Indian River Lagoon

Storm Water Outfall Best Maintenance Report

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By: The East Central Florida Regional Planning Council

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Indian River Lagoon Stormwater Outfall Maintenance Best Practice Strategy Report

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Executive Summary

The IRL is divided into two nutrient limiting zones. Phytoplankton has a higher mean abundance in restricted areas with little water turnover. The IRL is divided into two nutrient limiting zones, northern and southern portions. The northern zone, from Ponce Inlet to Melbourne, is limited by Phosphorus. The southern zone, Melbourne to Martin County, is limited by Nitrogen. Anoxic conditions from Eutrophic waters can cause mass mortalities of fish, invertebrates, and aquatic vegetation. Nutrients, Nitrogen and Phosphorus, are positively charged particles that bind to soil. If baffle box debris removal is neglected, nutrient and fecal coliform bacteria leaching will occur. Tree canopy cover influences the quantity of particulate matter (PM) from leaf litter, and roads with curbed inlets retain more PM than non-curbed streets Vacuum assisted street sweepers and regenerative- air sweepers both utilize vacuums, but regenerative-air sweepers utilize pressured air blasts onto pavement to make finer grain PM more accessible to vacuum. Mechanical street sweepers have a lifespan of five years and vacuum assisted street sweepers have a life span of eight years and are more efficient at nutrient and PM removal than mechanical street sweepers. Roads within residential land use have been shown to have 1439 mg of TN and 425.8 mg of TP per kg of PM. Prioritizing street sweeping should be based on land use and seasonal trends, fall and early spring months when concentrations of PM from leaf litter are highest on road surfaces, will maximize cost effectiveness for reductions of PM loading through street sweeping. There were a total of 3000 curbed miles of residential roads that were within the MCE generated high priority areas throughout the IRL region. The concentration of high priority areas within Brevard County, St. Lucie County, and Martin County suggest that these counties would benefit strongest from the implementation of a rigorous street sweeping regimen. The finding from this report estimated that if all 3000 curbed miles of roads were swept once a month 33,840 pounds of TN, 10,080 pounds of TP, and 10,584,000 pounds of PM would be removed from road surfaces, actively preventing these pollutants from contaminating the IRL.

1.Introduction

1.1 Project Purpose

The intent of this report is to provide a storm water outfall best maintenance plan (BMP) for the Indian River Lagoon (IRL). This report evaluated costs and pollutant mitigation efficiencies of current BMPs utilized throughout the IRL region. This report identified street sweeping as the most cost effective approach for mitigating nutrient enrichment. A Multiple Criterion Evaluation model was applied to determine areas that would benefit strongest through street sweeping.

1.2 Study Area

The IRL is located along the central east coast of Florida. Its northern boundary is located within Volusia County, and its southern boundary is found within Martin County. Its center mass is found within Brevard, Indian River, and St. Lucie counties. Spatial and temporal patterns of nutrient content and limitation suggest that patterns of external nutrient loading play a significant role in phytoplankton dynamics. The IRL is vulnerable to fluctuations in water quality due to its low levels of flushing capability, and has portions which are confined by land resulting in the reduction of tidal flow. Phytoplankton has a higher mean abundance in restricted areas with little water turnover. The IRL is divided into two nutrient limiting zones. The northern zone runs from Ponce Inlet to Melbourne and the southern zone runs from Melbourne to Martin County. The northern zone of the IRL has been found to be limited by Phosphorus and the southern zone to be limited by Nitrogen (Phlips, E.J., et. al. 2002). Algal growth is constrained by its limiting nutrient; blooms become possible when the limiting nutrient becomes readily available for uptake by the algae

1.3 Overview of Ecological Concerns

Eutrophic conditions increase the turbidity of water, effectively reducing the amount of available light needed for the submerged aquatic vegetation, seagrasses, to photosynthesize. The reduction or complete loss in the ability to photosynthesize will stress and cause mortality of seagrass which provides critical habitat and ecosystem function. Seagrass benefits its environment by settling sediments, oxygenating water and by reducing dissolved aquatic nutrient concentrations to support its biological processes. Eutrophic conditions ultimately lead to anoxic (oxygen deprived) states from the metabolic process of consumption by microorganisms on the newly deposited organic material from deceased algae and seagrass. Anoxic conditions resulting from eutrophic waters can cause mass mortalities of fish and invertebrates.

1.4 Nutrient Relationship with Storm Water

Storm water runoff serves as a medium for nutrient transport and delivery into aquatic systems. Nutrients, Nitrogen and Phosphorus, are positively charged particles that form bonds with the negatively charged clay particles found in soil. Particle size has been shown to determine the affinity at which nutrients will most frequently form bonds with. Particle sizes between 75-100 µm was shown to have the highest levels of Total Nitrogen (TN), and particle sizes between 1-75 µm was shown to have the highest concentration of Total Phosphorus (TP) (Miguntanna, *et. al.* 2010). These small particles are distributed onto road surfaces through wind and rain events. A previous study on storm water found an average of 147 kg of PM per curb mile of road surfaces in FL; PM recovered from residential land covers had an average TN of 1439 mg per kg of PM and an average TP of 425.8 mg per kg of PM (Berretta, Christian; *et. al.* 2011). Residential property strongly contributes to nutrient deposition on road surfaces and subsequent nutrient enrichment from storm water runoff.

2. Outfall Best Management and Maintenance Practices

Numerous best management practices are currently employed by the IRL counties in order to address nutrient loading to meet total maximum daily load (TMDLs) limits set by the Florida Department of Environmental Protection (FDEP) (ECFRPC 2015). Creation of county specific best maintenance plans for existing BMP infrastructure and practices will optimize nutrient mitigation performance. This section will analyze current best management practices (BMP) and infrastructure.

2.1 Baffle Boxes

Baffle boxes are frequently used as a BMP for improving water quality. They are designed to reduce aquatic pollution from nutrients, heavy metals, particulate matter (PM), and suspended solids. Baffle boxes operate by utilizing chambers, divided by baffle barriers, in which storm water influent must flow over. The chambers within the box slow water flow. Ideally, the large PM settles within the first chamber and smaller PM settles within the second chamber and the remaining effluent flows out of the baffle box over the second baffle void of PM (USEPAOW. 2001).

Baffle boxes come in a variety of sizes depending on anticipated storm water influent flows, but they are divided into two types. Type 1 baffle boxes operate as described above. Type 2 baffle boxes implement screens above the baffle barriers within the box. The screens are designed to provide further filtration to remove large PM, such as leaves and grass clippings that have not settled on the bottom of the chambers.

Baffle box site selection depends on a variety of parameters. Most baffle boxes currently in use were placed in confined drainage basins where other upstream BMPs, such as retention ponds and bio swales, could not be implemented, as well as areas containing tree canopy coverage over 25% and curbed streets. Tree canopy cover influences the quantity of PM from leaf litter, and roads with curbed inlets retain more PM than non-curbed streets.

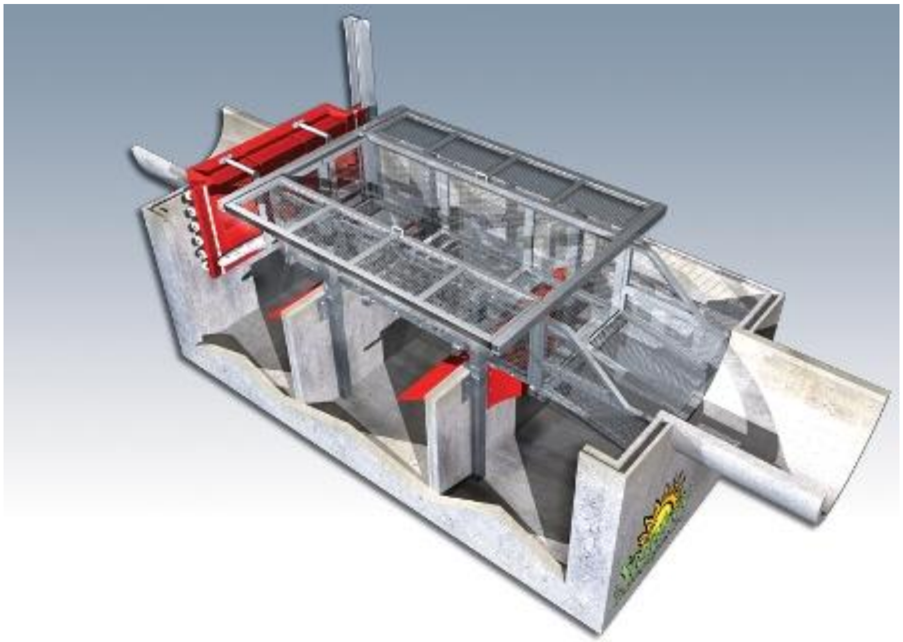


Figure 1: Type 2 baffle box with the filtration screen from Sun Tree Tech.

2.12 Baffle Box Effectiveness

A study in Sarasota FL, for the Florida Department of Environmental Protection, examined the effectiveness of its baffle boxes for nutrient, suspended solids (SS), phosphorous, and fecal coliform removal. Type 1 and type 2 baffle boxes were found to perform poorly at reducing nutrient, SS, and fecal coliform pollution. However, type 2 did show an increase in the reduction of pollutants over type 1(Deitche, M. Scott; *et. al.* 2010). The study addressed the reasoning behind the inefficiencies of the baffle boxes.

The screens in type 2 baffle boxes capture leaf litter and suspend them above the storm water influent. Screens inundate with PM, subsequently reducing water flow within the box. Within the screen, water can pool for days after rain events. Though PM is captured within the screen, nutrients leach into the effluent chamber of the baffle box. This was determined by clear water within the screen containing PM and turbid water in the effluent chamber. Leaf litter was also found in the chambers, showing the inefficiency of screened baffle boxes. The increase in fecal coliform bacteria is the result of the biological decay of PM captured within the screens and chambers. The decaying process reduces the dissolved oxygen levels promoting the growth of fecal coliform bacteria and nutrient leaching. Table 1 represents removal efficiencies for type 1 and type 2 baffle boxes.

Baffle Box	Suspended Solid Removal Efficiency (EMC)	Nitrogen Mass Removal Efficiency	Phosphorous Mass Removal Efficiency	Fecal Coliform Removal Efficiency (EMC)
Type 1 Average	-13.1%	0.50%	2.3%	-46.85%
Type 2 Average	21.8%	19.05%	15.50%	-117.95%

Table 1: Average EMC and total mass removal efficiencies of type 1 and type 2 baffle boxes from four baffle boxes (Deitche, M. Scott; et. al. 2010).

2.13 Baffle Box Maintenance

Baffle Boxes require frequent maintenance to maintain optimal performance. Type 1 baffle boxes require less maintenance than type 2 because the screens found within type 2 baffle boxes frequently inundate with PM. Maintenance for baffle boxes are site dependent, and require individual maintenance schedules based on the frequency in which screens and chambers become inundated with PM (Deitche, M. Scott; *et. al.* 2010). Crews are responsible for visual inspection of baffle boxes to determine individual maintenance schedules for each baffle box, and the removal of PM in screens by hand. It is expected that during fall and winter months, when street leaf litter peaks, baffle boxes will inundate with PM more frequently than during spring and summer months. If baffle box debris removal is neglected, nutrient and fecal coliform bacteria leaching will occur.

Martin County, (Nolte, Greg. 2016), performs routine topical inspection of their baffle boxes for half an hour each; this inspection removes any debris within screens and costs $45.00 per box. Each box is a cleaned annually with a vactor truck to remove PM from sumps for $130.00, and screens are replaced annually for $590.00. This totals $760.00 of annual maintenance costs per box. Costs for installation vary depending on numerous variables. Martin County, according to the Engineering Department, has paid $13,000-$27,000 for 4’x8’ baffle boxes; $18, 00-$41,000 for 5’x10’ baffle boxes; $20,000-$40,000 for 6’x12’ baffle boxes; and $80,000-$100,000 for 10’x16’ baffle boxes, excluding installation costs.

2.2 Street Sweeping

Street sweeping is a common BMP utilized to reduce nutrient loading into waterways. There are three types of street sweeping vehicles commonly used by municipalities: mechanical, vacuum-assisted sweepers, and regenerative-air sweepers. Mechanical sweepers utilize a broom and conveyor belt system to capture PM found on roads. Vacuum assisted street sweepers and regenerative-air sweepers both utilize vacuums, but regenerative-air sweepers utilize pressurized air blasts onto pavement to make finer grain PM more accessible to vacuum (Urban Drainage and Flood Control District, 2010). The PM collected by street sweeping requires proper disposal at landfills or approved dump sites.

2.21 Street Sweeping Effectiveness

Land use type can affect PM concentrations, specifically PM bound to nutrients. The University of Florida quantified nutrient removal of various storm water BMPs for the Florida Stormwater Association Educational Foundation (FSAEF); the results show the effectiveness of street sweeping at removal of phosphorous and nitrogen from roads within various land use types: residential, commercial, and highway. Total Nitrogen (TN) and Total Phosphorous (TP) removal values were calculated in mg of TN or TP per kg of dry PM captured by street sweepers, shown in Table 2. TP removal values were highest from highway land use: 622.0 mg/kg of PM; TN removal values were highest from residential land use: 1439.0 mg/kg of PM (Berretta, Christian; *et. al.* 2011).

Land Use	Mean TP mg/kg of PM	Mean TN mg/kg of PM
Commercial	482.6	789.1
Residential	425.8	1439.0
Highway	622.0	826.6

Table 2: Nutrient removal values from street sweeping based on surrounding land use (Berretta, Christian; *et. al.* 2011). Values expressed in units of mg of TN or TP removed per kg of PM collected from street sweeping.

2.22 Street Sweeping Maintenance

Street sweeping maintenance can optimize nutrient loading reduction and storm water outfall preservation by addressing physical and temporal parameters: land uses and seasonal rain patterns.

Street sweeping roads, within residential land uses, will target reducing nitrogen loading, since fertilizers, applied to lawns are common sources of nitrogen. Nutrients that are not utilized by lawns leach into the soil, where they bind to fine grain clay particles. Storm water runoff and wind can transport these small particles of soil. It is critical to street sweep residential areas with drainage basin feeding into the IRL to remove PM pollutants.

Seasonal weather patterns also influence optimal street sweeping maintenance scheduling. There is a relationship between rain events and pollutant concentrations. The first flush phenomenon is the initial period of storm water runoff during which the concentration of pollutants is substantially higher than during later stages; intensity of rain events also increases pollutant loading (Lee, J.H; *et. al.* 2002*)*. Antecedent dry periods, the amount of time between two rain events, affects pollutant concentrations on roads; the length of the antecedent dry period has a positive feedback loop with increased pollutants (Soller, Jeffrey; *et. al.* 2005). Utilizing local seasonal patterns of rain intensity and antecedent dry periods will generate stronger maintenance plans for street sweeping. Prioritizing roads based on land use and seasonal rain events will maximize cost effectiveness for PM loading reduction.

Mechanical street sweepers have a lifespan of five years before they become decommissioned, and vacuum assisted street sweepers have a lifespan of eight years (EPA 1999). The City of Lakeland's Construction and Maintenance Department reported vacuum assisted street sweepers cost $75,000-$180,000, which reduced to an average cost of $33.8 per curb-mile[1] swept; the estimated cost includes maintenance, fuel, and employee salary (EPA 1999). These averages represent cost values from 1998, requiring inflation adjustment. Table 3 below shows cost adjustment for 2016 inflation according to the Bureau of labor Statistics' consumer price index historical inflation rates.

Sweeper Truck Cost	Cost/curbed mile	Cost/mile
$109,010-$261,625	**$49.13**	**$98.26**

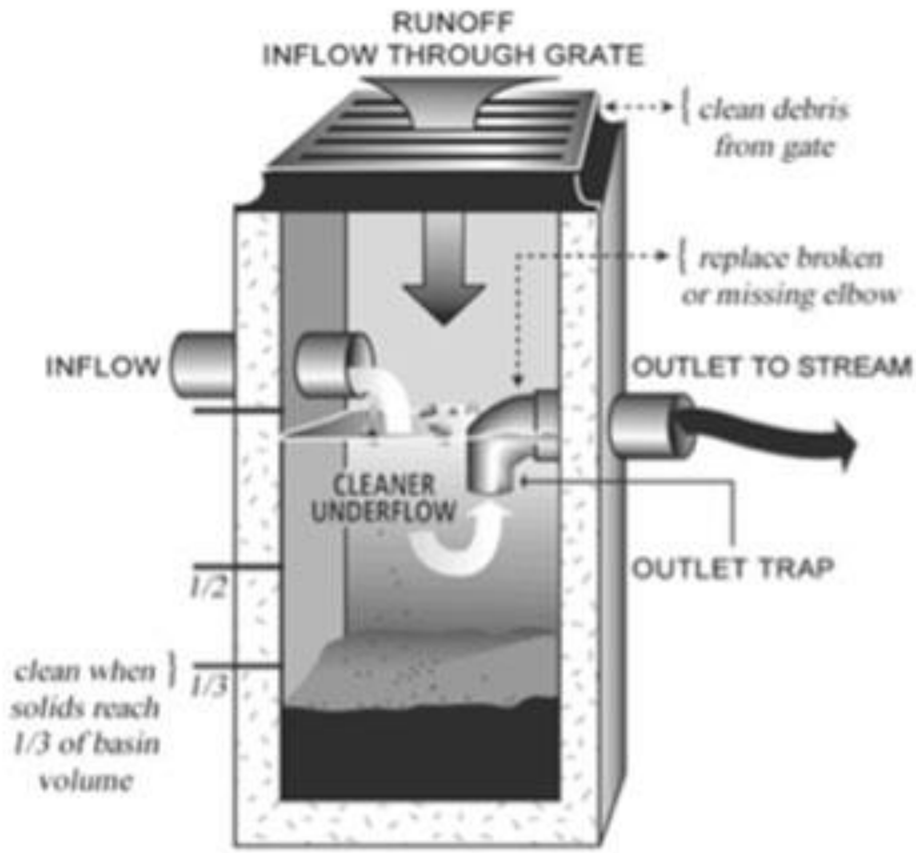
Table 3: Costs for vacuum assisted street sweeping operation costs adjusted for 2016 inflation rates.

Figure 2: A vacuum assisted street sweeper from New Providence New Jersey's Public Works Department.

[1] Curbed miles represent one side of a road; total cost per mile will require doubling the cost for curbed mile.

2.3 Catch Basins

A catch basin is a storm water inlet that has a concrete or steel sump that is below the influent and effluent storm water pipe. The sump is designed to capture PM, preventing its dispersal into storm water outfalls associated with the catch basin (City of Oakland Park). Catch basins are critical components of storm water infrastructure.



Fig**ure 3:** Catch basin, Doetsch Environmental Services, with a sump below the inlet and outlet storm water pipes.

2.31 Catch Basin Effectiveness

A catch basin can retain large quantities of PM within its sump depending on its size and volume of storm water influent. Ideally, PM settles below the water line trapping nutrients. Research from the University of FL for the Florida Stormwater Association Educational Foundation (FSAEF) quantified nutrient capture and removal for catch basins occurring in varying land uses: Commercial, Residential, and Highway. Units were expressed as mg of TP or TN per kg of removed PM. Catch basins along highways were most effective at nitrogen and phosphorous removal, 1926.3 mg/kg of PM and 566.6 mg/kg of PM: followed by catch basins within residential areas, and then catch basins within commercial areas (Berretta, Christian; *et. al.* 2011). Table 4 below compares mean TN and TP concentrations.

Land Use	**Mean TP mg/kg of PM**	**Mean TN mg/kg of PM**
Commercial	530.9	1459.7
Residential	559.2	1803.9
Highway	566.6	1926.3

Table 4**:** Nutrient removal values from catch basins based on surrounding land use (Berretta, Christian; *et. al.* 2011). Values expressed in units of mg of TN or TP removed per kg of PM.

2.32 Catch Basin Maintenance

Catch basin's effectiveness at mitigating nutrient loading is determinant on the frequency of maintenance and site selection. Sumps frequently become inundated with PM and require maintenance from vacuum trucks to remove the PM. Like baffle boxes, catch basins would benefit from individual maintenance scheduling based on storm water influent volume and PM deposition. The Oregon Department of Environmental Quality suggest the removal of PM from sumps once a month, or if PM accumulates above one third to the waterline (Oregon Department of Environmental Quality). However, if a catch basin receives low levels of PM deposition annual cleaning will suffice. Maintenance crews need to address which basins would benefit from an increased vacuum cleaning regimen. According to Volusia County Road and Bridge Department, basin cleaning costs an average of $94.00 to clean out one catch basin (Maroney, Sean. 2016).

3. BMP Cost and Effectiveness Comparison

A best maintenance plan for storm water outfalls within the IRL needs to provide a cost-effective nutrient loading mitigation strategy in order to satisfy total maximum daily loads, (TMDL) set by the FDEP. IRL counties stated that inadequate funding was the strongest impediment for implementing basin management action plans to meet TMDL requirements (ECFRPC 2015).

This report provides a cost effective maintenance plan to reduce nutrient and PM loading into the IRL through street sweeping. Storm water outfalls will also be maintained by removing PM off streets before it becomes deposited into storm water infrastructure. Rates of TN and TP removal were compared in order to determine street sweeping as the preferred best maintenance practice. Table 5 below compiles a cost comparison of TN and TP per pound removal for baffle boxes, catch basins, and street sweeping BMPs.

BMP	Mean TN ($/lb.)	Mean TP ($/lb.)
Desoto Baffle Boxes: Brevard County (Satellite Beach 2015)	13,944	120,364
Catch Basin (FSAEF)	1,016	1,656
Street Sweeping(Satellite Beach 2015)	79	175

Table 5: BMP cost comparison for baffle boxes, catch basin, and street sweeping

3.1 Baffle Box

Findings in this report suggest that the environmental benefits baffle boxes provide do not justify the costs associated with the maintenance, initial purchase, and installation. To recover 1 lb. of TP and TN, it is necessary to purchase and annually maintain 4.4 type 2 baffle boxes and 1.8 type 2 baffle boxes (Deitche, M. Scott; *et. al.* 2010). Brevard County had an average cost of $13,944/lb. of TN and $120,364/lb. for baffle boxes on Desoto Avenue (Satellite Beach Utility 2014).

Budget funds set aside for baffle boxes should be considered for reallocation towards increased street sweeping regimens to provide a greater impact on nutrient loading reduction, while effectively reducing PM deposition into storm water infrastructure.

3.2 Street Sweeping

The report for FSAEF found an average of 1439 mg of TN and 425.8 mg of TP per kg of PM per curb mile, recovered by street sweeping within residential land uses throughout FL, and averaged 147 kg of PM recovered per mile swept (Berretta, Christian; et. al. 2011). Using these values, a breakdown of removal rates was performed to quantify nutrient removal per mile from street sweeping residential land uses. Cost analyses was created from using the data from Table 3 and shown on Table 6. This shows vacuum assisted street sweepers are more efficient at nutrient and PM removal than the mechanical street sweepers frequently contracted out to municipalities in the IRL region.

Nutrients	mg/kg	lbs./curb mile	Curb miles/lb.	Costs/lb.
TN	1439	0.47	2.13	$104.65
TP	426	0.14	7.15	$351.28

Table 6 Nutrient removal rates calculated from values obtained through the FSAEF report on storm water maintenance.

Street sweeping has been identified to provide the most cost effective approach to reduce nutrient loading. Residential and commercial land uses, which significantly contribute to nutrient loading, permeate throughout all five IRL counties. Since lack of funding is the strongest inhibitor to meeting TMDLs within BMAPs, individual street sweeping maintenance plans for the IRL provide a practical solution to address TMDL requirements for IRL counties.

4. Generalized Best Maintenance Schedule

4.1 Baffle Boxes and Catch Basins

Baffle boxes and catch basins will require frequent visual inspections and screen cleaning. Each box will require annual or biannual sump cleaning by vacuum trucks depending on the individual baffle box and catch basins characteristics. If tree canopy coverage exceeds 40%, jurisdictions should expect to perform increased maintenance on baffle boxes and catch basins to remove leaf litter from sumps and screens. Below, Table 7 depicts a maintenance schedule to be applied to existing catch basins and baffle boxes.

BMP	Cursory Inspection	Sump Cleaning with Vac Truck	Screen Replacement
Baffle Box Type1	Weekly	Fall and Spring	N/A
Baffle Box Type 2	Weekly	Fall and Springs	Annually
Catch Basin	Weekly until PM deposition is understood	Fall and Spring	N/A

Table 7: Maintenance schedule for baffle boxes and catch basins.

4.2 Street Sweeping

Street Sweeping will require a maintenance schedule based upon seasonal variables. Winter and spring months will require extensive street sweeping due to the long antecedent dry periods experienced during these months. As part of this report, street sweeping routes were created for each county by clipping residential roads to MCE generated high priority areas. This analysis identified roads that benefit best from a street sweeping regimen to meet TMDLs for the IRL. Routes received a priority ranking based on expected nutrient load reductions. Roads within high priority were given estimations of TN, TP, and PM removal and costs for the IRL region and each of the five counties within the study area: Volusia, Brevard, Indian River, St. Lucie, and Martin County.

5. Methodology

5.1 Data Collection

The original road shapefile was obtained through Florida Department of Transportation. Outfall data for the IRL was obtained through the East Central Florida Regional Planning Council shapefile database. The Florida GAP land cover raster was obtained through the Unites States Geological Survey online download site.

5.2 GIS

All shapefile and raster data sets were projected in NAD 1983 HARN State Plane Florida East FIPS 0901 (US Feet). All raster data sets were given resolutions of 100 feet.

All county boundary shapefiles were merged to create a study area boundary shapefile. The original road shapefile was clipped to the IRL boundary shapefile. A new field was added to the clipped road shapefile and was populated with road length in miles. The GAP land cover raster was reclassed into natural areas (1), agriculture (2), fresh water (3), salt water (4), medium intensity development (5), low intensity development (6), high intensity development (7), and developed open space (8). The newly reclassed land cover raster was converted into polygons and then clipped to the IRL counties shapefile. The saltwater shapefile was created by extracting the saltwater from the GAP land cover vector shapefile.

The Euclidean Distance tool was performed on the outfall, saltwater, and road shapefiles to generate raster Euclidean distance data sets which would be used in the Multiple Criterion Evaluation (MCE) IDRISI model. The reclassed land cover data for the IRL study area was further reclasssed to assign Landscape Development Intensity Indexes (LDI) to individual land classes based from previous LDI coefficients (Brown, *et. al.* 2004) and were multiplied by 100.

Land Class	Land Class Value	LDI Index
Natural Undeveloped Areas	1	**100**
Agriculture	2	**360**
Fresh Water	3	**100**
Salt Water	4	**100**
Medium Intensity Developed	5	**900**
Low Intensity Developed	6	**800**
High Intensity Developed	7	**900**
Developed Open Space	8	**183**

Table 8: LDI Values for IRL Land Cover

5.23 IDRISI pre-processing

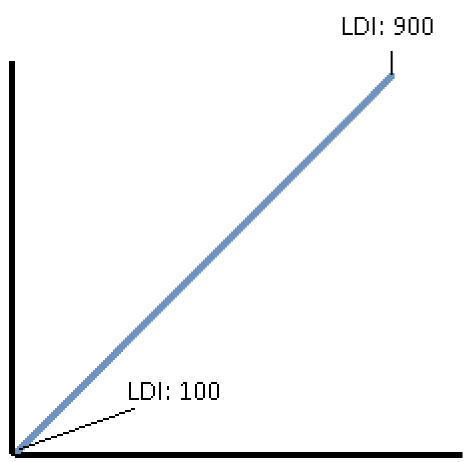
In order to process data sets in IDRISI, the extents must be identical to all files, requiring extensive geo-processing within ArcMap.

All raster data sets were reclassed to a value of 1, converted to vector files, and individually clipped to the IRL counties shapefile. A boundary file was formed by using the intersect tool for each of the clipped vector shapefiles. All original raster data were converted into vector polygons and clipped to the border shapefile. The clipped vector files were then converted into raster data sets with identical extents. The raster data sets were then converted into ASCII format, which allowed them to be used within IDRISI software.

All raster data sets were imported into IDRISI. Each data set of Euclidean distance functions (saltwater, outfall, and roads) and the LDI land cover data were assigned mathematical distance relationship functions using the Fuzzy tool in IDRISI.

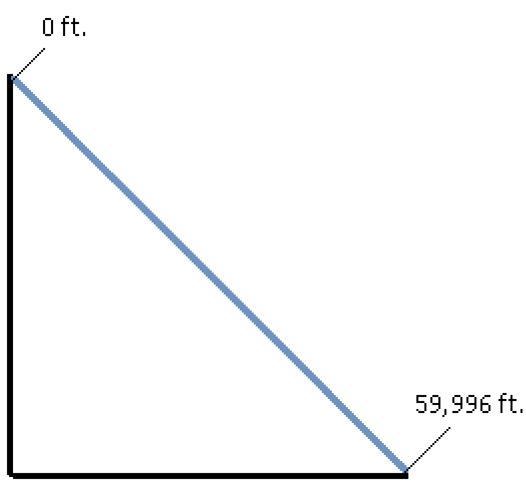
A linear monotonically increasing function was applied using Fuzzy tool to the LDI land class file. The first inflection point was set to the LDI value of 100, and the last inflection point was set to 900 which was the highest LDI value. These inflection points were chosen because natural and aquatic land covers have the lowest probability of contributing to high levels of PM, N, and P on road surfaces. The probability of PM, N, and P deposition on road surfaces rises along with the increase of LDI values. Low density development land class (LDI: 800) and medium through high density developed land classes (LDI: 900) were given high LDI indexes because nutrient pollution on road surfaces are highly correlated with residential and developed land covers.

Figure 4: Land Cover Fuzzy Data Set



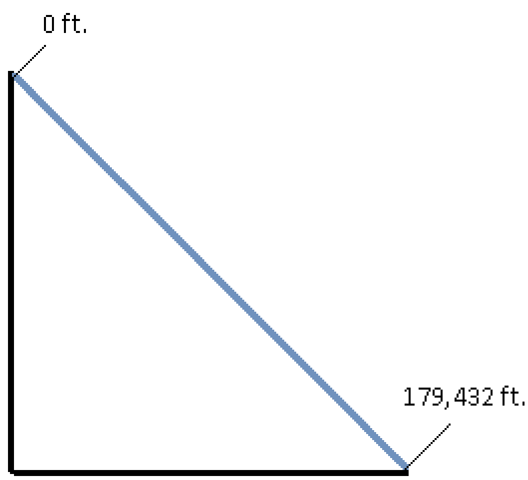
A linear monotonically decreasing function was applied using the Fuzzy tool to the Euclidean distance road file (road0). The output fuzzy file was in byte format. The first inflection point was set to 0 ft. The final inflection point was set to 59,996 ft., the maximum distance from a road within the IRL study area. Though there is not a relationship between distance from roads and nutrient deposition, these inflection values and function type were assigned in order for the MCE model to prioritize areas with close proximity to roads.

Figure 5: Euclidean Distance Road Fuzzy Data Set



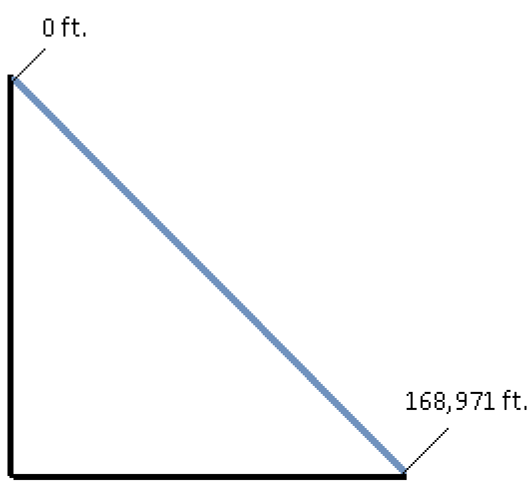
A linear monotonically decreasing function was applied using the Fuzzy tool to the Euclidean distance Salt Water file. The output fuzzy file was in byte format. The first inflection point was set to 0 ft. and the final inflection point was set to 179,432 ft., the maximum distance from saltwater within the IRL study area. Though there is not a direct relationship between nutrient deposition on road surfaces and distance from salt water, there is a negative correlation between potential nutrient deposition from storm water into the IRL and proximity to the IRL's water. As proximity to saltwater decreases the probability that nutrient pollutants on road surfaces will be deposited into the IRL through storm water increases. This decreasing function was used in order for the MCE model to prioritize areas in close proximity to salt water.

Figure 6: Euclidean Distance Salt Water Fuzzy Data Set



A linear monotonically decreasing function was applied using the Fuzzy tool to the Euclidean distance Outfall file. The output fuzzy file was in byte format. The first inflection point was set to 0 ft. and the final inflection point was set to 168, 71 ft., the maximum distance from an outfall. This decreasing function was given to the outfall data file. Though there is not a direct relationship between nutrient deposition on road surfaces and distance from outfalls, there is a negative correlation between potential nutrient deposition from storm water into the IRL and proximity to outfalls. As proximity to outfalls decreases, the probability that nutrient pollutants on road surfaces will be deposited into the IRL through storm water outfalls increases. This decreasing function was used in order for the MCE model to prioritize areas in close proximity to outfalls.

Figure 7: Euclidean Distance Outfall Fuzzy Data Set



5.24 Multiple Criterion Evaluation

A Multiple Criterion Evaluation model was run using IDRISI software and the fuzzy files for outfalls, roads, salt water, and LDI land cover. The fuzzy files were given a factor weighting to dictate individual importance for the MCE model. The LDI land cover fuzzy file was assigned the highest weighting because land cover has the strongest effect on nutrient and PM deposition on road surfaces.

Fuzy Data set	Factor Weight
LDI Land Cover	**50%**
Outfall	**20%**
Salt water	**20%**
Road	**10%**

Table 9: MCE Weighting

5.25 Street Sweeping Road Selection

The MCE output was converted into ASCII format accessible by ArcMap. The MCE data set was reclassed to create high priority, medium priority, and low priority street sweeping areas. The reclassed MCE raster file was converted into vector polygon format, and further refined by selecting only polygons that were greater than 100 acres. This was performed to focus on large contiguous high priority areas that would benefit strongest from street sweeping.

MCE Values	***Reclassed Value***	***Priority Street Sweeping Areas***
30 – 239	***1***	**Low**
240 – 249	***2***	**Medium**
250 - 255	***3***	**High**

Table 10: MCE Reclassification

New shapefiles were created from selecting residential road types from IRL road shapefile. This selection was performed to focus street sweeping areas in nutrient rich residential land covers, and also for practicality for potential street sweeping[2]. The residential road file was clipped to the high priority and medium priority greater than 100 acre polygon files. This provided means of determining total mileage of roads that are within high priority areas. Attribute fields were added to both residential clipped road files to include pounds of TN, TP, and total PM per curb mile. This was done using the field calculator by multiplying miles by nutrient and PM values per mile from Table 6. The clipped road file and the high priority polygon file were clipped to Volusia County, Brevard County, Indian River County, St. Lucie County, and Martin County boundary files. Total mileage of residential roads and estimations of TN, TP, and total PM, within high and medium priority areas for each county were calculated.

All road and MCE vector shapefiles and rasters can be obtained through the East Central Florida Regional Planning Council. TN, TP, and PM attributes for the road shapefiles are expressed in pounds per curb mile.

[2] Highways, state and county roads are often difficult, more expensive, and dangerous to street sweep due to the frequency of traffic and fast speed limits.

6. Recommended Street Sweeping Maintenance

6.1 IRL Region

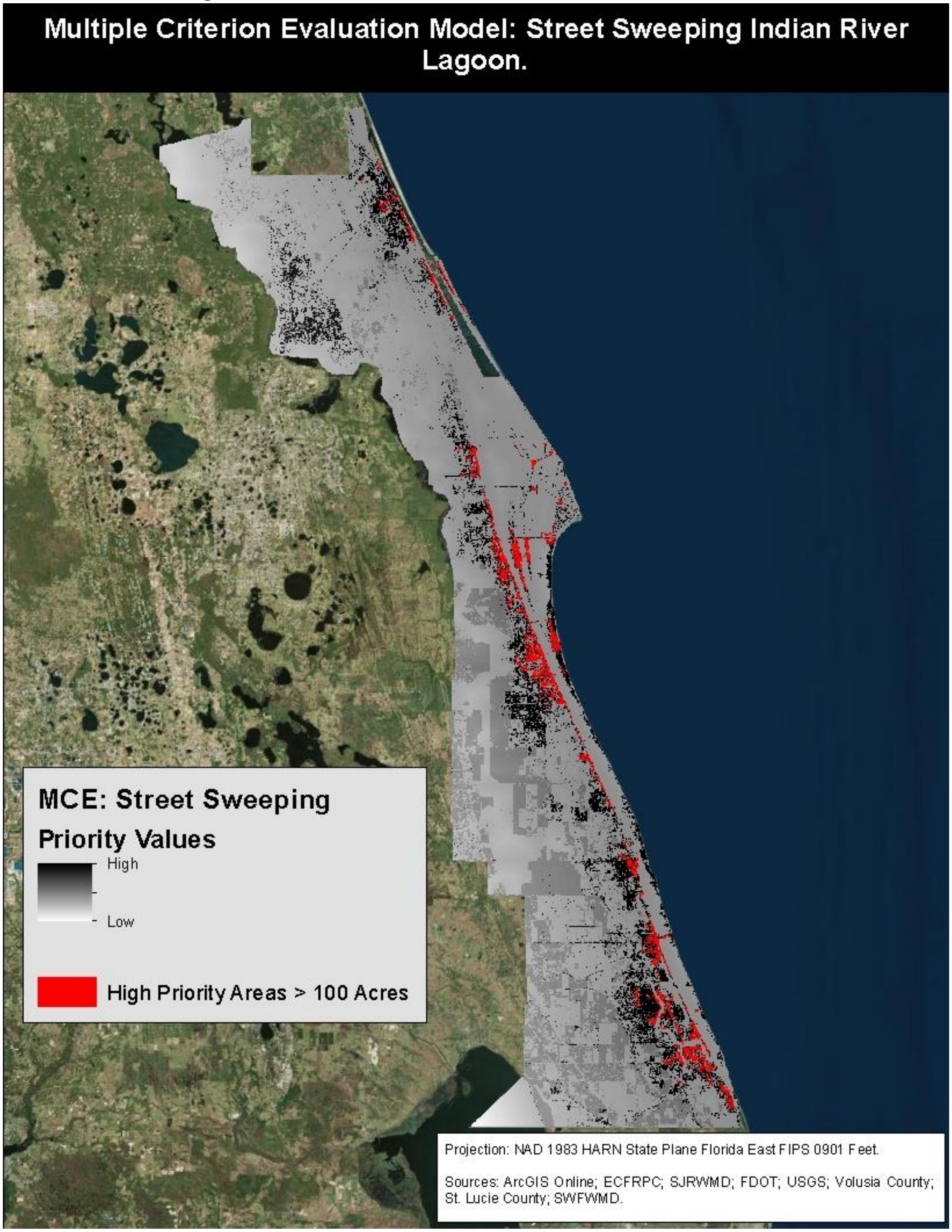


Figure 8: Multiple Criterion Evaluation Model Output for Street Sweeping In Volusia County

Based on the parameters of the model (distance from outfalls, salt water, and roads, and land cover type) the MCE output for the IRL region has identified 71,410 acres of land cover which have the highest contribution of nutrient and PM deposition on road surfaces. There was a total of 1500 miles (3000 curb miles) of residential roads that were within the MCE generated high priority areas throughout the IRL region. There was a total of 2323 miles (4646 curb miles) of roads within the MCE generated medium priority areas. If all of the IRL roads were swept twice a month, an estimated 33,840 pounds of TN, 10,080 pounds of TP, and 10,584,000 pounds of PM would be removed from road surfaces, actively preventing these pollutants from contaminating the IRL.

The concentration of high priority areas within Brevard County, St. Lucie County, and Martin County suggest that these counties would benefit strongest from the implementation of a rigorous street sweeping regimen. A breakdown of estimated nutrient removal, PM removal, and costs from street sweeping the priority roads of the entire IRL region is shown below in Table 11.

Region	Curb Miles of Priority Roads	Street Sweep Frequency	TN Removal (lbs)	TP Removal (lbs)	PM Removal (lbs)	Cost
IRL	18,000	Bimonthly	8460	2520	2,646,000	$ 882,000
IRL	36,000	1x month	16920	5040	5,292,000	$ 1,764,000
IRL	72,000	2x month	33840	10080	10,584,000	$ 3,528,000

Table 11 Estimated nutrient removal, PM removal, and costs for the IRL region through street sweeping efforts using data from Tables 3 and 6, for the IRL region.

6.2 Volusia County

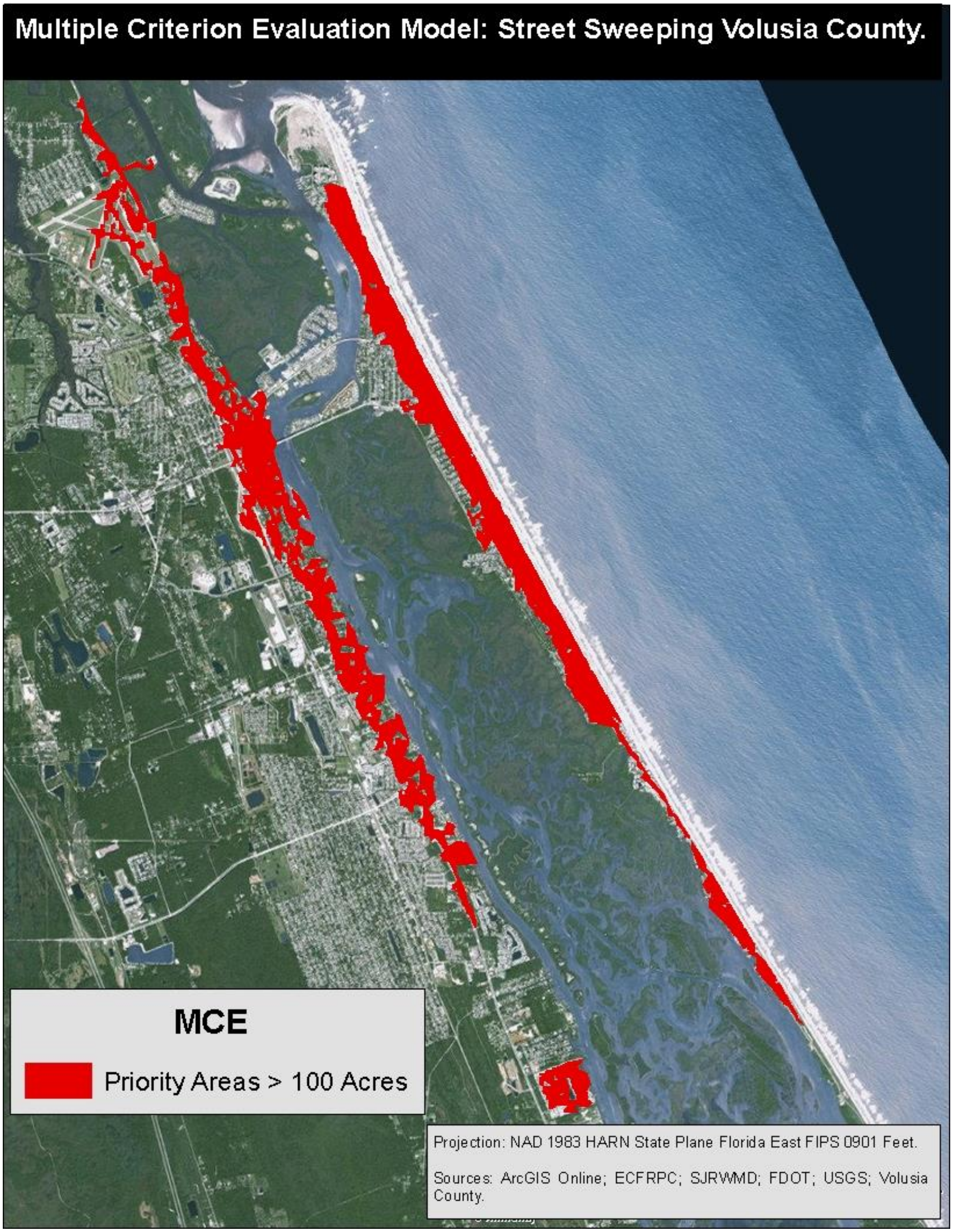


Figure 9: Multiple Criterion Evaluation Model Output for Street Sweeping In Volusia County

6.21 Street Sweeping: Priority Roads

Ponce Inlet represents the northern extent of IRL study area. Only roads that were south of Ponce Inlet were included in the analysis for Volusia County. There were 2792 acres of high priority areas, and 16,745 acres of medium priority areas within Volusia County. There was a total of 73 miles (146 curb miles) of residential roads that were within the MCE generated high priority areas, and a total of 462 miles (924 curb miles) within the MCE generated medium priority areas. This report estimated TN, TP, TPM load reductions if priority roads were swept once a month of 823.44, 245.8, 257,544 pounds per year.

6.22 Maintenance Schedule

Volusia County would benefit from implementing a frequent street sweeping regimen in order to actively work towards reducing nutrient and PM enrichment of the IRL and decreasing PM build up within the storm water infrastructure, including outfalls associated with the IRL. Street sweeping seasonal prioritization should be during the fall and early spring months, when concentrations of PM from leaf litter are highest on road surfaces, removal of PM during these months aid in the prevention of organic material from clogging storm water infrastructure, including outfalls. A breakdown of estimated nutrient removal, PM removal, and costs from street sweeping the priority roads is shown below in Table 12.

Curb Miles of Priority Roads	Street Sweep Frequency	TN Removal (lbs) per year	TP Removal (lbs) per year	PM removal (lbs) per year	Cost per Year
876	**Bimonthly**	**411.72**	**122.64**	**128,772**	**$43,037.88**
1,752	**1x month**	**823.44**	**245.28**	**257,544**	**$86,075.76**
3,504	2x month	1,646.88	490.56	515,088	$172,151.52

Figure 10: Estimated nutrient removal, PM removal, and cost values, based on data found in Tables 3 and 6, for Volusia County Fl.

6.3 Brevard County

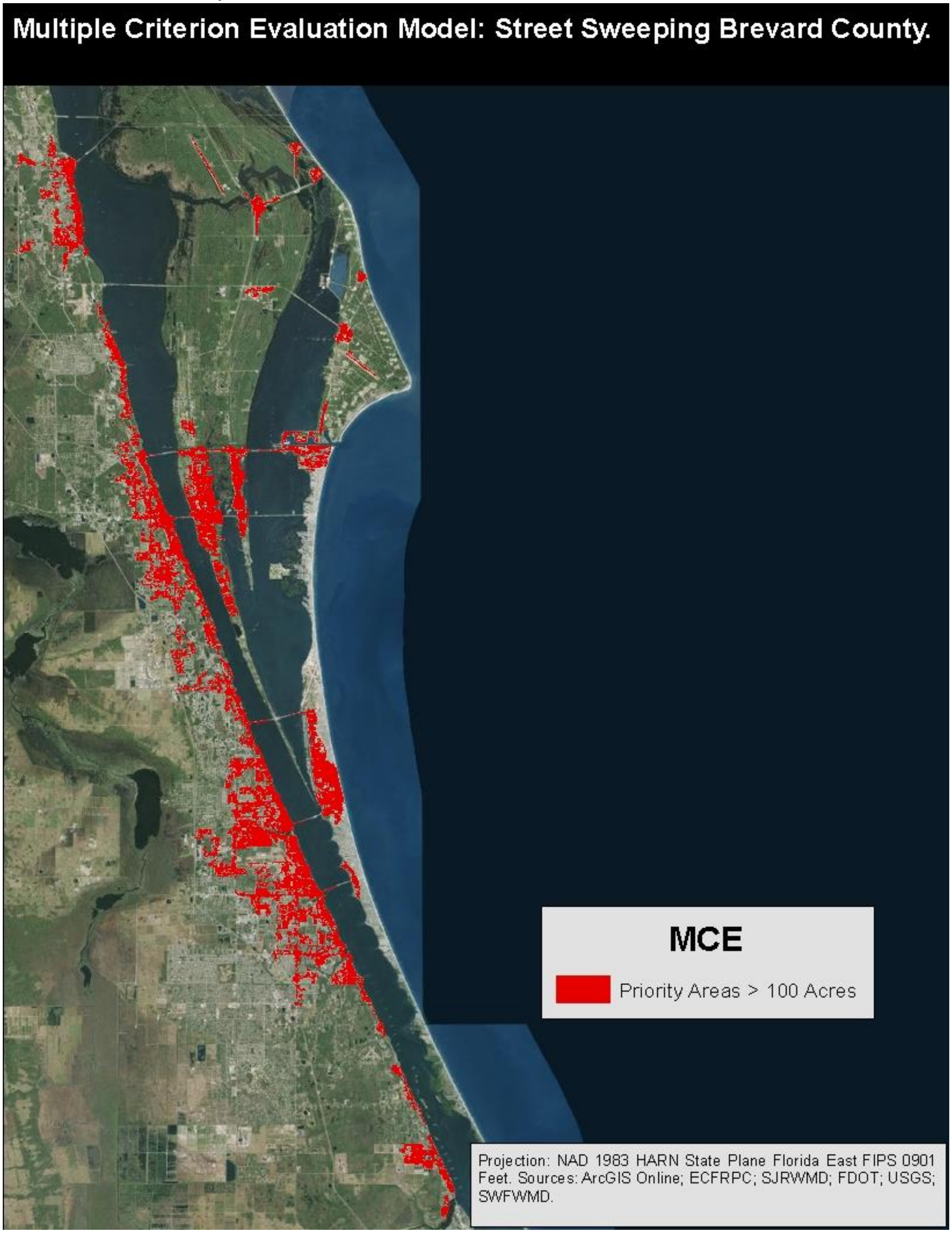


Figure 11: Multiple Criterion Evaluation Model Output for Street Sweeping In Brevard County

6.31 Street Sweeping: Priority Roads

Brevard County had a total of 823.18 miles (1,646.36 curb miles) of residential roads within MCE generated high priority areas. There was a total of 38,452 acres of high priority areas greater than 100 acres in Brevard County. There was a total of 3,434.8 miles (6,869.6 curb miles) of residential roads within the MCE generated medium priority areas. There was a total of 29,078.87 acres of medium priority areas greater than 100 acres. Based on the results from the MCE model, Brevard County has the highest contribution of nutrient enrichment to the IRL through storm water runoff from road surfaces. Street sweeping Brevard County's roads, within the MCE generated high priority areas, is crucial to nutrient enrichment mitigation efforts for the IRL due to the nature of the IRL's hydrology in this particular region. The Banana River Lagoon and southern portions of the Mosquito Lagoon are known for their poor flushing abilities (Lapointe, et. al. 2015). Nutrient and PM enrichment from storm water runoff from roads within this poorly flushed region can have a stronger potential to cause ecological disturbances than nutrient enrichment from run off into other regions of the IRL that cycle water effectively from tidal flow in and out of inlets. This report estimated TN, TP, TPM load reductions of 9,285.47, 2,765.89, and 6,401,048 pounds per year if Brevard County's priority roads were swept once a month.

6.32 Maintenance Schedule

Street sweeping seasonal prioritization should be during the fall and early spring months, when concentrations of PM from leaf litter are highest on road surfaces, removal of PM during these months aid in the prevention of organic material from clogging storm water infrastructure, including outfalls. There should also be a prioritization of street sweeping roads that are associated with the Banana River. A breakdown of estimated nutrient removal, PM removal, and costs from street sweeping priority roads in Brevard is shown below in table 13.

Curb Miles of Priority Roads	Street Sweep Frequency	TN Removal (lbs) per year	TP Removal (lbs) per year	PM removal (lbs) per year	Cost per Year
9,878.16	Bimonthly	4,642.74	1,382.94	3,200,524	$ 485,314
19,756.32	1x month	9,285.47	2,765.89	6,401,048	$ 970,628
39,512.64	2x month	18,570.94	5,531.77	12,802,095	$ 1,941,256

Table 13: Estimated nutrient removal, PM removal, and cost values, based on

6.4 Indian River County

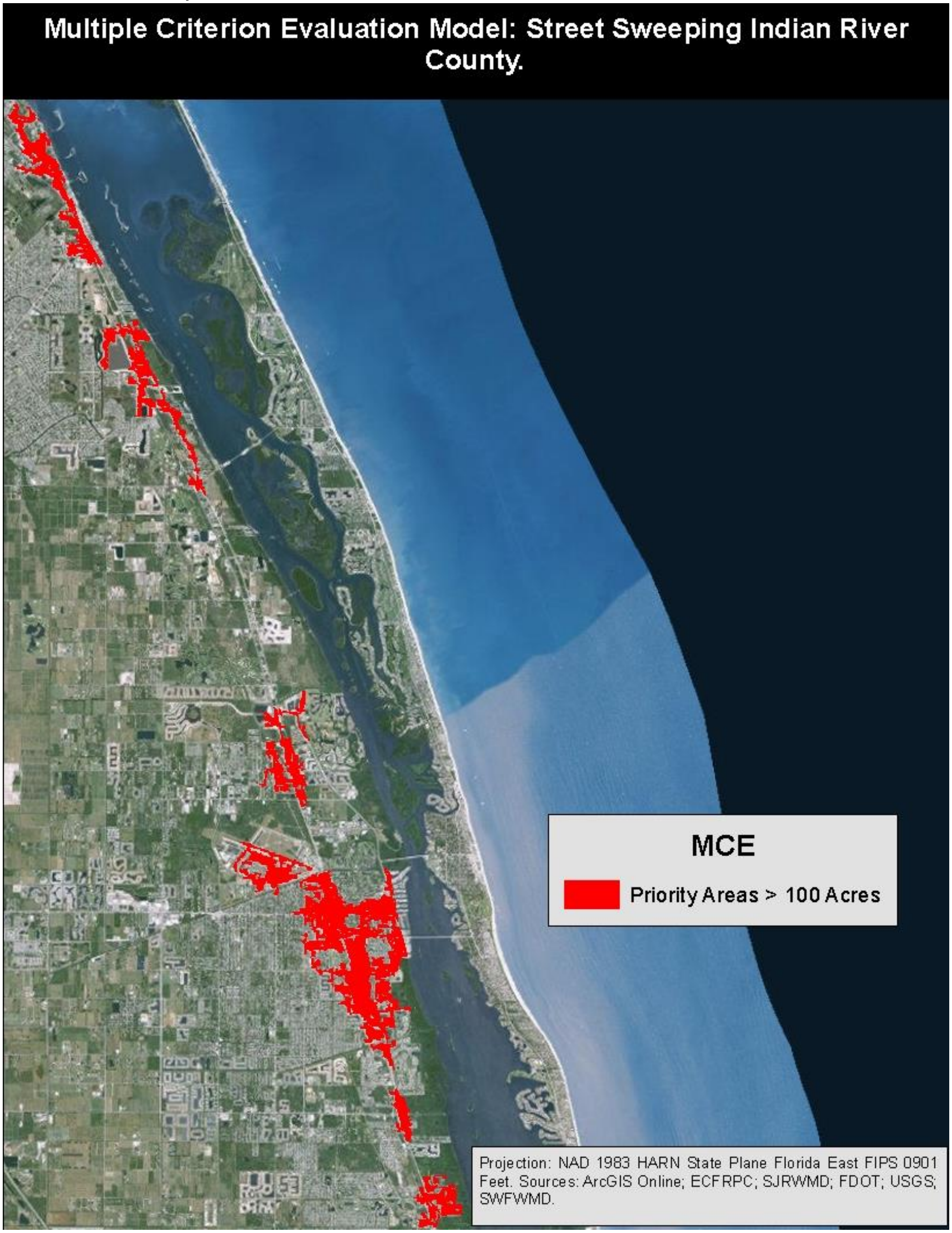


Figure 12: Multiple Criterion Evaluation Model Output for Street Sweeping In Indian River County

6.41 Street Sweeping: Priority Roads

There was a total of 76 miles (152 curb miles) of residential roads within MCE generated high priority areas. There was a total of 3,921.45 acres of MCE generated high priority areas within Indian River County. There was a total of 449 miles (898 curbed miles) of residential roads within MCE generated medium priority areas. There was a total of 17,264.59 acres of medium priority areas. The MCE model found development on the western shores of the IRL in Indian River County to have the highest contribution to nutrient and PM pollution. This report estimated TN, TP, TPM load reductions of 857.28, 255.36, and 590,976 pounds per year if Indian River County's priority roads were swept once a month.

6.42 Maintenance Schedule

Street sweeping seasonal prioritization should be during the fall and early spring months, when concentrations of PM from leaf litter are highest on road surfaces, removal of PM during these months aid in the prevention of organic material from clogging storm water infrastructure, including outfalls. A breakdown of estimated nutrient removal, PM removal, and costs from street sweeping the priority roads in Indian River County is shown below in Table 14.

Curb Miles of Priority Roads	Street Sweep Frequency	TN Removal (lbs) per year	TP Removal (lbs) per year	PM removal (lbs) per year	Cost per Year
912	Bimonthly	428.64	127.68	295,488	$ 44,806.56
1,824	1x month	857.28	255.36	590,976	$ 89,613.12
3,648	2x month	1,714.56	510.72	1,181,942	$ 170,277.24

Table 14: Estimated nutrient removal, PM removal, and cost values, based on data found in Tables 3 and 6, for Indian River County Fl.

6.5 St. Lucie County

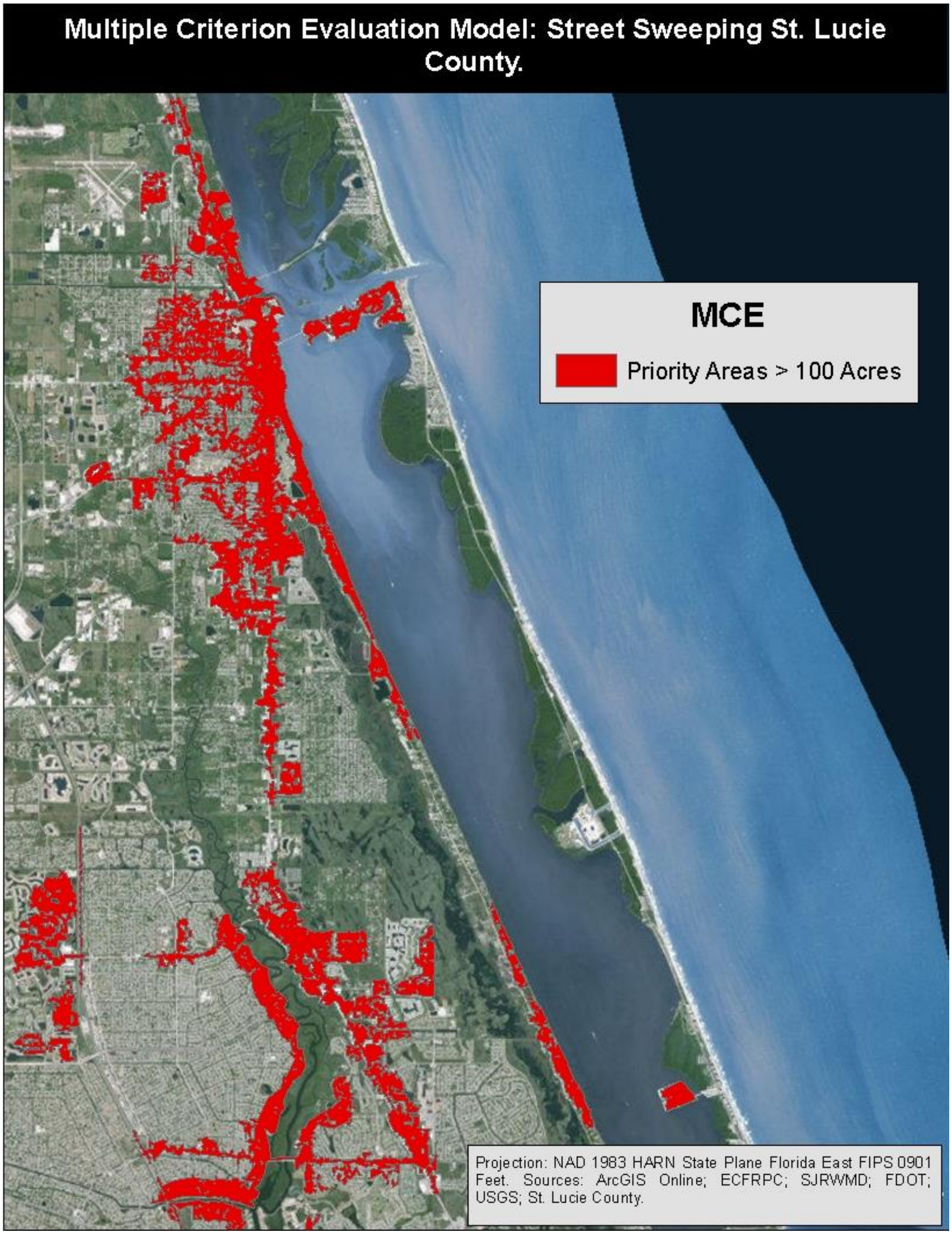


Figure 13: Multiple Criterion Evaluation Model Output for Street Sweeping In St. Lucie County

6.51 Street Sweeping: Priority Roads

There was a total of 237.54 miles (475.08 curb miles) of residential roads within MCE generated high priority areas. There was a total of 3,872.28 acres of MCE generated high priority areas within St. Lucie County. There was a total of 29,422.05 acres of medium priority areas, and 662.7 miles (1,325.4 curbed miles) of residential road within those areas. The MCE output prioritized coastal residential areas near Ft. Pierce Inlet. Residential areas in close proximity to the St. Lucie River, and its various tributaries that feed into the IRL, were also prioritized by the MCE street sweeping model. This report estimated TN, TP, TPM load reductions of 2,679.45, 789, 13, and 1, 857, 11.04 pounds per year if St. Lucie County's priority roads were swept once a month.

6.52 Maintenance Schedule

Street sweeping seasonal prioritization should be during the fall and early spring months, when concentrations of PM from leaf litter are highest on road surfaces, removal of PM during these months aid in the prevention of organic material from clogging storm water infrastructure, including outfalls. A breakdown of estimated nutrient removal, PM removal, and costs from street sweeping the priority roads in St. Lucie County is shown below, Table 15.

Curb Miles of Priority Roads	Street Sweep Frequency	TN Removal (lbs) per year	TP Removal (lbs) per year	PM removal (lbs) per year	Cost per Year
2,850.48	Bimonthly	1,339.73	399.07	923,400	$ 140,020.5
5,700.96	1x month	2,679.45	798.13	1,847,11.04	$ 280,088.16
11,401.92	2x month	5,358.9	5,358.9	3,694,22.08	$ 560,176.33

Table 15: Estimated nutrient removal, PM removal, and cost values, based on data found in Tables 3 and 6, for St. Lucie County.

6.6 Martin County

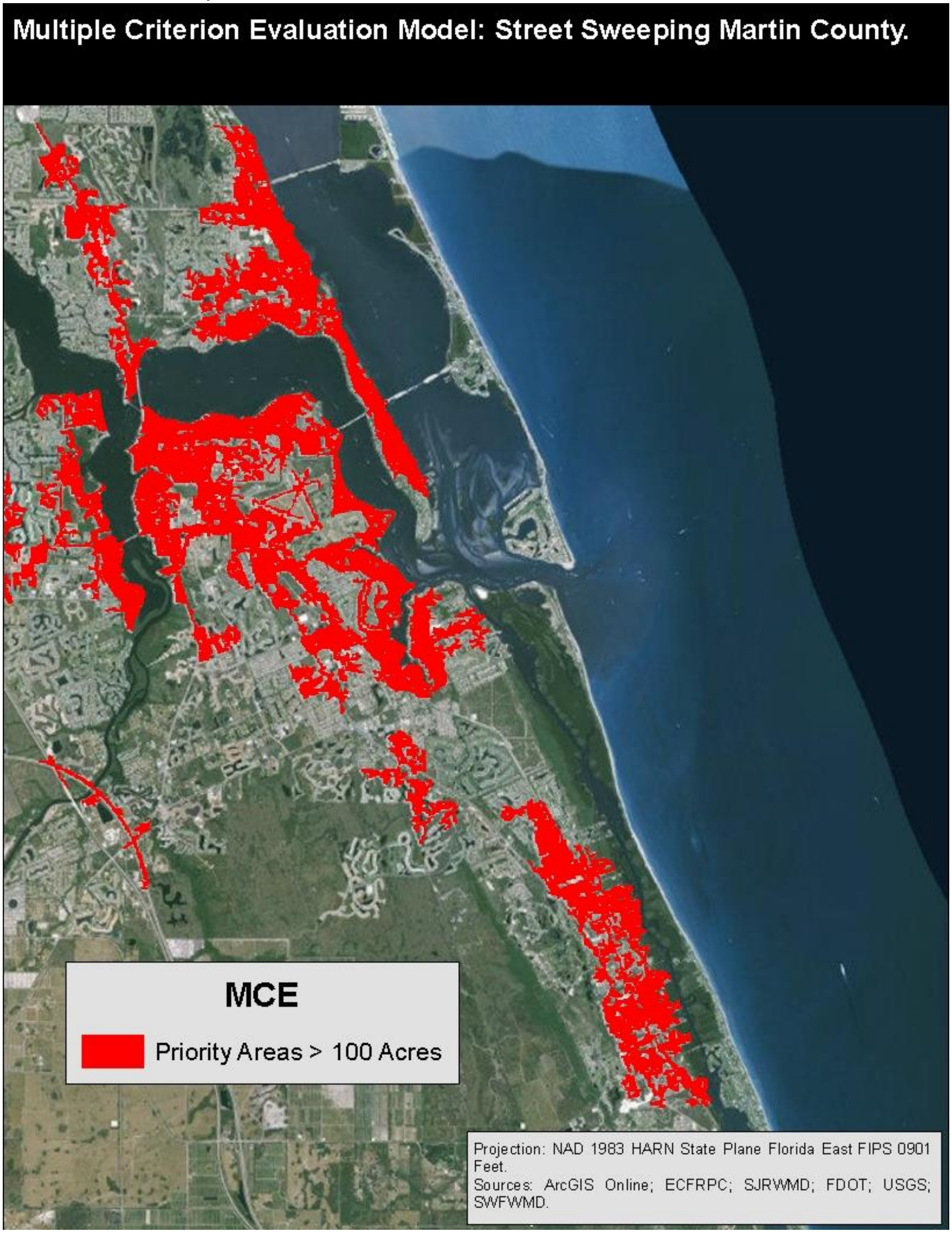


Figure 14: Multiple Criterion Evaluation Model Output for Street Sweeping In Martin County

6.61 Street Sweeping: Priority Roads

There was a total of 289.76 miles (579.52 curb miles) of residential roads within MCE generated high priority areas. There were a total of 14, 431.89 acres of high priority areas in Martin County. The MCE output modeled the majority of high priority street sweeping areas in development near the St. Lucie Inlet. There were 10,045.34 acres of MCE generated medium priority areas, and 107.81 miles (215.62 curb miles) of residential roads within those areas. The MCE output prioritized residential costal development near St. Lucie Inlet. This report estimated TN, TP, TPM load reductions of 3,268.49, 973.59, and 2,253,173.76 pounds per year if Martin County's priority roads were swept once a month.

6.62 Maintenance Schedule

Street sweeping seasonal prioritization should be during the fall and early spring months, when concentrations of PM from leaf litter are highest on road surfaces, removal of PM during these months aid in the prevention of organic material from clogging storm water infrastructure, including outfalls. A breakdown of estimated nutrient removal, PM removal, and costs from street sweeping the priority roads in St. Lucie County is shown below, Table 16.

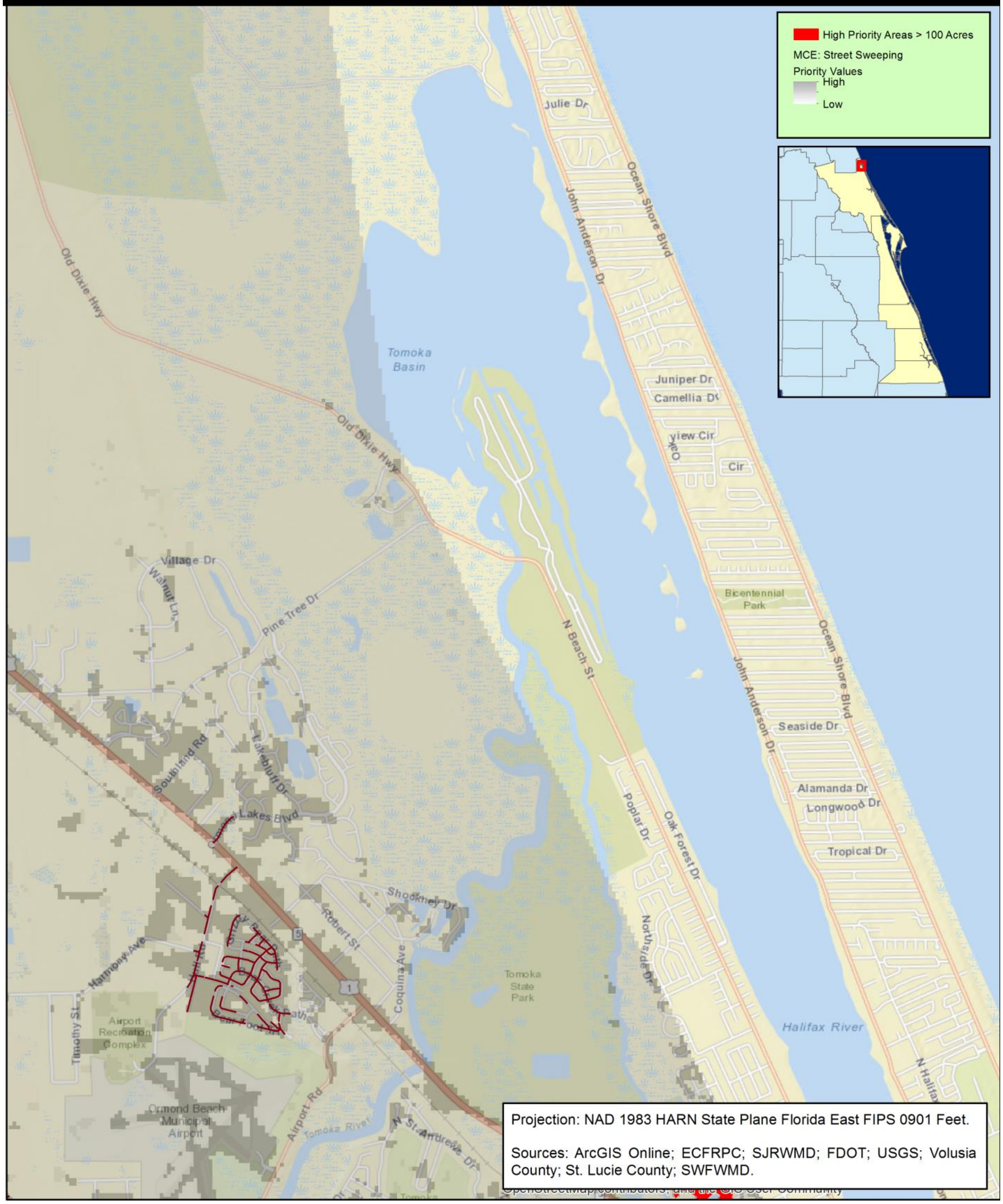
Curb Miles of Priority Roads	Street Sweep Frequency	TN Removal (lbs) per year	TP Removal (lbs) per year	PM removal (lbs) per year	Cost per Year
3,477.12	Bimonthly	1,634.25	486.8	1,126,586.88	$ 170,830.9056
6,954.24	1x month	3,268.49	973.59	2,253,173.76	$ 341,661.8112
13,908.48	2x month	6,536.99	1,947.19	4,506,192	$ 683,323.62

Table 16: Estimated nutrient removal, PM removal, and cost values, based on data found in Tables 3 and 6, for Martin County.

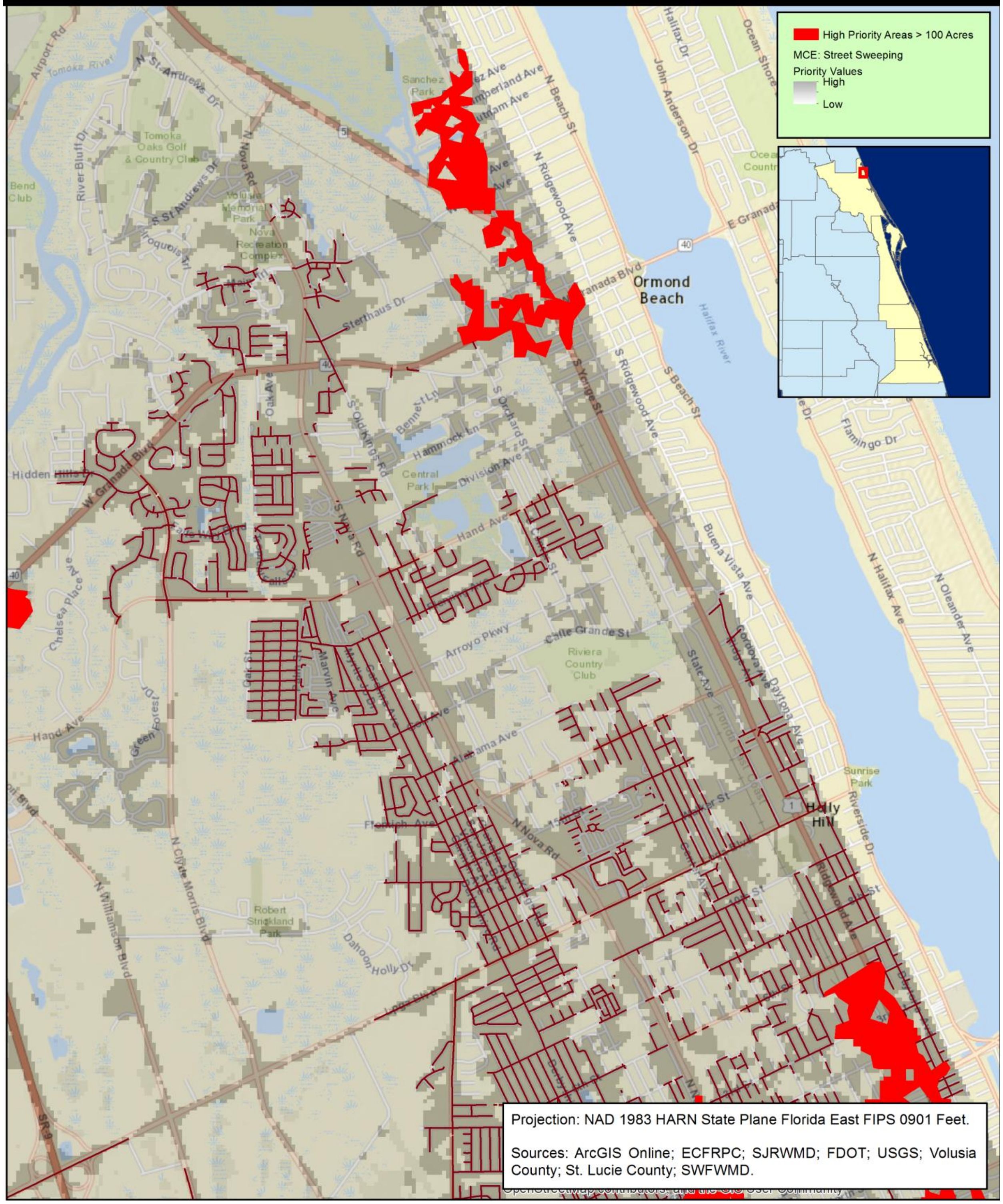
7. Map Series

The map series on the following pages depict the street sweeping priorities as outlined in section 6 of this report.

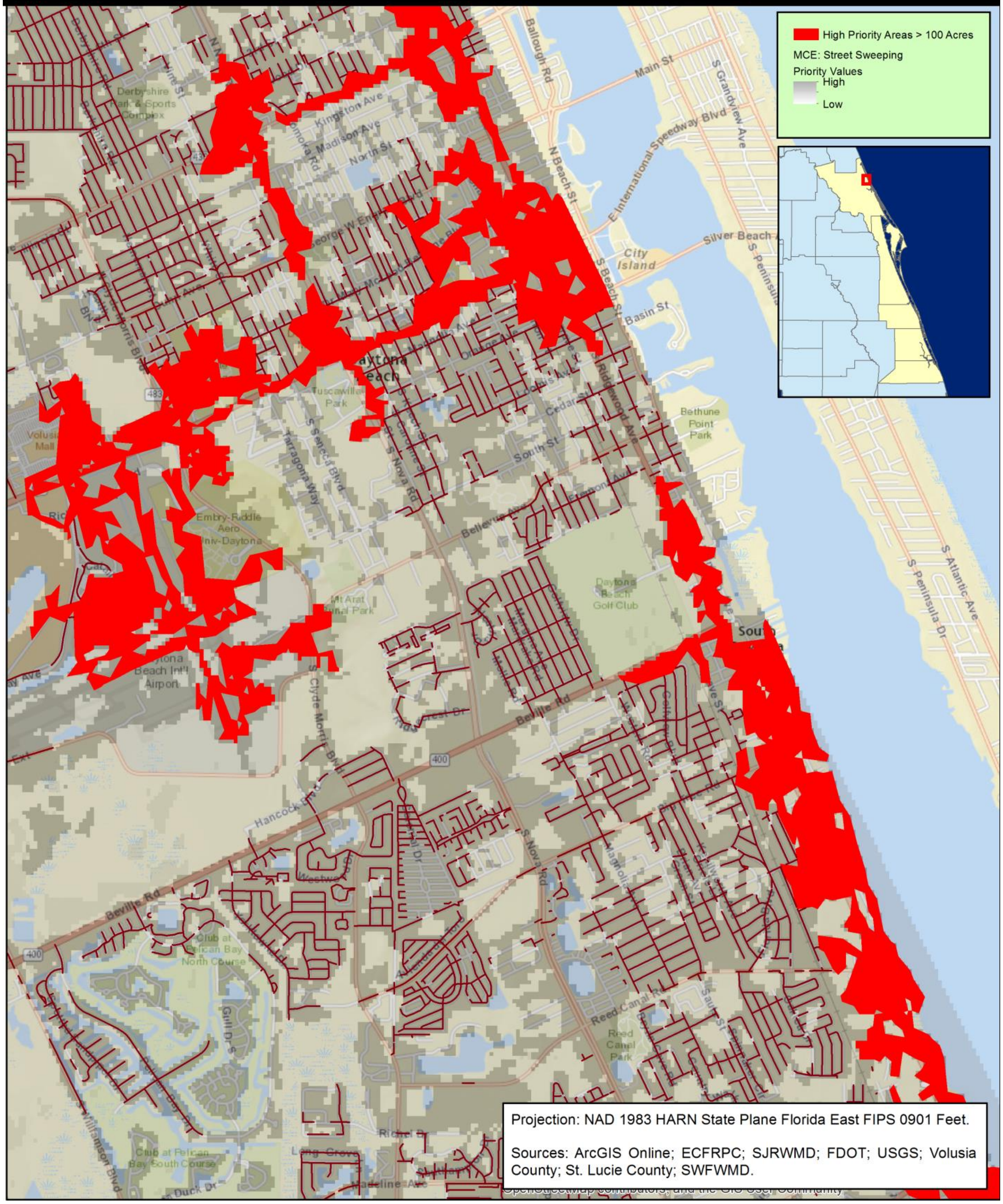
Multiple Criterion Evaluation Model: Street Sweeping Indian River Lagoon.



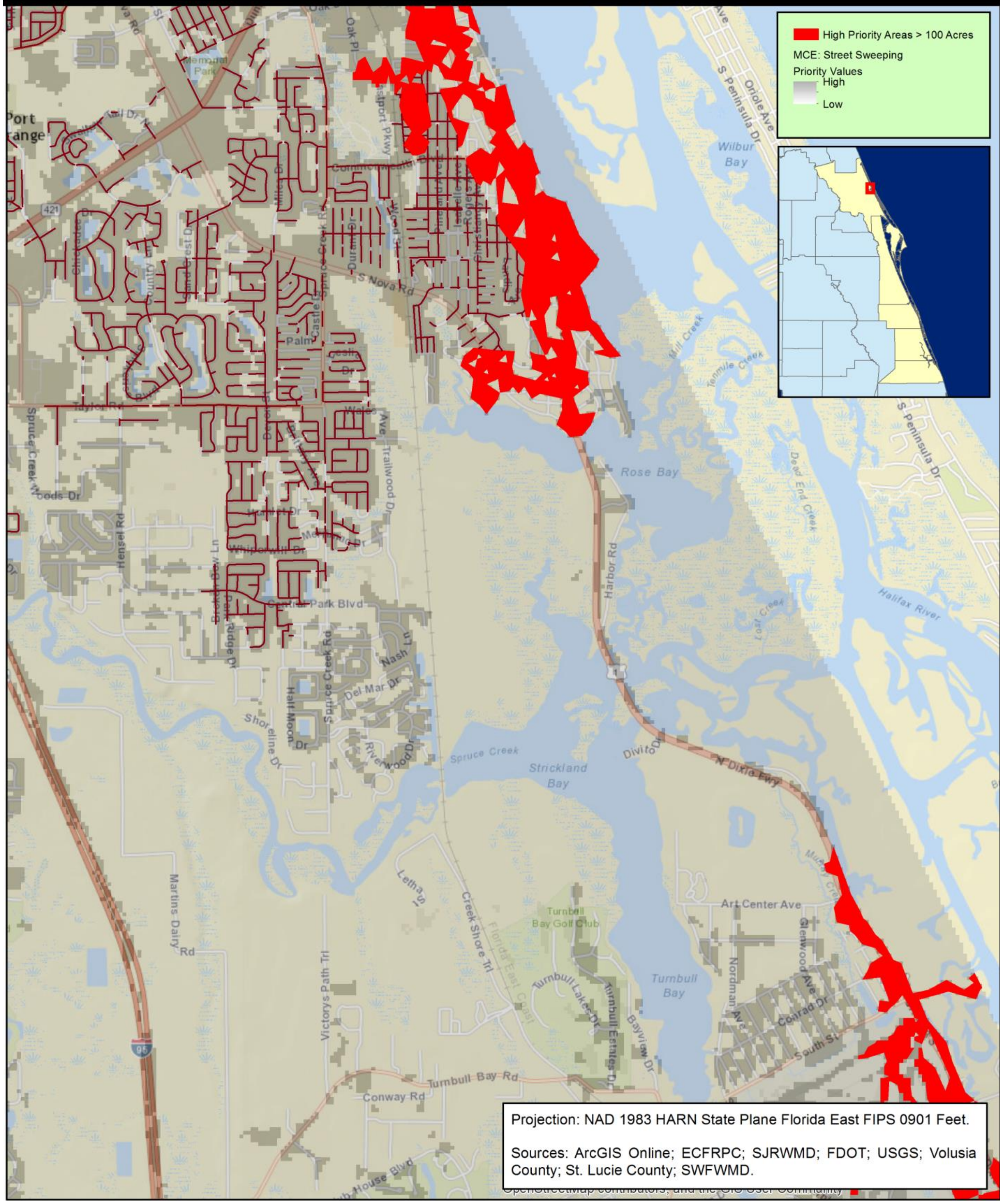
Multiple Criterion Evaluation Model: Street Sweeping Indian River Lagoon.



Multiple Criterion Evaluation Model: Street Sweeping Indian River Lagoon.



Multiple Criterion Evaluation Model: Street Sweeping Indian River Lagoon.



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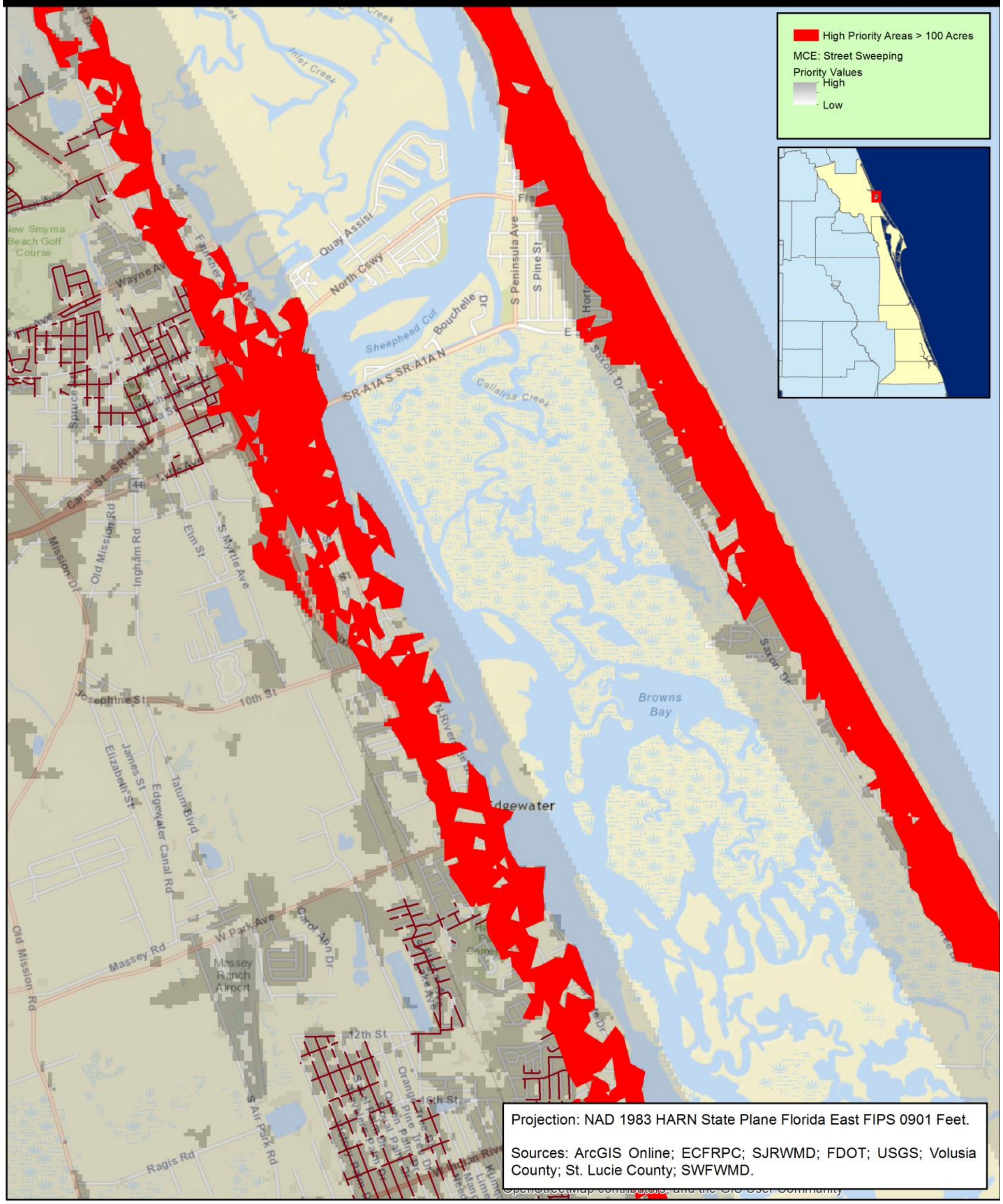
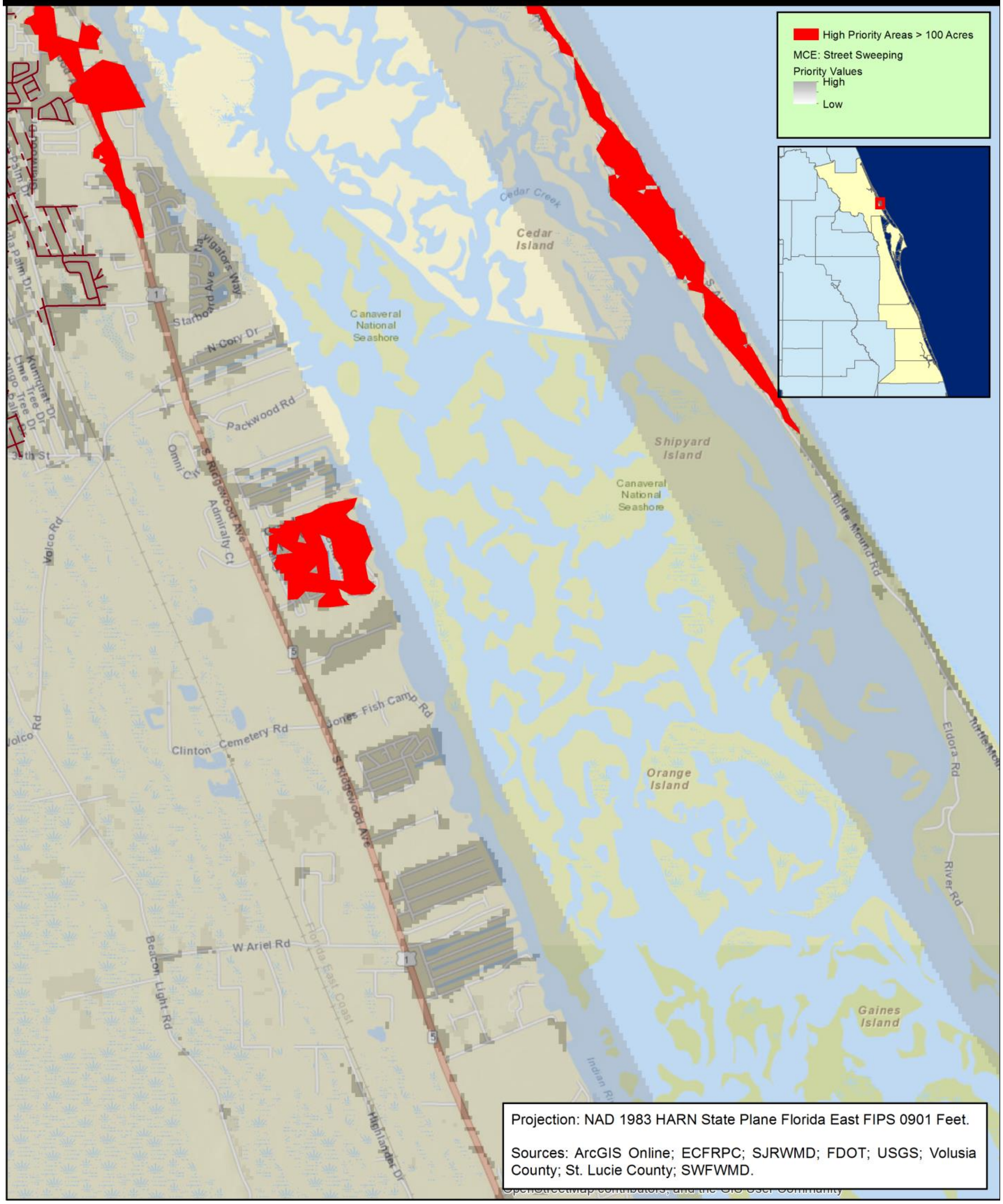


Multiple Criterion Evaluation Model: Street Sweeping Indian River Lagoon.



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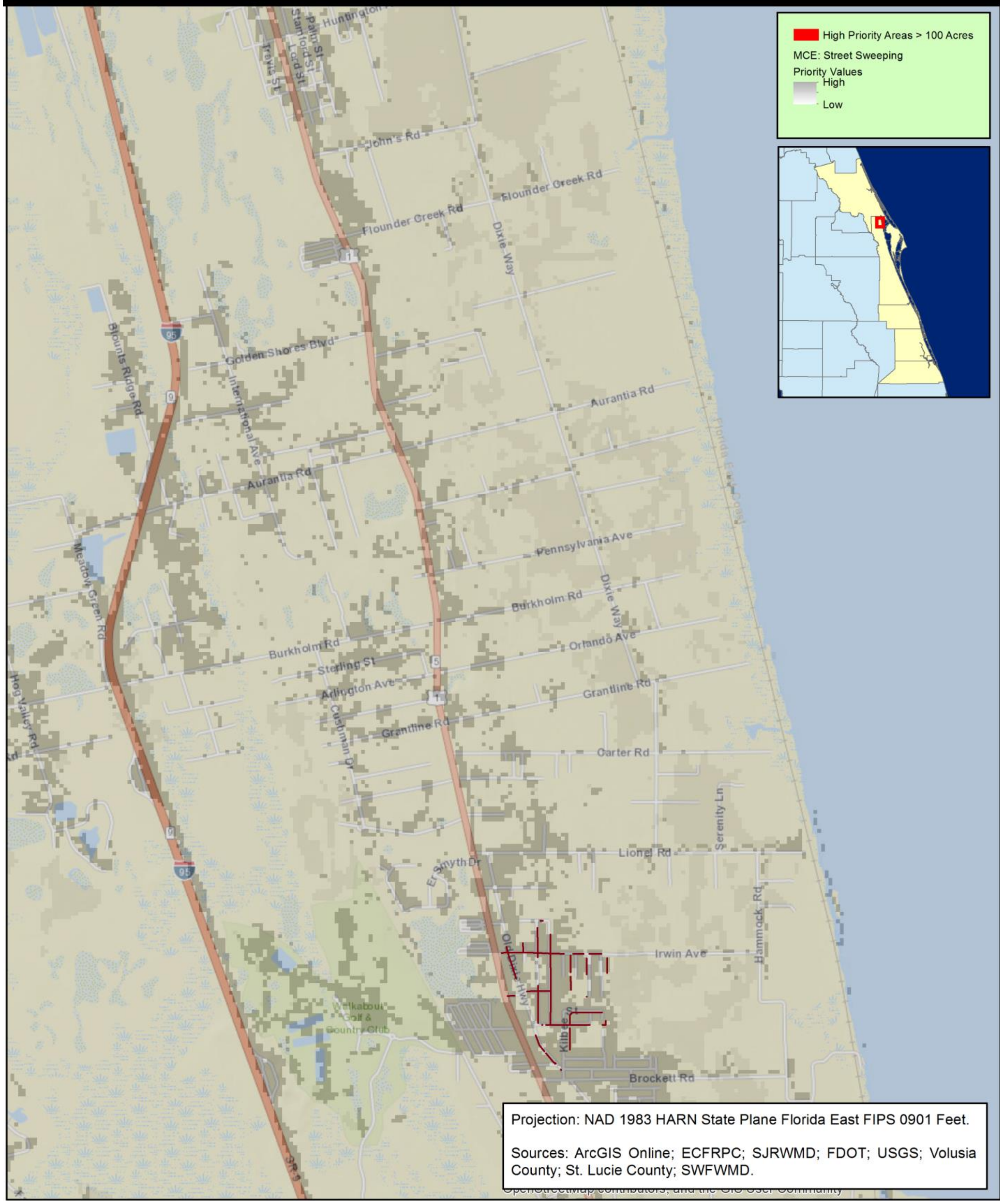

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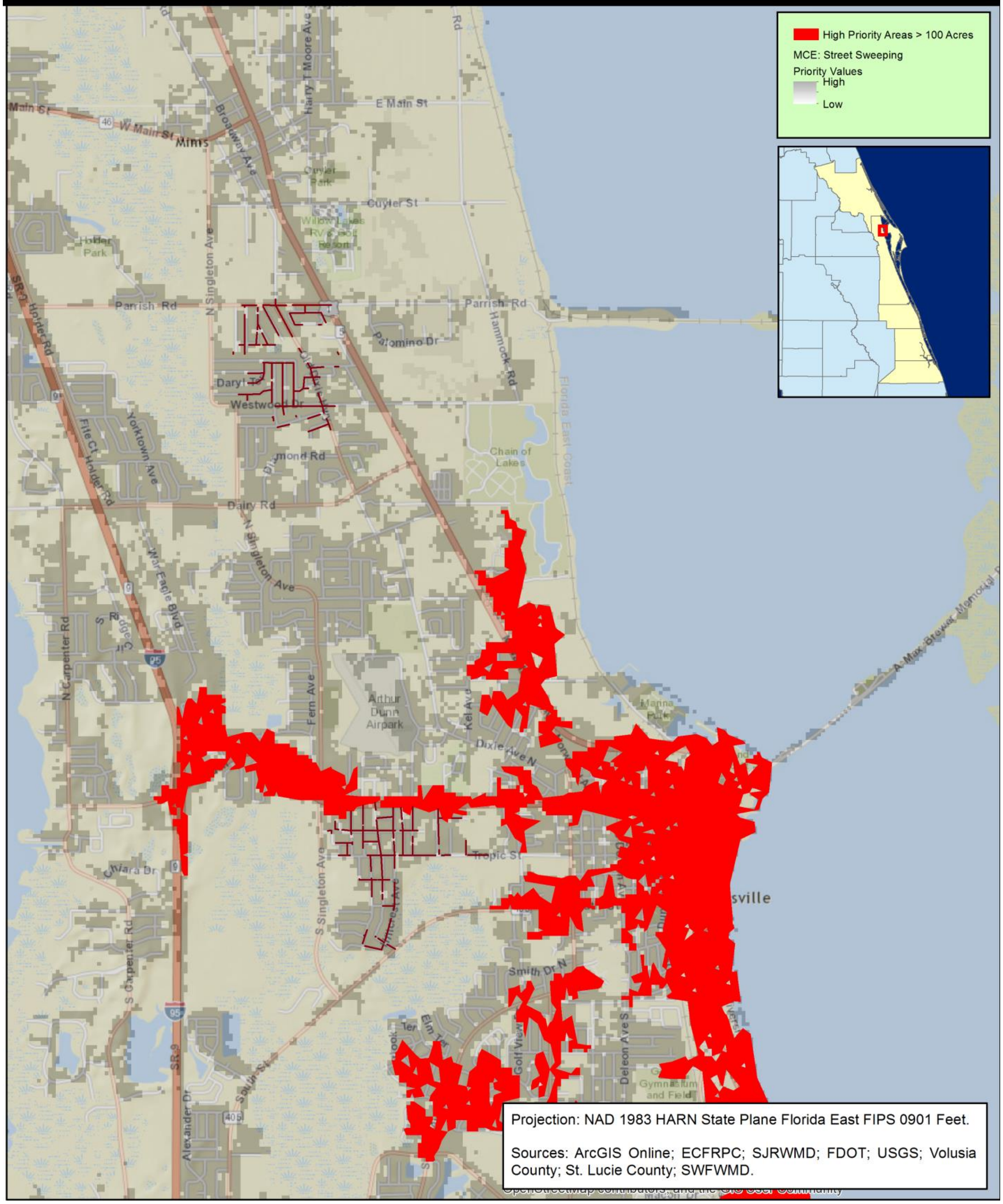
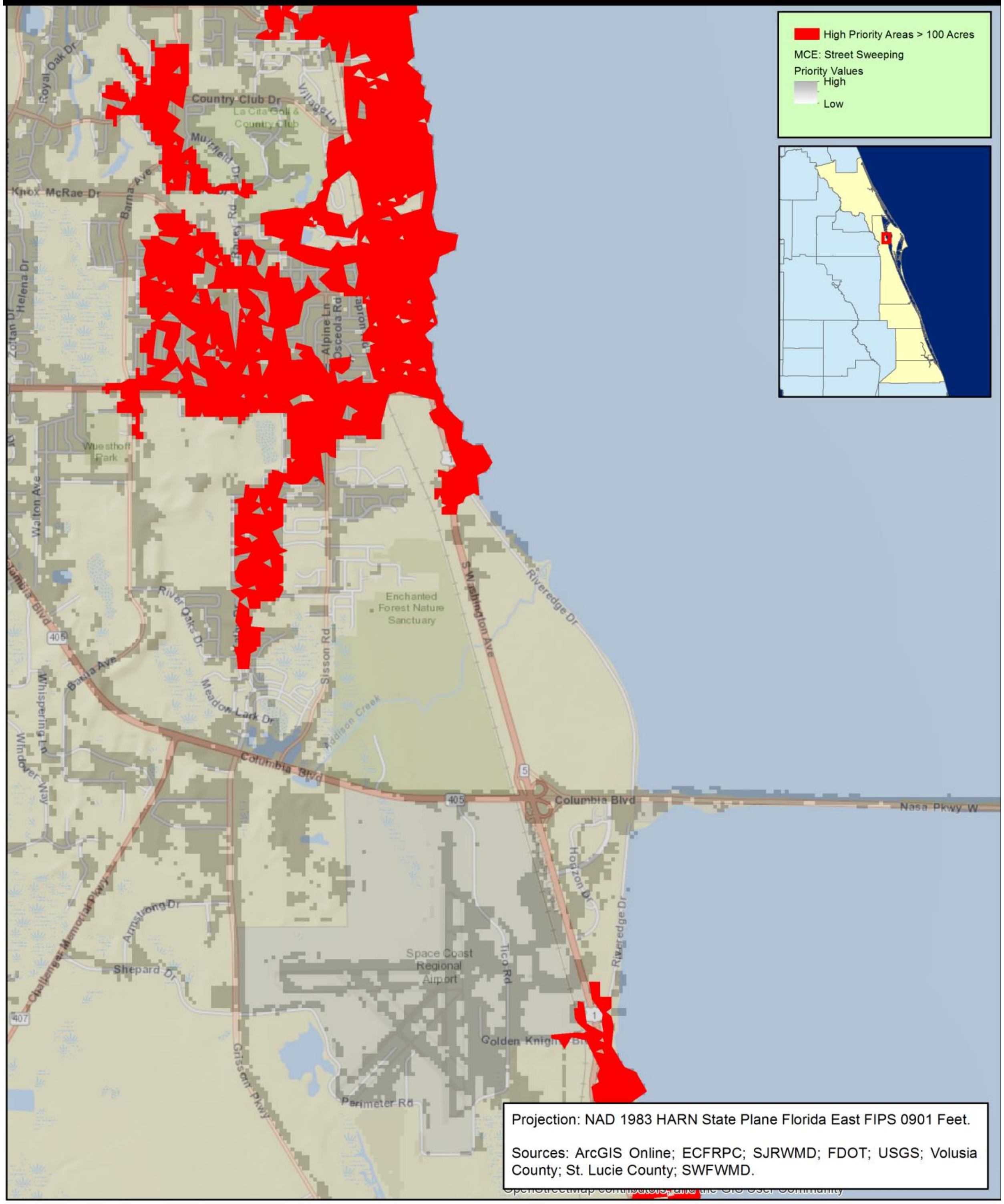
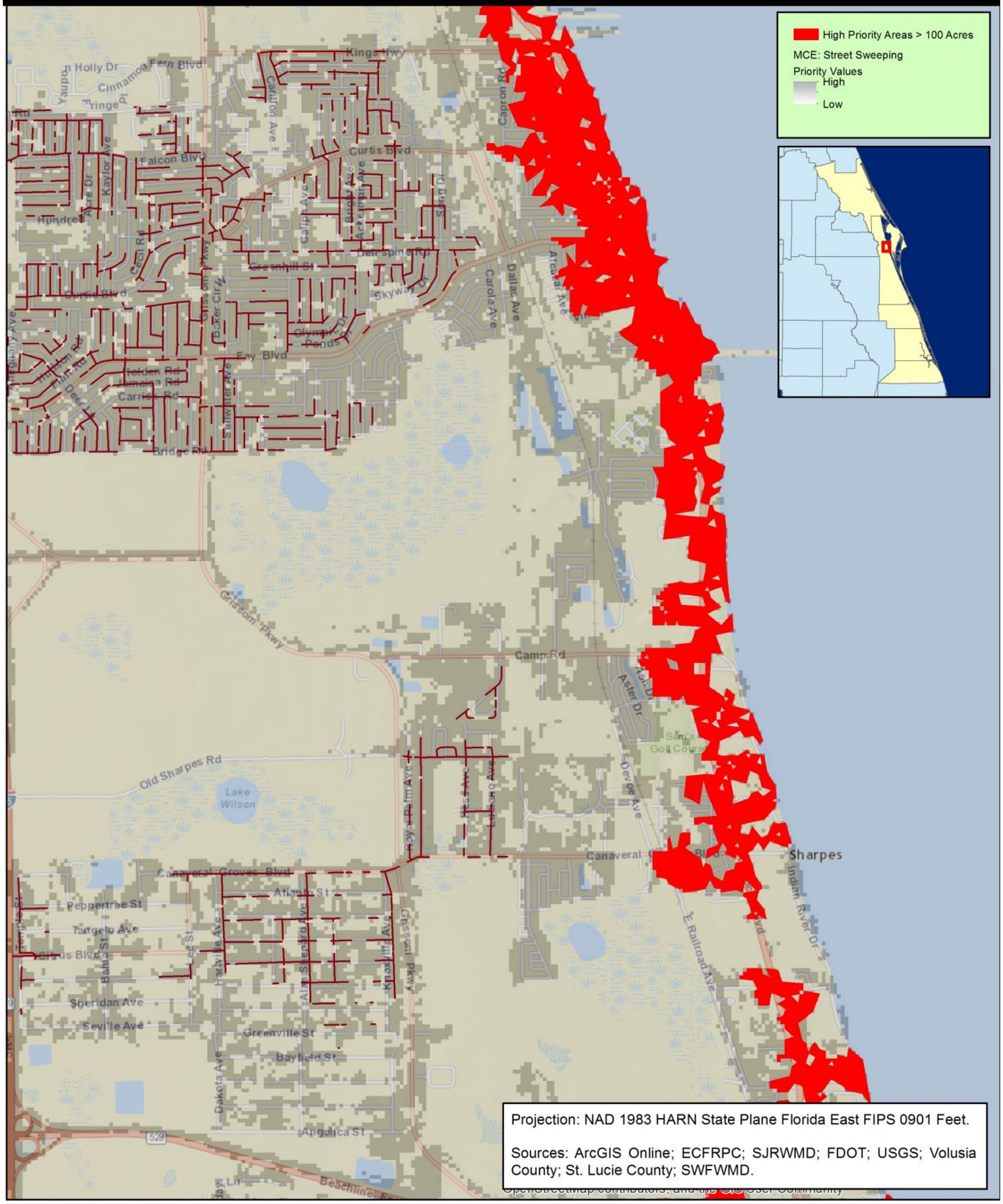


Multiple Criterion Evaluation Model: Street Sweeping Indian River Lagoon.



Multiple Criterion Evaluation Model: Street Sweeping Indian River Lagoon.



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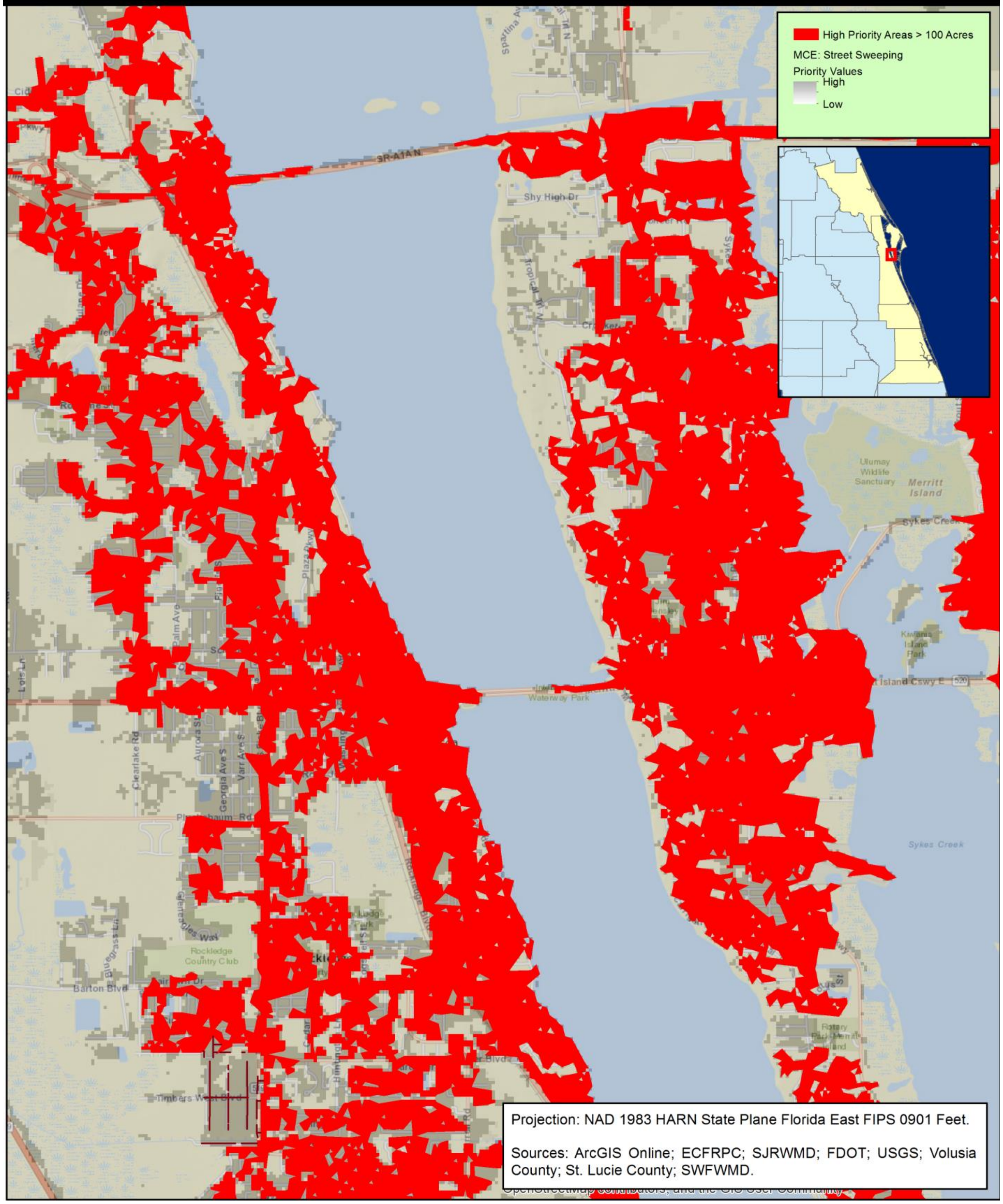
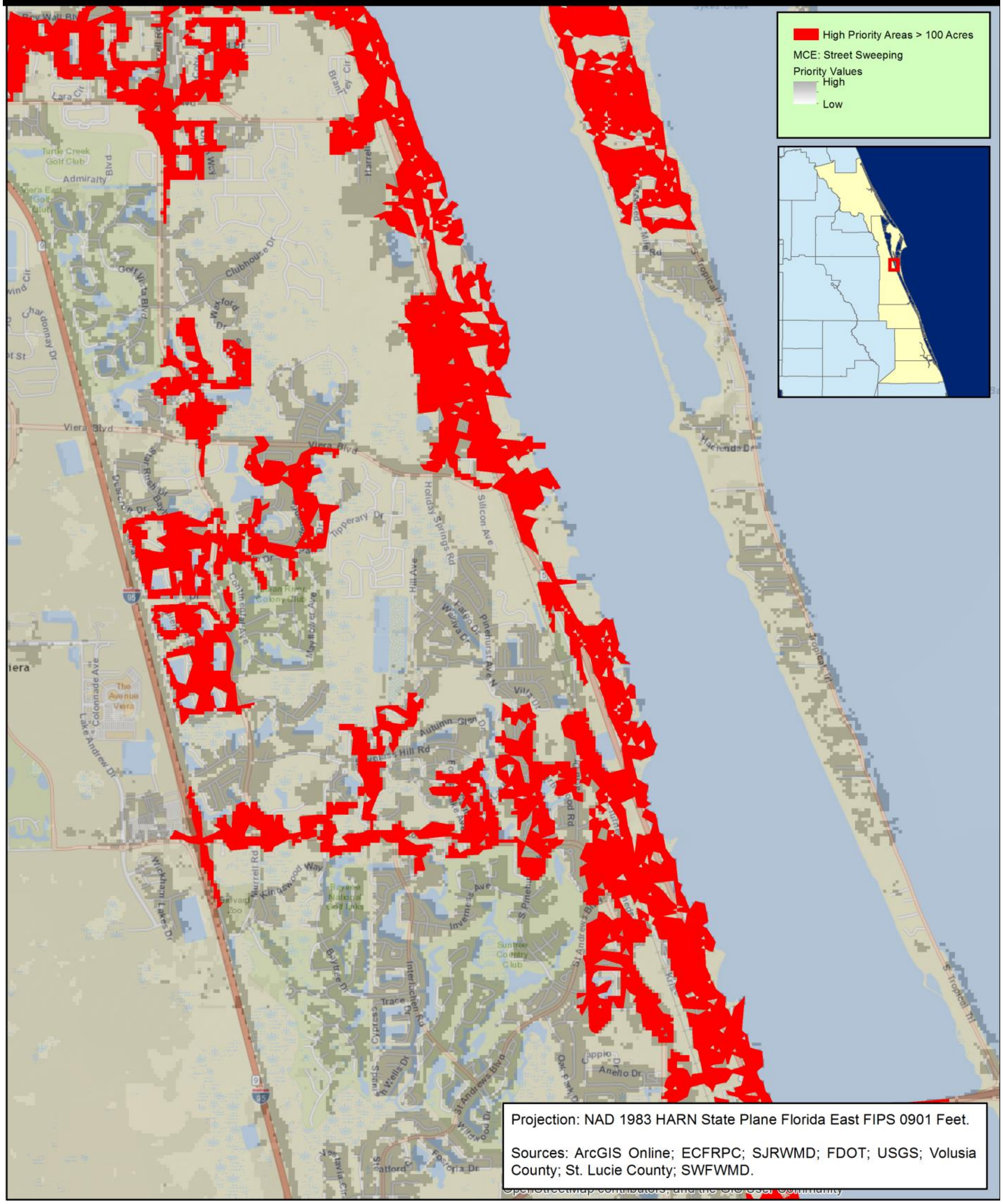


Multiple Criterion Evaluation Model: Street Sweeping Indian River Lagoon.



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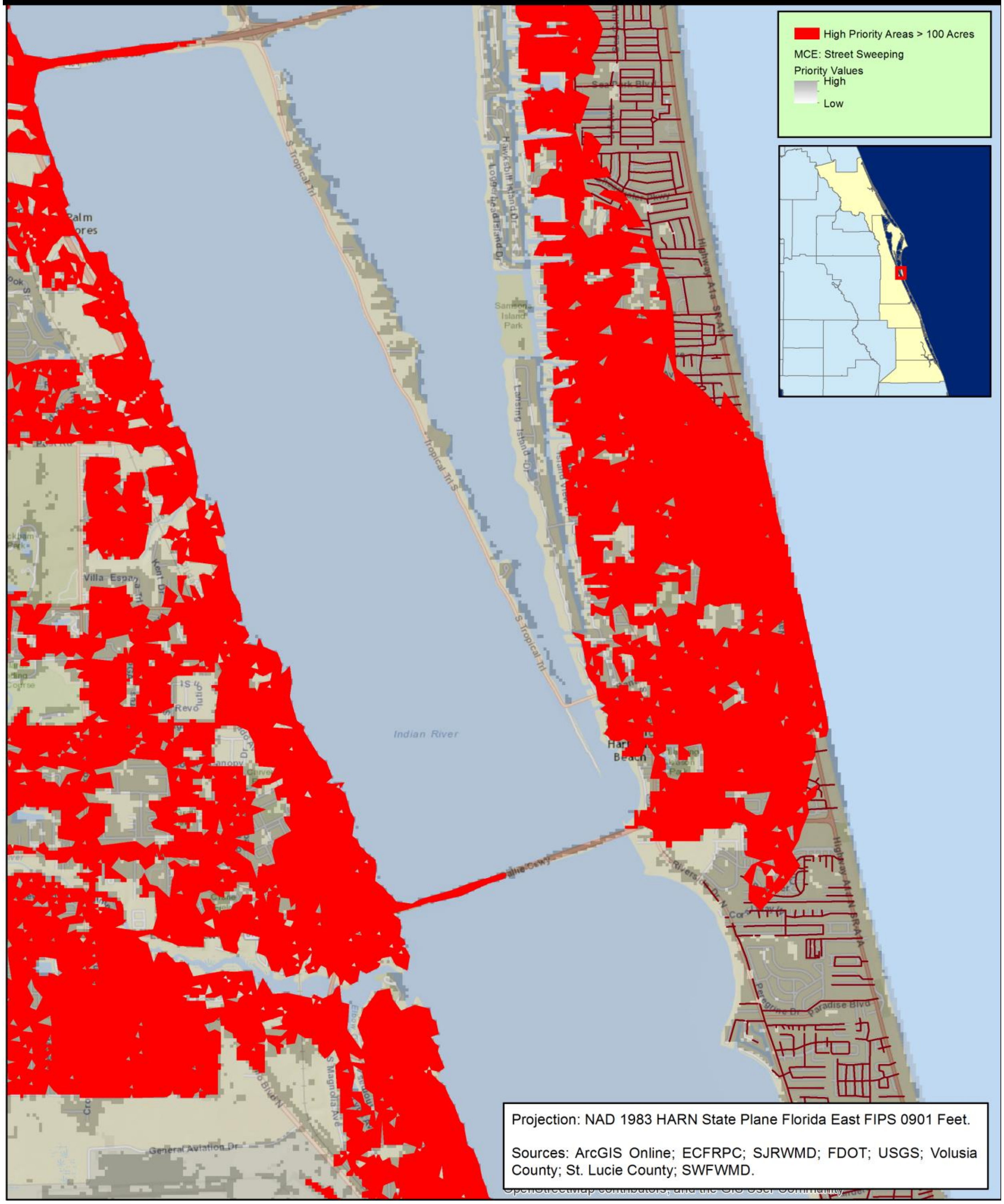

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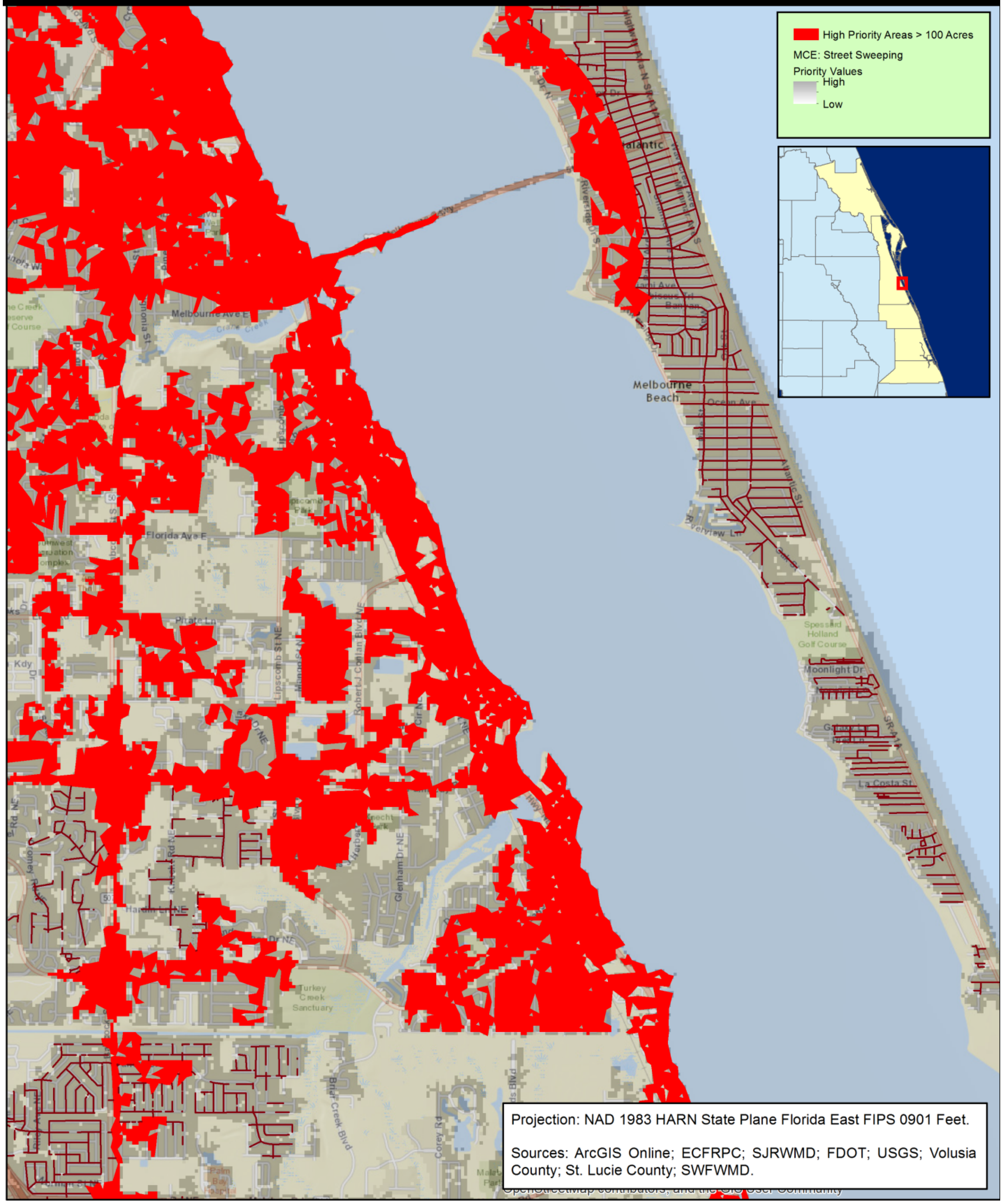

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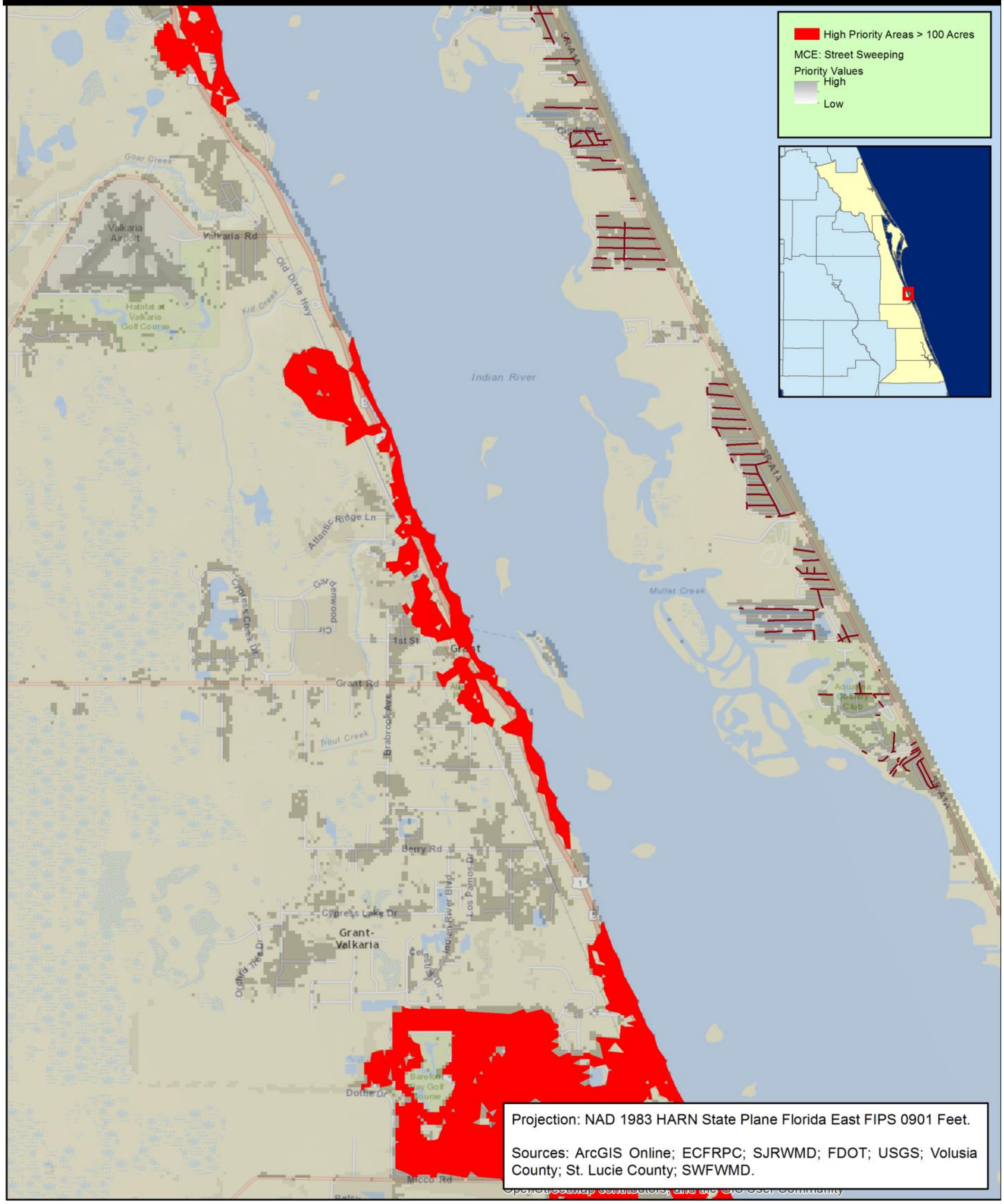

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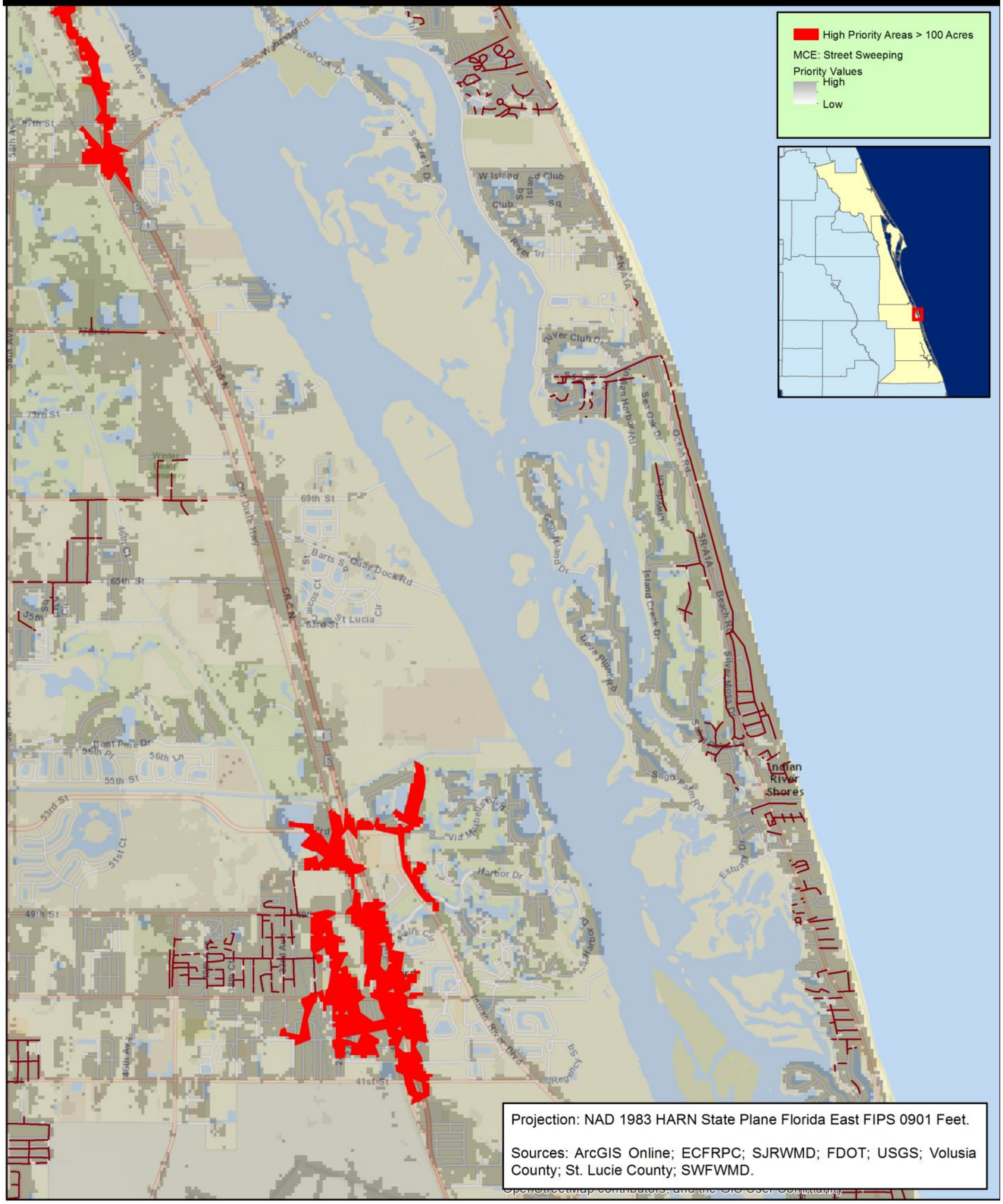

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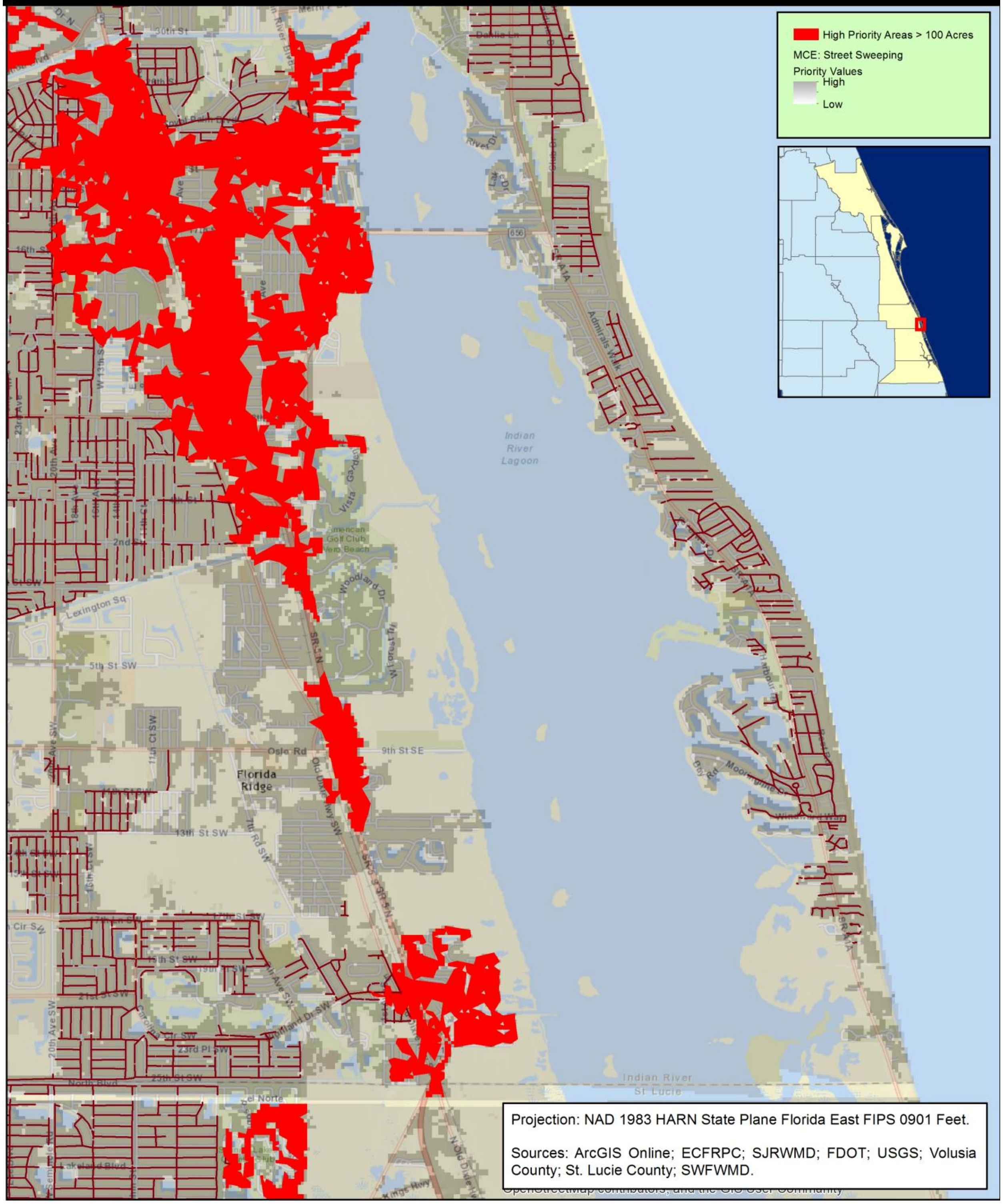

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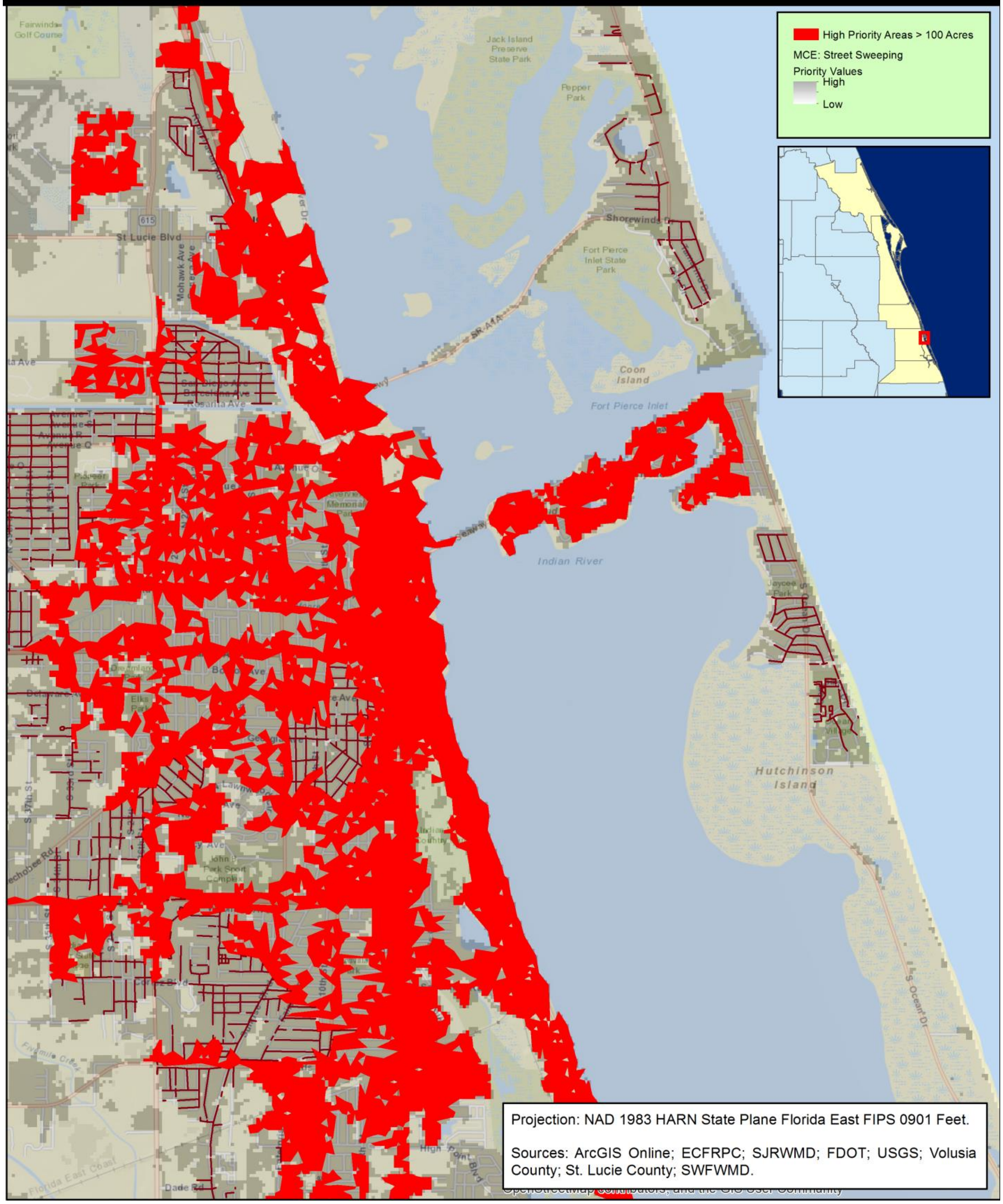
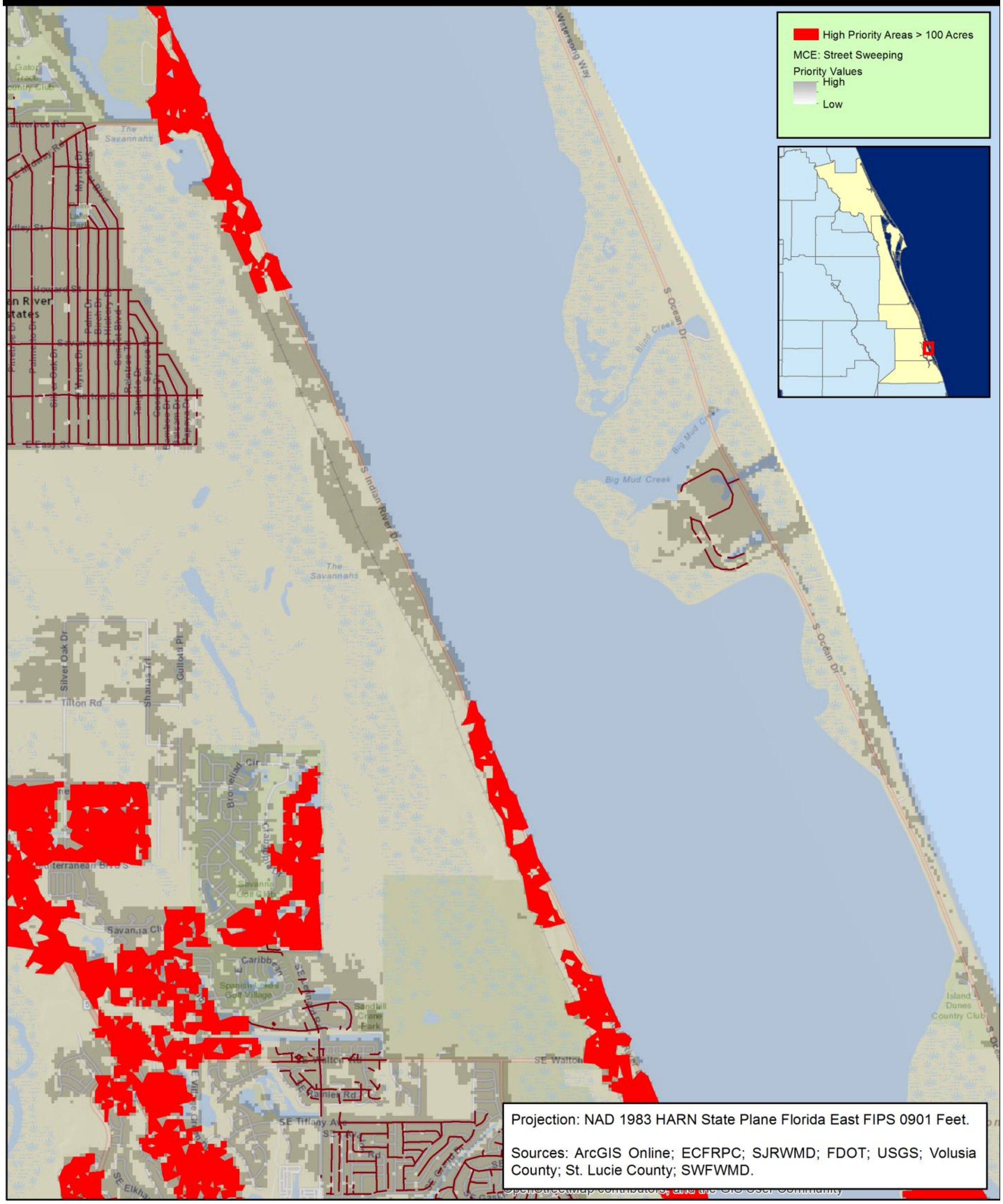


Multiple Criterion Evaluation Model: Street Sweeping Indian River Lagoon.



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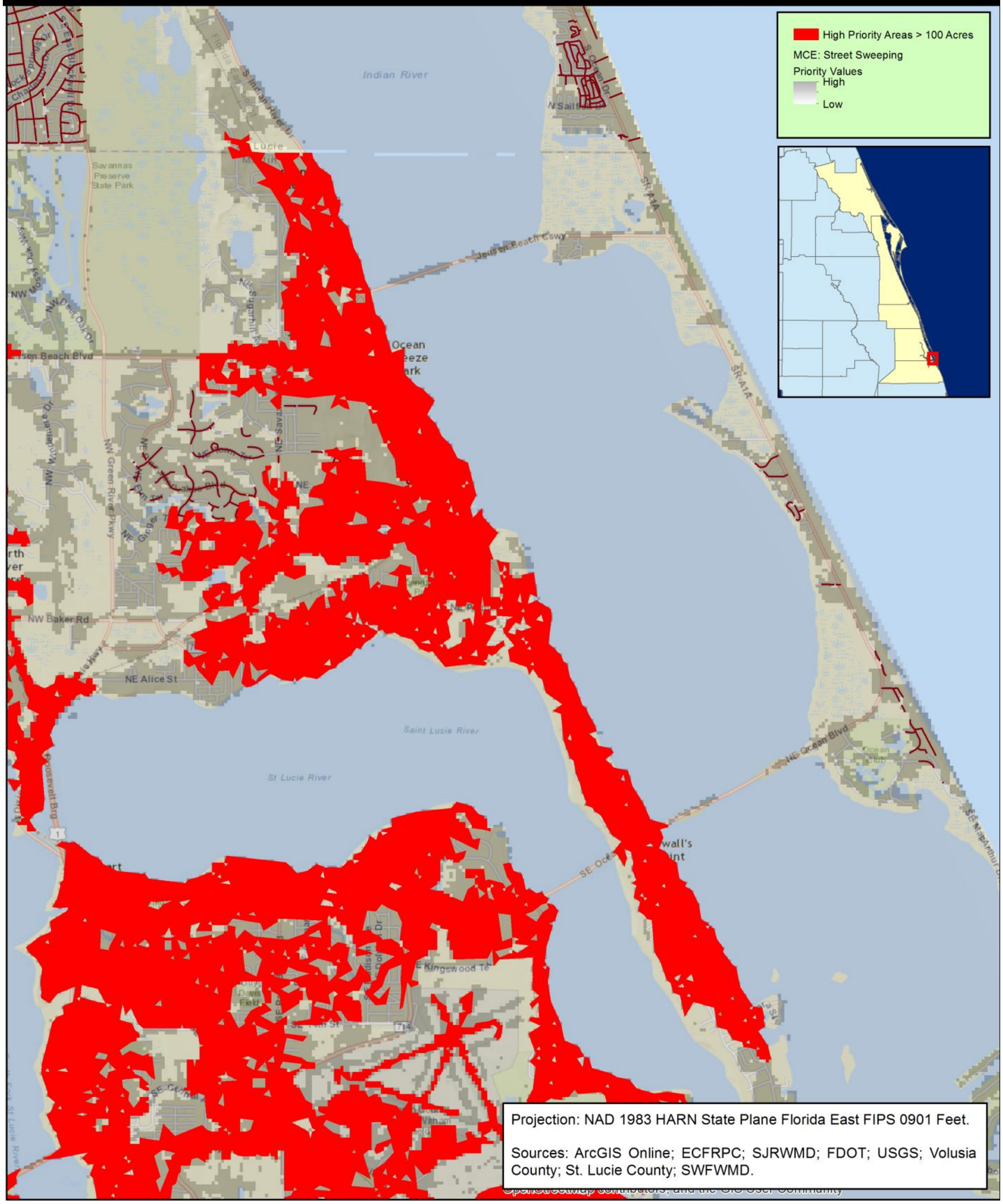

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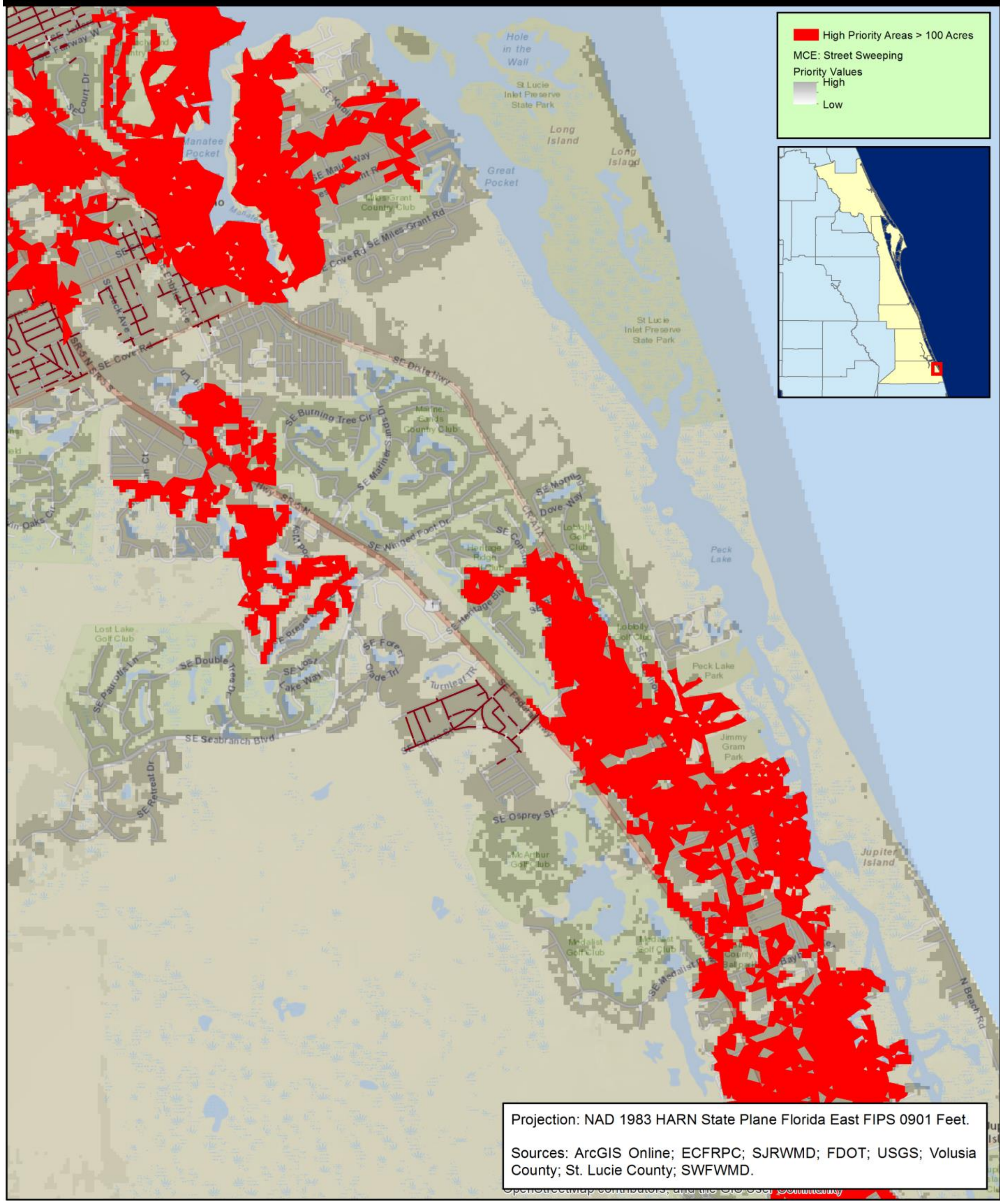

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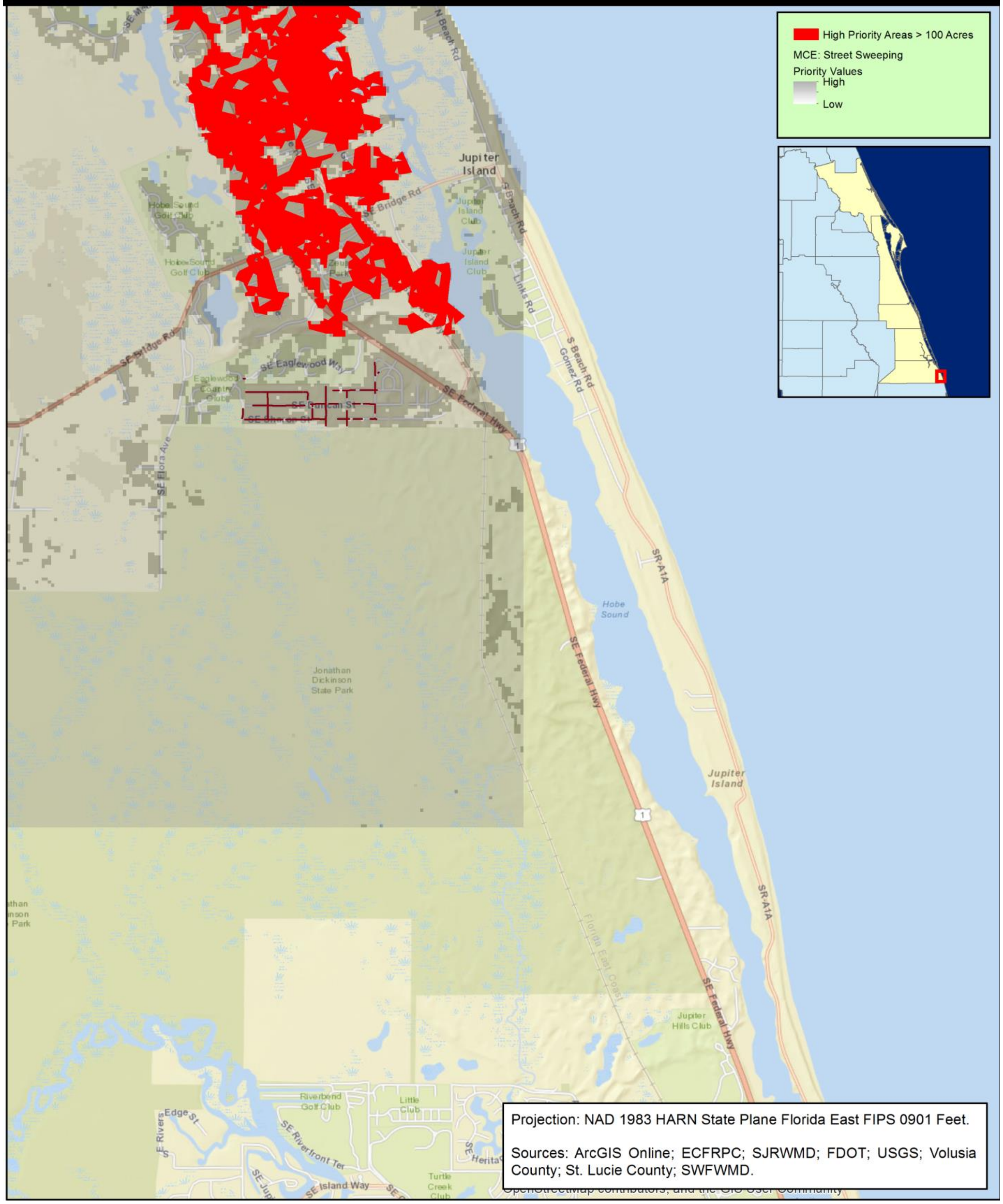

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