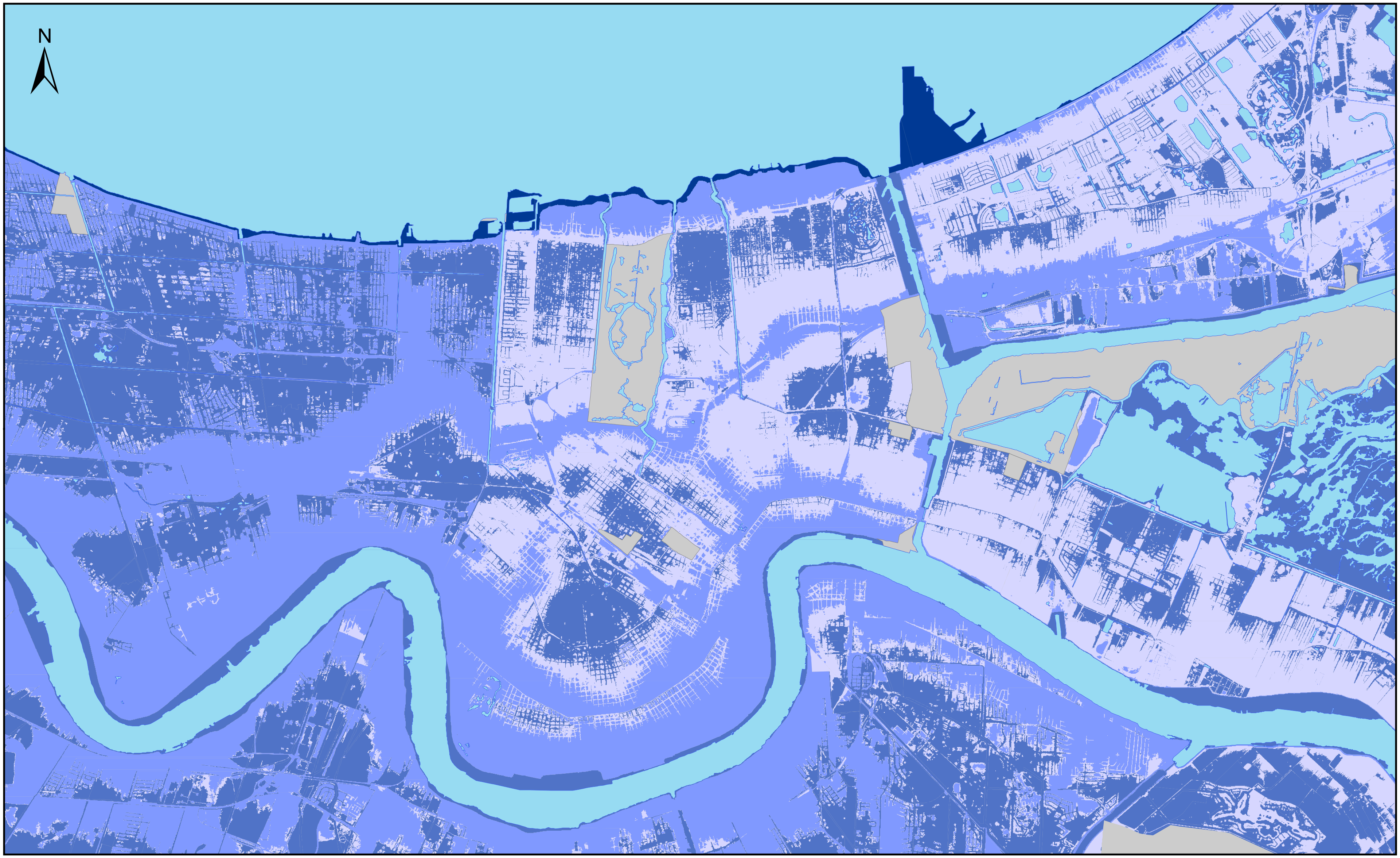
RESULTS

Figure 9 shows the FEMA flood zone map, symbolized by the four main flood zone types in the New Orleans area. Figure 10 shows the socioeconomic vulnerability map, symbolized by census block group from low to high vulnerability level.

Figures 11 and 12 show the combined flood and socioeconomic vulnerability index maps, symbolized from low to high vulnerability level. In both figures, the areas in red represent areas with the highest overall combined vulnerability. Residents in these areas would likely have the greatest difficulty preparing for, responding to, or recovering from a flooding event. Figure 11 represents the combined vulnerability when all X flood zones are considered equally (assigned a value of 1), while Figure 12 represents the vulnerability when X – area of low hazard due to levees – is assigned a higher risk value of 1.5. This distinction is important, because in comparing to the two figures we can see that by considering areas protected by levees to be higher risk, this raises the vulnerability level in many parts of this city. This is evident in the increase in red from Figure 11 to 12, particularly in the center of the city and areas south of the river.

Figure 13 highlights areas considered to be "high risk" and identifies the type of risk(s) in that area. While the distinction between high and low risk used in the analysis was a very rough estimate, these results are still useful for understanding the dominating risk type in various parts of the city. This information helps supplement the results presented in Figures 11 and 12 by showing what is driving the high vulnerability scores in different areas. When considering appropriate interventions, it is important to know if an area is experiencing high flood risk, socioeconomic vulnerability, or both. Areas that have high risk of either type deserve special attention, but decision makers should be especially focused on areas in red which are considered high risk in both categories. The areas shown in red also represent a correlation between high socioeconomic vulnerability and residing in a high-risk flood zone. Further investigation with more precise methods into this relationship is needed, but these results point to a concerning trend that is seen in many cities: groups that are at the highest risk socioeconomically often live in the areas with the greatest climate hazards.

Figure 9: FEMA Flood Zone Designations, New Orleans, LA



Flood Zone Types

- X, 0.2% annual chance flood hazard
- X, area with reduced risk due to levee
- AE, 1% annual chance flood hazard
- VE, coastal area, >1% annual chance flood hazard
- Open Water
- No Data

1:120,000

0 0.5 1 2 Miles

Datum: NAD 1983
Projection: Lousiana State Plane
Coordinate System 2011, South 1702

Source: FEMA

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December 7, 2020

Figure 10: Socioeconomic Vulnerability Index, New Orleans, LA

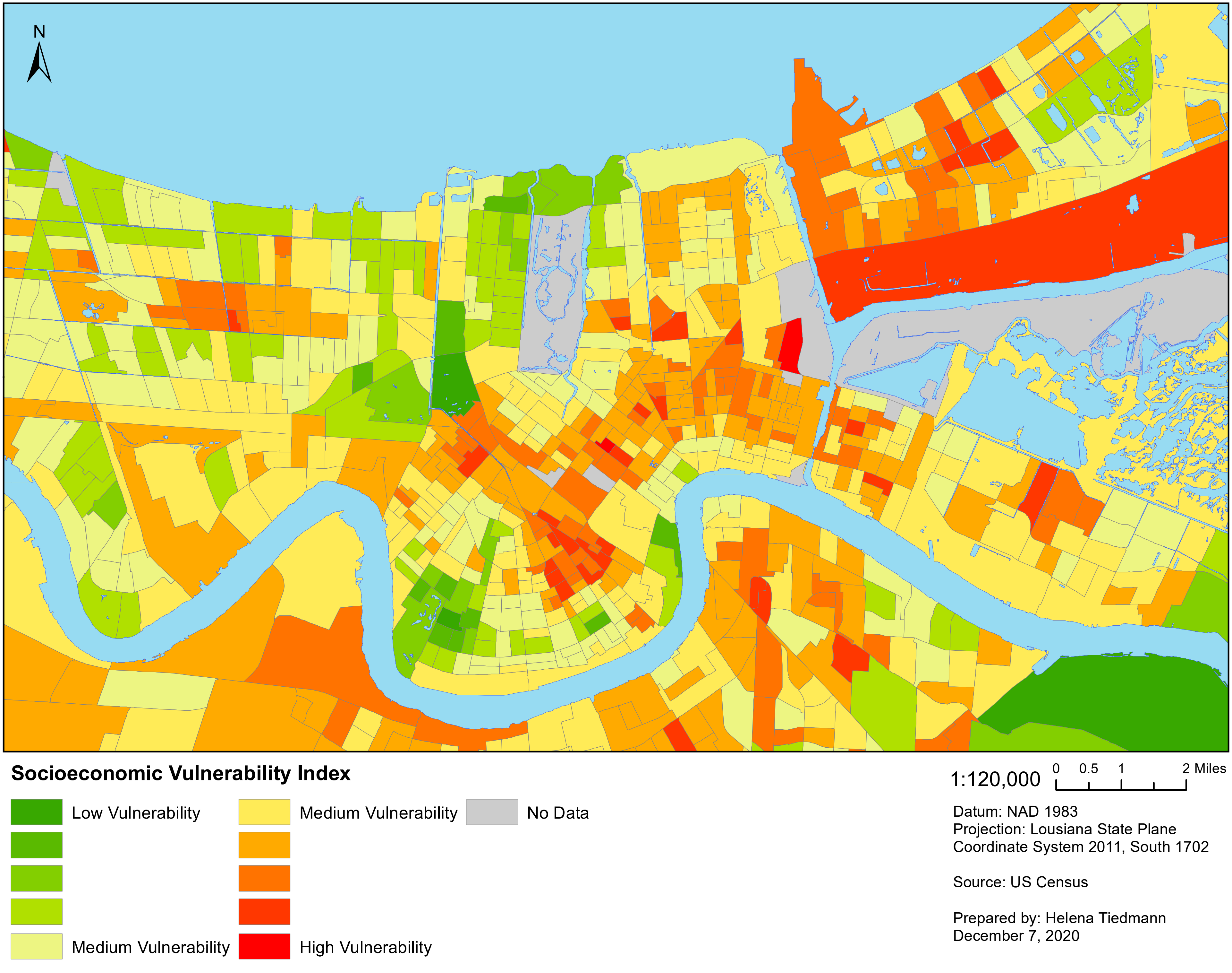
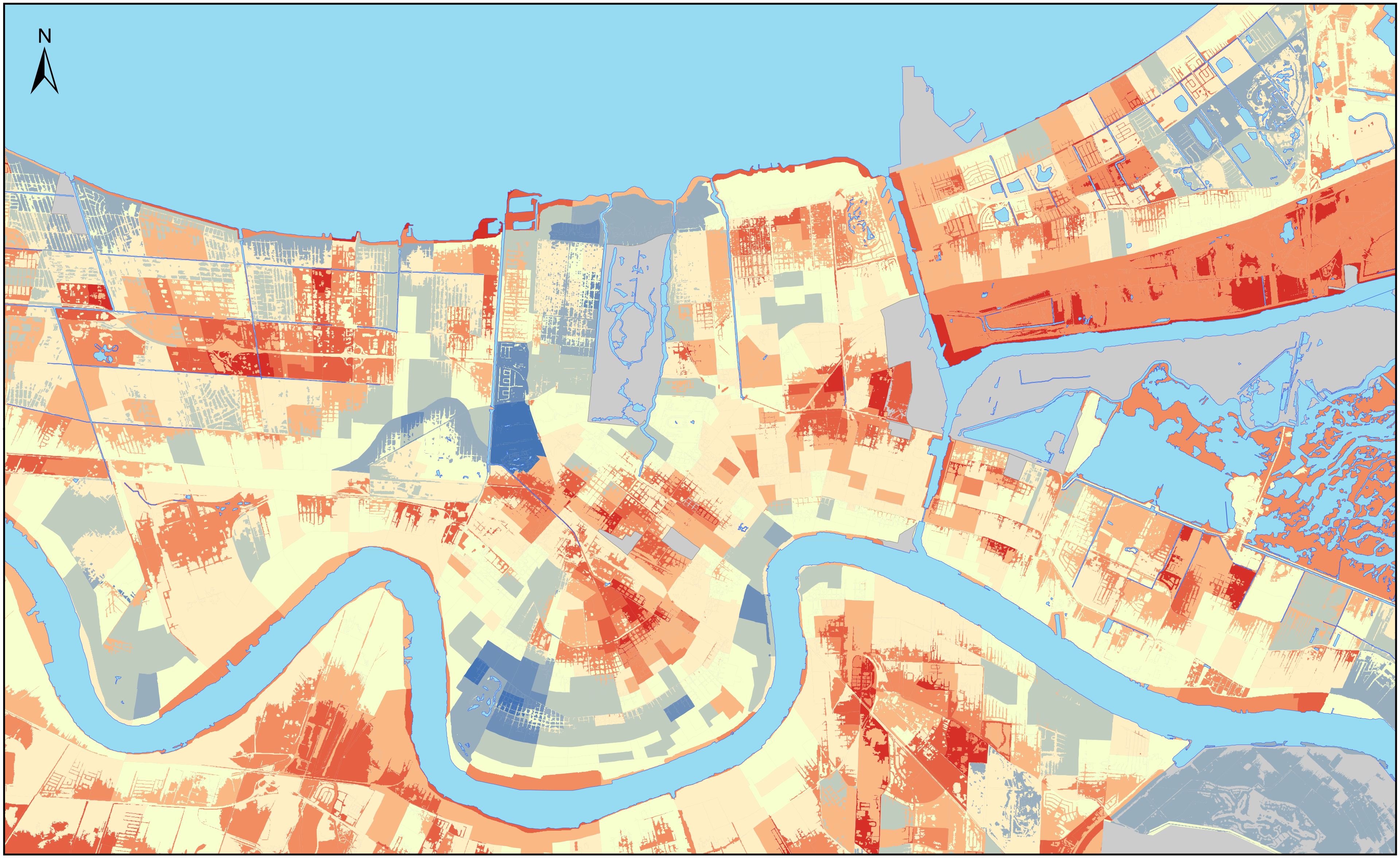


Figure 11: Combined Socioeconomic and Flood Vulnerability Index, New Orleans, LA



Socioeconomic and Flood Vulnerability Index

Low Risk
Medium Risk
Medium Risk
High Risk
No Data
Open Water

1:120,000 0 0.5 1 2 Miles

Datum: NAD 1983
Projection: Lousiana State Plane Coordinate System 2011, South 1702
Sources:
US Census
FEMA

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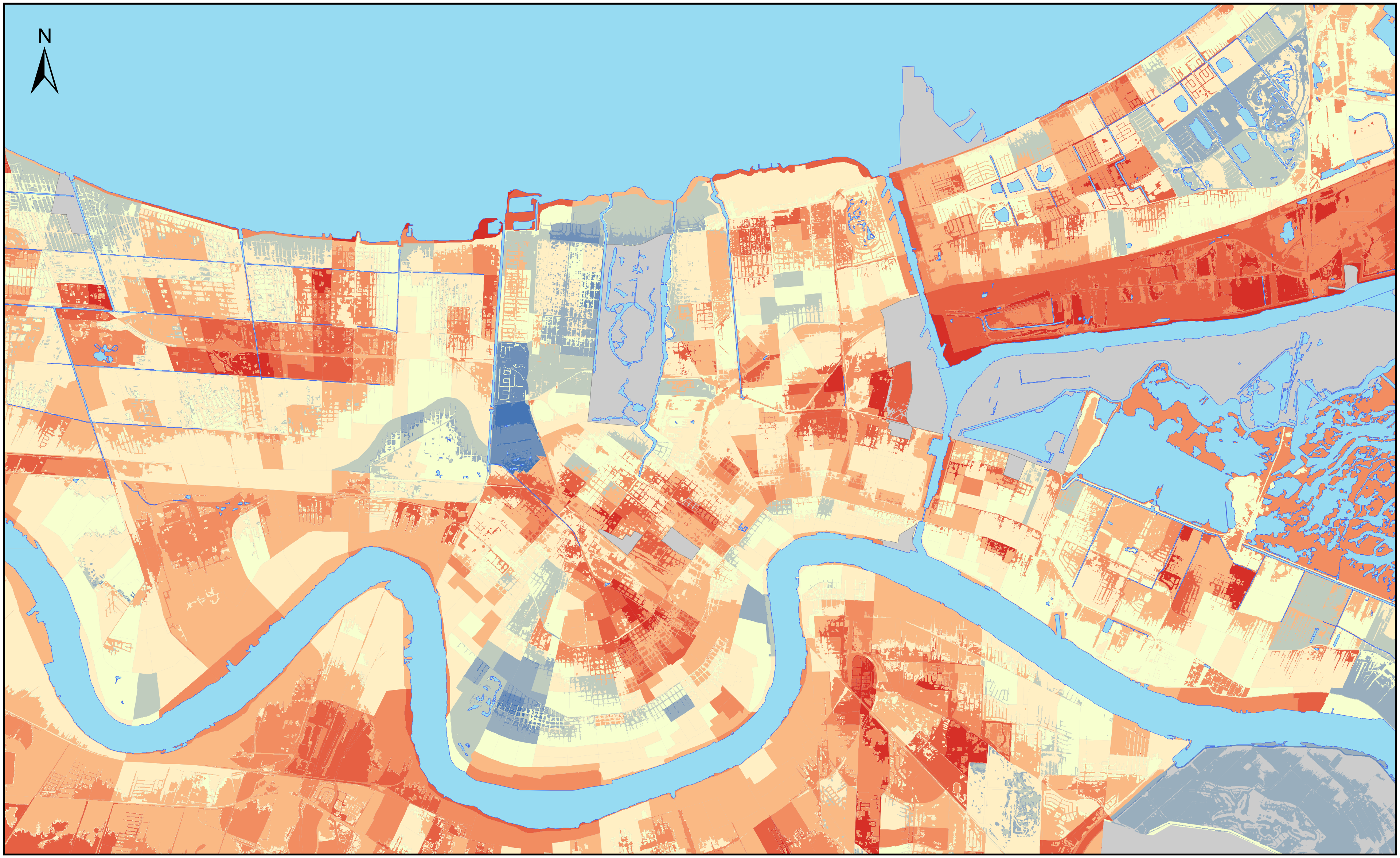
December 7, 2020

Figure 12: Socioeconomic and Flood Vulnerability Index Differentiating Levee Protection, New Orleans, LA



Socioeconomic and Flood Vulnerability Index

Low Risk

Medium Risk

High Risk

No Data

Open Water

1:120,000

0 0.5 1 2 Miles

Datum: NAD 1983
Projection: Lousiana State Plane
Coordinate System 2011, South 1702
Sources:
US Census
FEMA

Prepared by: Helena Tiedmann
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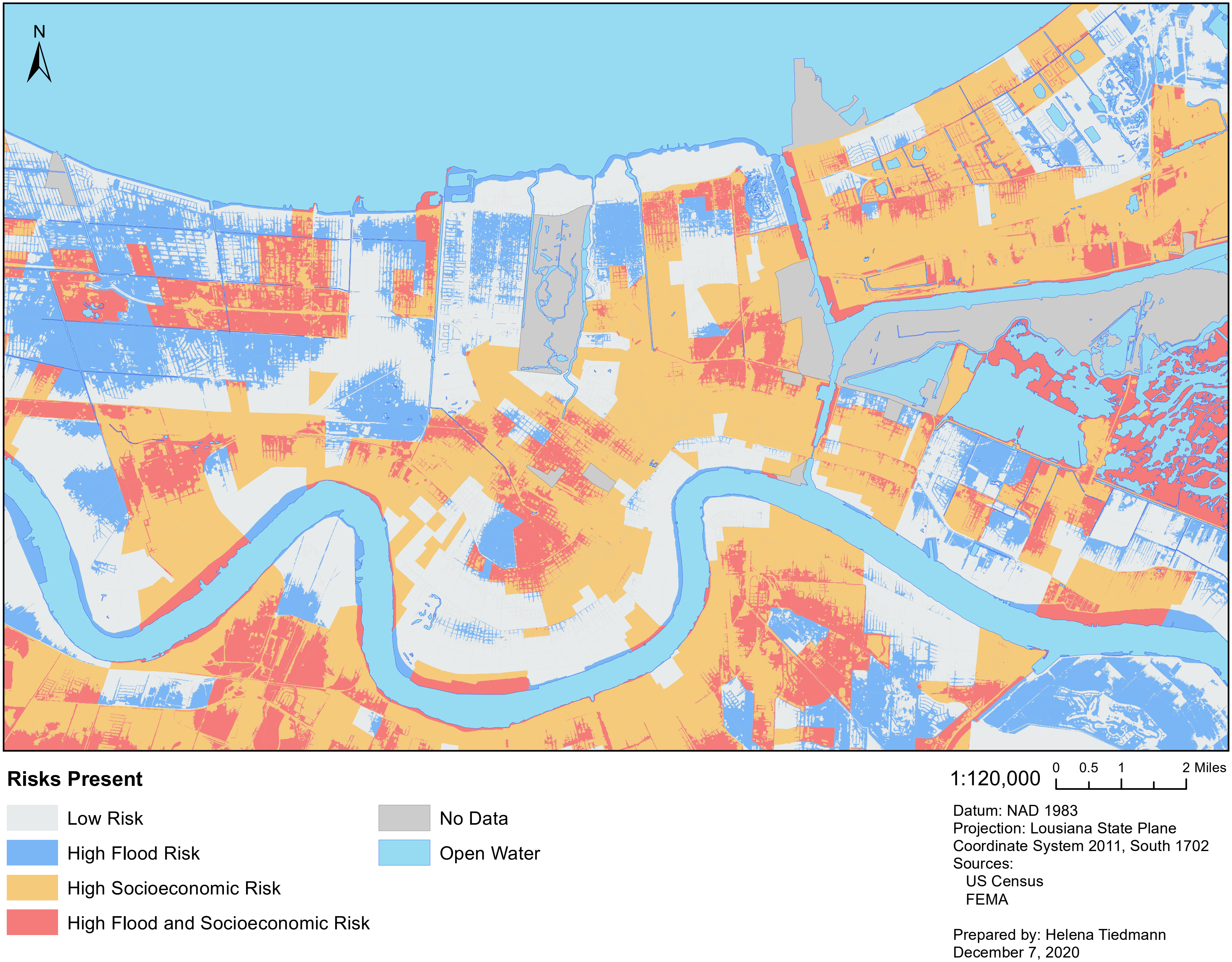
Figure 13: Areas of High Flood and Socioeconomic Risk, New Orleans, LA



CONCLUSIONS

There are a number of limitations to this work and assumptions that require discussion. First, a reduced number of attributes (five) was considered in the socioeconomic vulnerability index instead of the full 29 parameters identified in the SoVI®. Additionally, the assignment of values to flood zones for the purpose of calculating combined risk was not as precise as it could be. Finally, the designation of high and low flood and socioeconomic risk undertaken to produce Figure 13 was a rough distinction, at best. While all of these assumptions were logically sound given the scope and timing of the project, future work should certainly focus on improving the precision and accuracy of these methods and expanding to the full SoVI®.

Despite the assumptions and simplifications to the methods that were made in this study, the results still provide useful information for decision makers seeking to better understand flood risks and improve resiliency. In particular, the results highlight the importance of considering flood risks and socioeconomic vulnerability together and demonstrate that not all areas with a given flood zone designation have equal abilities to overcome flooding events. Specifically, significant portions of New Orleans fall under the "AE" flood zone type, but there is great variation in the socioeconomic vulnerability of residents living in such zones. Furthermore, the combined vulnerability scores presented in Figures 11 and 12 show that even if the flood risk is relatively low in an area with high socioeconomic vulnerability, if a flood hazard *were* to occur, residents would have limited ability to recover. Figure 13, on the other hand, reveals the correlations between hazard types and highlights areas that deserve increased attention from decision makers. For many complex reasons beyond the scope of this paper, we often see residents who experience higher socioeconomic vulnerability living in areas with higher flood risk. Understanding where these trends are occurring is an important first step for decision makers trying to improve outcomes.

This study also serves as a further proof of concept to the methods employed by Bixler and Yang in their 2020 report and demonstrates that these methods are widely applicable to other cities in the U.S. In this particular city, we see that there are differences in combined vulnerability based on whether or not we take into account the fact that levees are responsible for reducing risk. This information could be important for decision makers, as not all neighborhoods in levee protection zones have equal resources. Overall, despite several simplifying assumptions, this study produced results that quantitatively identify areas of high combined vulnerability. This work could therefore be a useful tool for decision makers trying to improve community resilience to climate hazards and prepare for more frequent and intense flooding events.

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