SAND2018-11826PE

Siting of Microgrids in Puerto Rico to Improve Community Resilience

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October 15, 2018

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Analysis Goal

Identify potential microgrid locations that increase resilience of the community

Explore portfolios of these microgrids that cost-effectively meet resilience goals

Infrastructure Sector Data

Existing Grid Layout

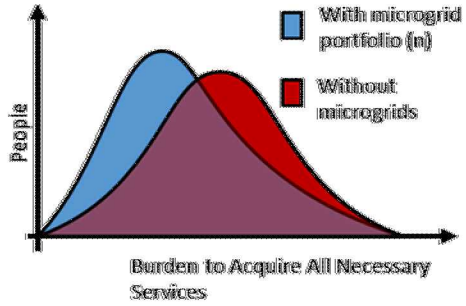
Microgrid Equipment Costs

Population Characteristics

Potential Microgrid Locations

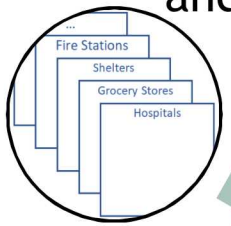
Microgrid Portfolio Resilience Impacts

- Service Level
- Infrastructure Service Community Burden
- Cost



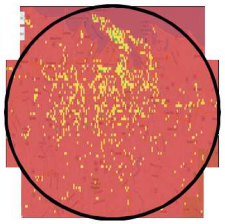
Sandia Analysis Process

1 Infrastructure Data and Threat Analysis

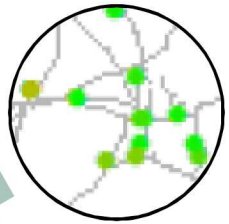


2 Determine Locations Providing High Service Levels

Tool: ReNCAT

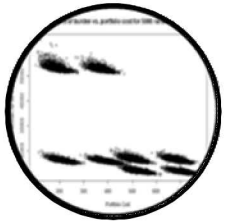


3 Examine Candidate Microgrid Locations



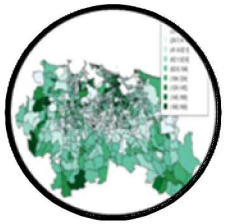
4 Finalize Candidate Microgrid Locations

5 Cost/Benefit Tradeoff Analysis



6 Visualize Metrics and Resilience Options

Tool: MPEx



Step 1
Infrastructure Data and Threat Analysis

Threat Characterization

Overview of Threats, Data Sources, and Relative Probabilities

Hazard	Source	Threat Profile Used	50-yr Probability of Exceedance	Link
Flooding	FEMA FIRM	100-yr and 500-yr (return period)	39% (100-yr) 9.5% (500-yr)	www.fema.gov/flood-mapping-products
Wind	ASCE	100-yr and 700-yr (return period)	39% (100-yr) 6.9% (700-yr)	windspeed.atcouncil.org/
Landslide	USGS	Susceptibility: highest, high, moderate, low	N/A	pr.water.usgs.gov/public/online_pubs/mism_i_1148/index.html
Earthquake	USGS	Structure Damage: Moderate, Light	2%	earthquake.usgs.gov/hazards/hazmaps/islands.php#prvi

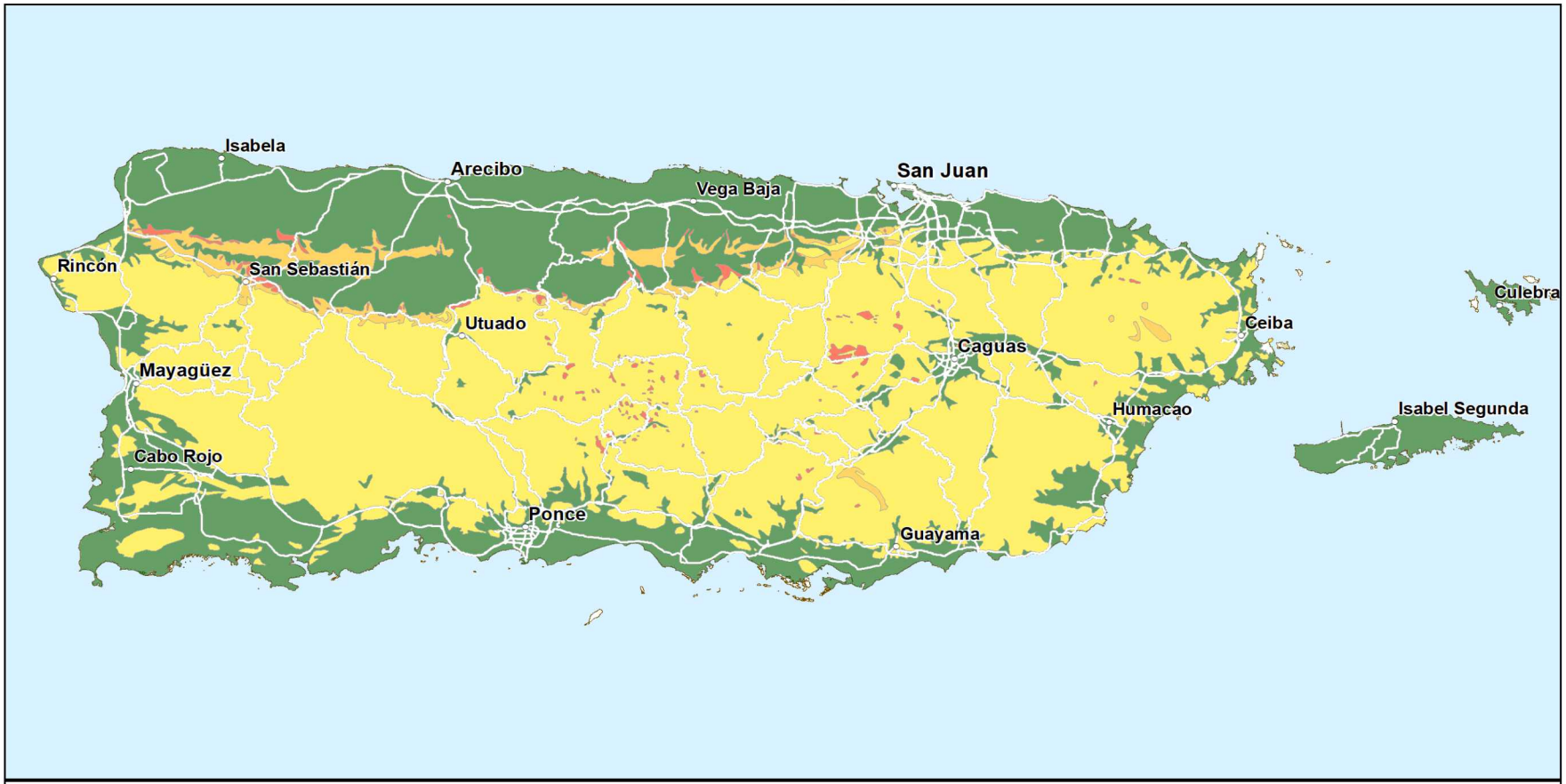
- Compared to June 01 report, added landslide and earthquake threats
- Landslide often coincident with heavy rainfall

Threat Characterization - Earthquake

Southwest corner of island plus a very small area near Rincón exceed moderate damage at 2% probability over 50 years

Threat Characterization - Landslide

Northern Cordillera ridge has high susceptibility. Small pockets of very high susceptibility throughout. Many smaller towns entirely within the moderate susceptibility zone.

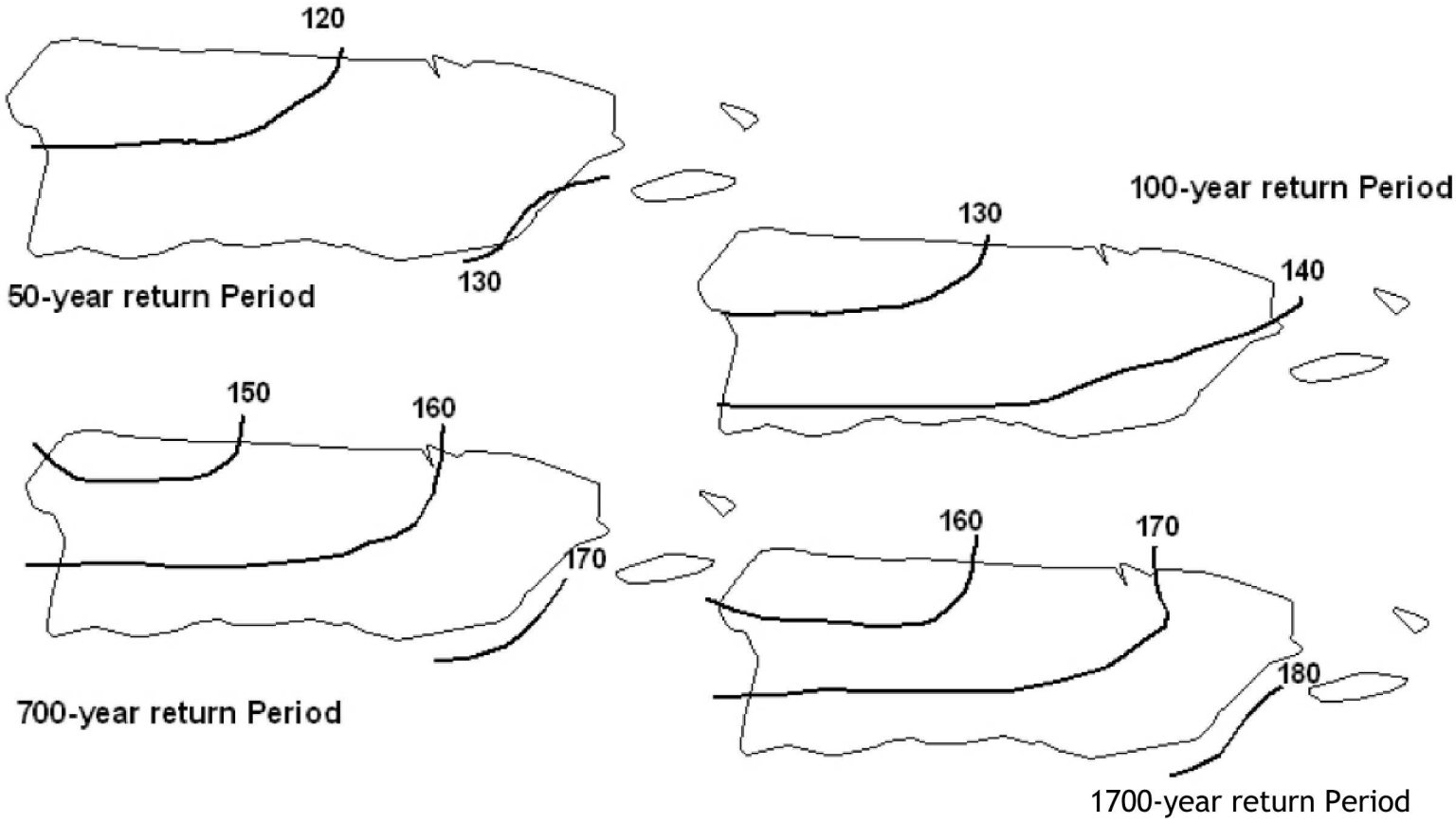


Threat Characterization - Flood

Large sections of San Juan, Ponce, Mayaguez, Cabo Rojo, Caguas, and several other towns within the 100-yr flood zone. Often (not always) the critical infrastructure is outside this zone.

Threat Characterization - Wind

Slight gradient from southeast to northwest, peak gust wind speeds on flat open terrain

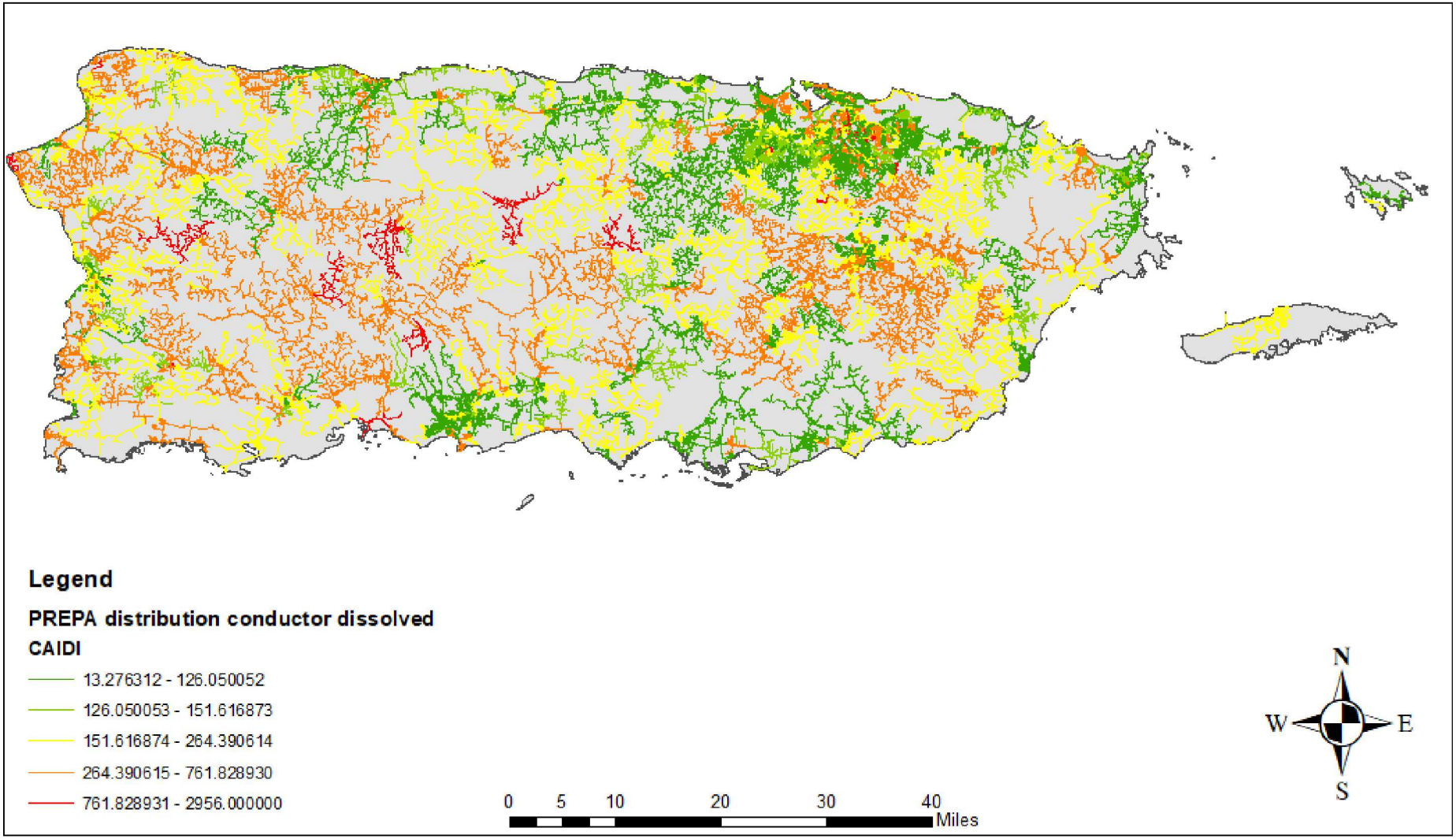


windspeed.atcouncil.org/

Historic Outages

Map of 2015 CAIDI by feeder (in minutes)

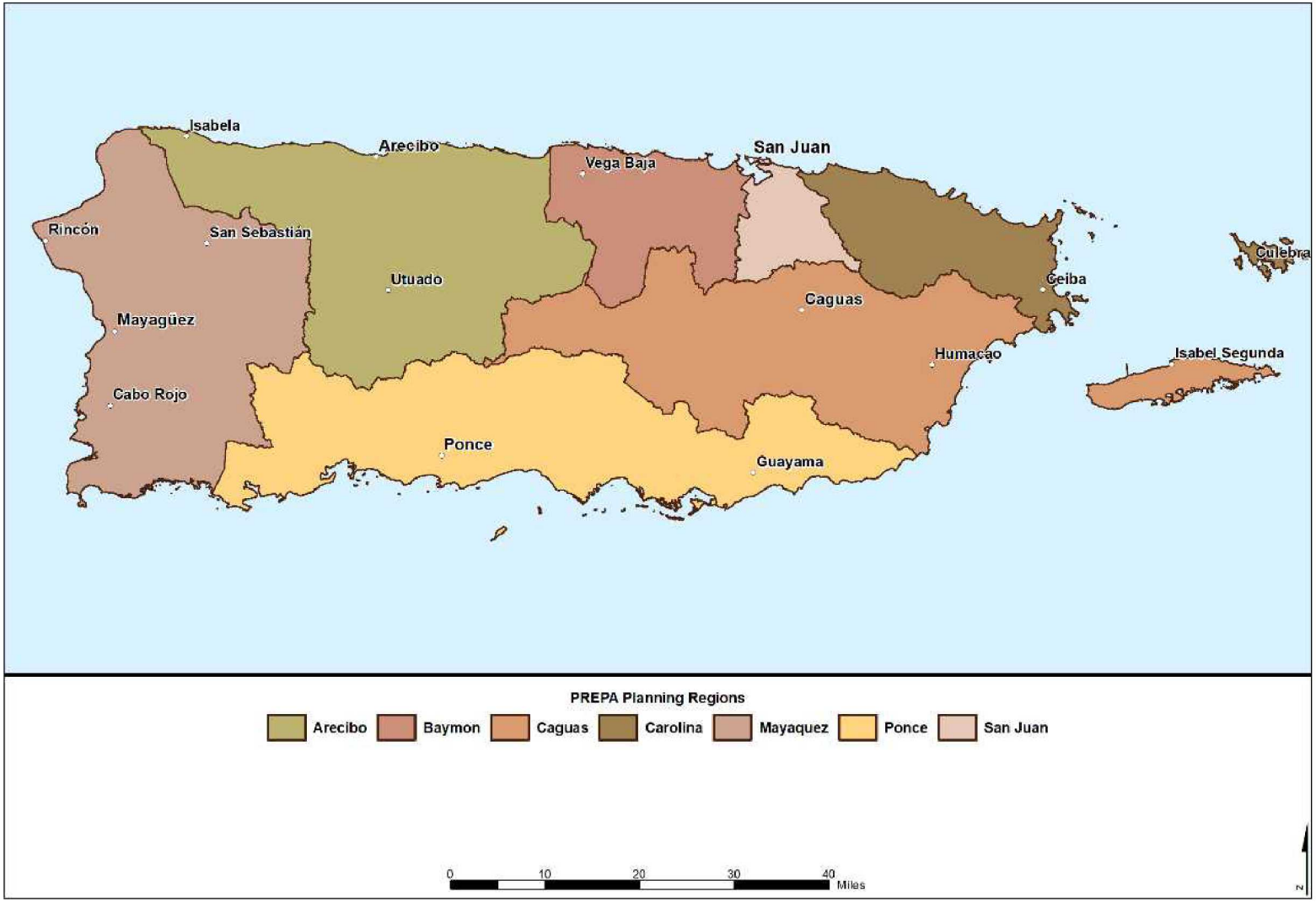
Source: PREPA



Analysis Scope

Aggregation of analysis results by PREPA planning region

An expansion from the June 01 report which focused on the greater San Juan area

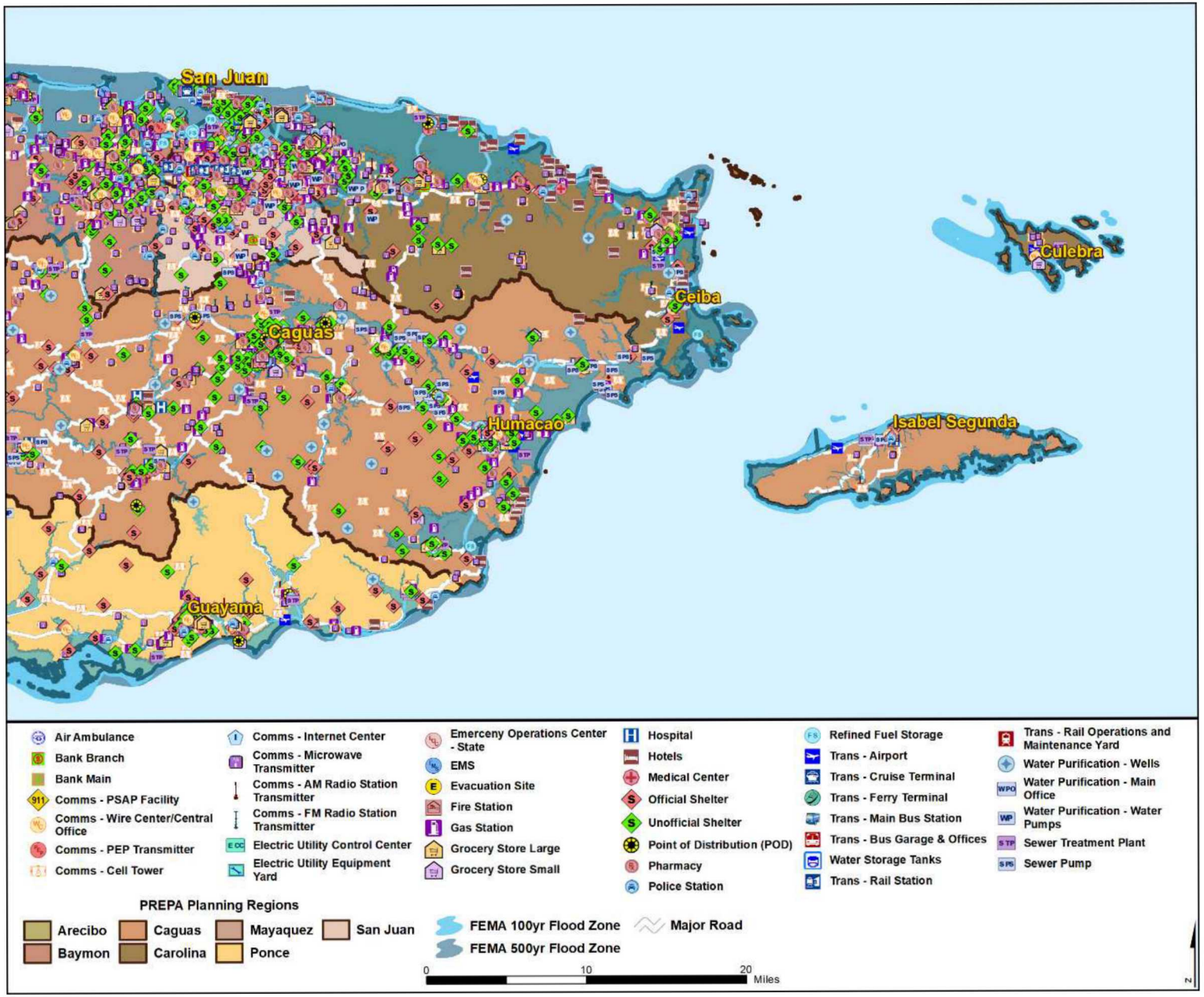


Critical Infrastructure

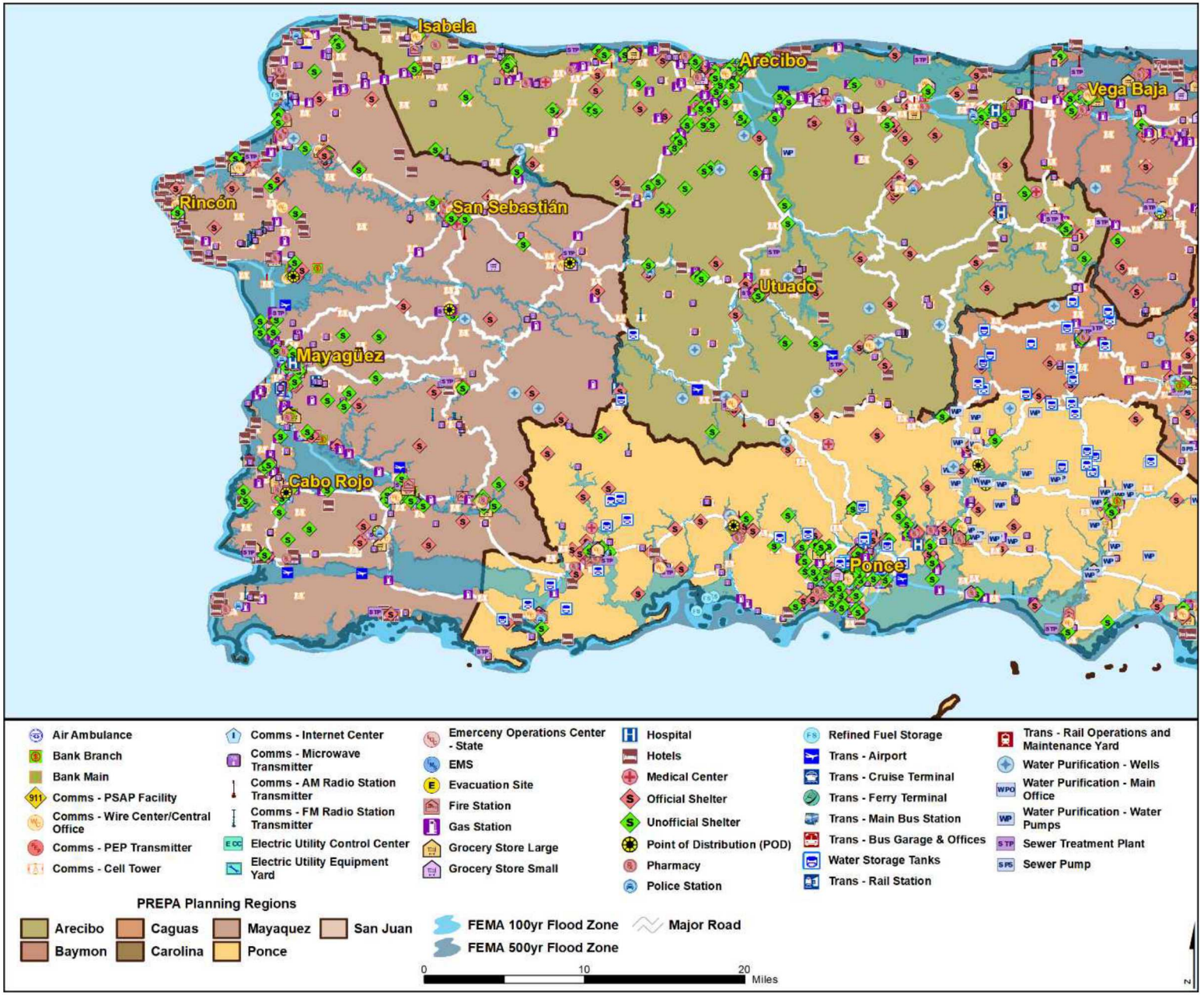
- Focus on the services provided to people
- Included 42 critical infrastructure types (6,643 individual points) and 15 service types

Infrastructure Category	Primary Data Source(s)	Verification Source
Air Ambulances	HSIP Gold 2015	
Airports	FAA; HIFLD Open; Google Maps	
AM Radio Transmitters	FCC Antenna Database	
Bank Branches	OSM; Google Maps; HSIP Gold 2015	Google Maps; Navteq
Bank Main Locations	HSIP Gold 2015	Google Maps
Bus Garage and Offices	Google; Google Maps	
Cell Towers	FCC Antenna Database	
Cruise Terminals	Google; Google Maps	
Electric Utility Control Center	Google; Google Maps	
Electric Utility Equipment Yard	Google; Google Maps	
EMS	HSIP Gold 2015	
EOC	Google; Google Maps	
Evacuation Sites	http://redsismica.uprm.edu/English/tsunami/mapa/info/index.php?tw=san_juan	
Ferry Terminals	Google; Google Maps	
Fire Stations	HSIP Gold 2015	Google Maps
FM Radio Station Transmitters	FCC Antenna Database	
Gas Stations	OSM; Google Maps	Google Maps; Navteq
Grocery Stores - Large	OSM; Google Maps	Google Maps; Navteq
Grocery Stores - Small	OSM; Google Maps	Google Maps; Navteq
Hospitals	HSIP Gold 2015; OSM; Google Maps	Google Maps; Navteq
Hotels	OSM; Google Maps	Google Maps
Internet Centers	GRIT, Inc.; Google; Google Maps	
Main Bus Stations	Google; Google Maps	
Medical Centers	Google	
Microwave Transmitters	FCC Antenna Database	
Official Shelters	HIFLD; Puerto Rican Government	Google Maps
PEP Transmitters	FCC; Google Maps	
Pharmacies	OSM; Google Maps	Google Maps; Navteq
Points of Distribution	https://www.fema.gov/news-release/2017/09/26/federal-teams-continuing-deliver-supplies-puerto-rico-and-us-virgin-islands	Google Maps
Police Stations	HSIP Gold 2015; Google Maps	Google Maps
PSAP Facilities	Google; Google Maps	
Rail Operations and Maintenance Yard	Google; Google Maps	
Rail Stations	Google; Google Maps	
Refined Fuel Storage	EIA; Google	Google Maps
Sewer Pumps	Puerto Rican Government	Google Maps
Sewer Treatment Plants	Puerto Rican Government	Google Maps
Unofficial Shelters	OSM, HSIP Gold 2015; HIFLD	Google Maps
Water Pumps	Puerto Rican Government	Google Maps
Water Purification	HIFLD; Puerto Rican Government	Google Maps
Water Purification Main Office	Puerto Rican Government	Google Maps
Water Storage Tanks	Puerto Rican Government	Google Maps
Wire Centers	GRIT, Inc.; Google Maps	

Critical Infrastructure



Critical Infrastructure



Step 2
Determine Locations Providing High Service Levels

Infrastructure exclusion profiles

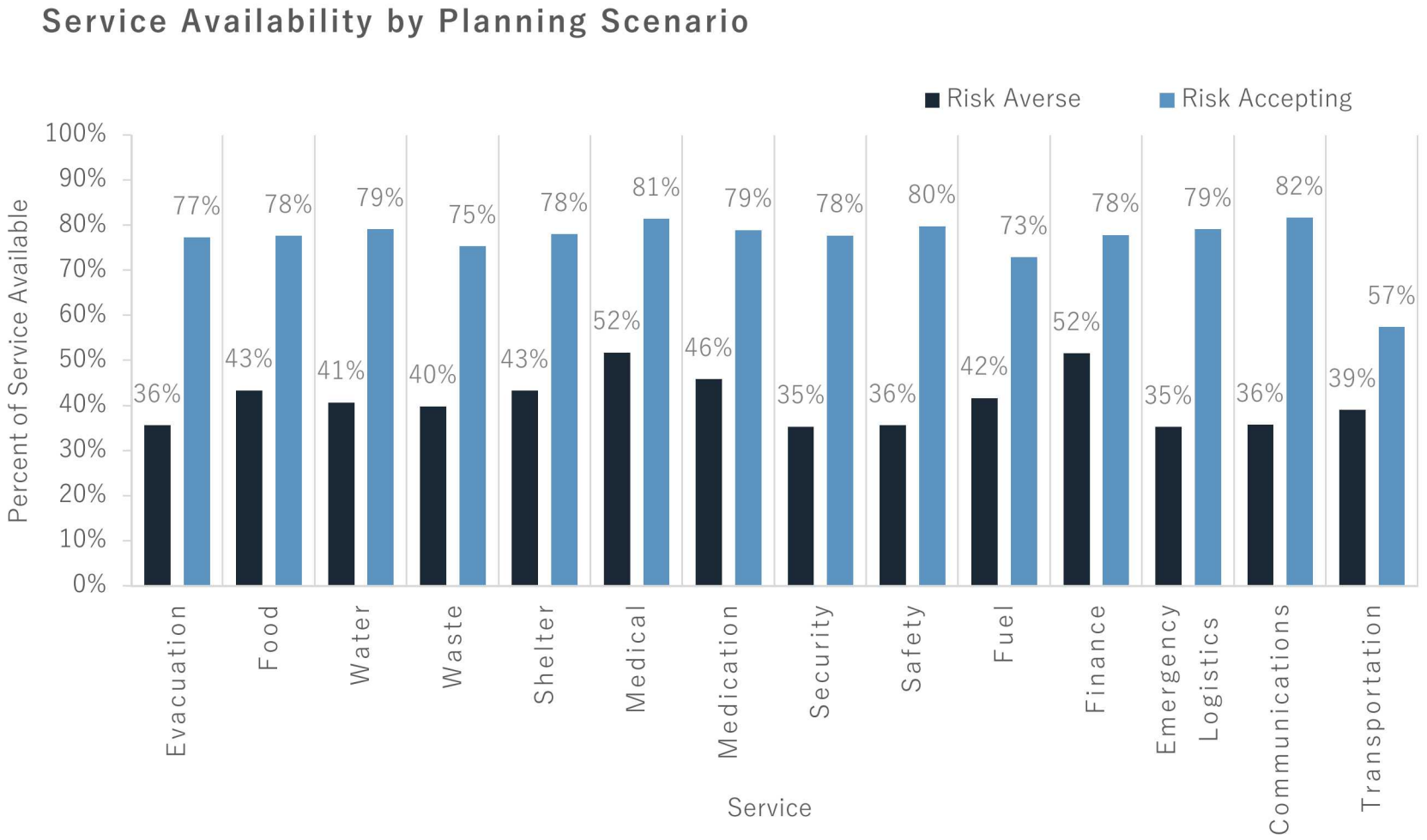
Balancing act: suggested areas for microgrids should be outside of, but close to heavily damaged areas in order to serve displaced/vulnerable populations

Initially, suggested microgrid areas exclude infrastructure based on the following exclusion profiles (some exceptions noted later)

Most analysis performed using Risk Averse and Risk Accepting profiles

Exclusion Profile	Wind Exclusions	Flood Exclusions	Earthquake Exclusions	Landslide Exclusions
Risk Averse	-	In 500 yr zone	Medium and higher damage zones	Medium and higher susceptibility zones
Risk Accepting	-	In 100 yr zone	High and higher damage zones	High and higher susceptibility zones
100 yr Flood	-	In 100 yr zone	-	-
500 yr Flood	-	In 500 yr zone	-	-
Landslide Med	-	-	-	Medium and higher susceptibility zones
Landslide High	-	-	-	High and higher susceptibility zones
Earthquake Med	-	-	Medium and higher damage zones	-

How much infrastructure is available?



Excluding assets with medium landslide susceptibility represents the primary difference between Risk Averse and Risk Accepting

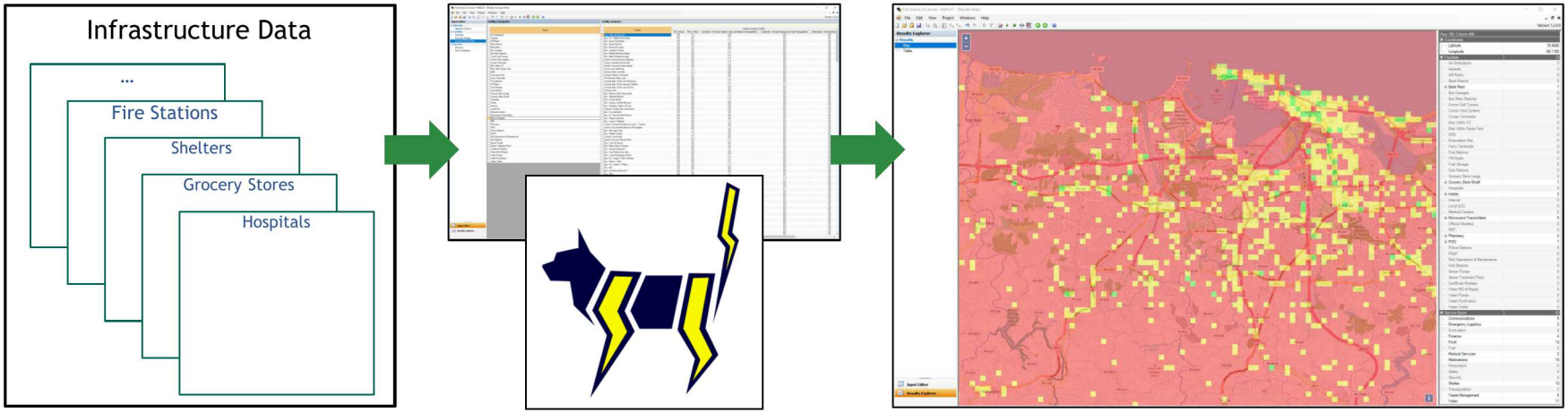
Services, not Sectors

- Infrastructure types mapped to one or more service types
- Different sectors can provide the same service at various contribution levels
- Concerned with identifying resilient nodes within that provide high levels across the different service types

Community Service	Level of Contribution by Infrastructure Sector		
	High	Medium	Low
Communications	Cell Towers; Wire Centers; Internet		Microwave Transmitters
Emergency Logistics	Local Emergency Operations Center; PEP	AM Radio Station Transmitters; FM Radio Station Transmitters	Evacuation Sites ; Points of Distribution; Official Shelters; Unofficial Shelters; Wire Centers; Cell Towers
Evacuation	Evacuation Sites; PEP; Airports	Wire Centers; Rail Stations; Bus Main Stations; Cruise Terminals	Police Stations; Local Emergency Operations Center; Cell Towers; Rail Operations and Maintenance; Bus Garages; Ferry Terminals
Finance	Bank Mains	Bank Branches	Wire Centers
Food	Points of Distribution; Large Grocery Stores; Airports	Small Grocery Stores	Official Shelters; Unofficial Shelters; Hotels; Gas Stations; Pharmacies; Cruise Terminals
Fuel	Gas Stations; Fuel Storage		
Medical Services	Hospitals; EMS	Air Ambulances; Medical Centers	Fire Stations; Pharmacies
Medications	Pharmacies	Hospitals	Points of Distribution; Official Shelters; Unofficial Shelters; Gas Stations; Large Grocery Stores; Medical Centers
Restoration	Electric Utility Control Center; Electric Utility Equipment Yard	Airports	Fuel Storage
Safety	Fire Stations; PSAP	EMS	Wire Centers; Cell Towers
Security	Police Stations; PSAP		Wire Centers; Cell Towers
Shelter	Official Shelters; Hotels	Unofficial Shelters	
Transportation	Rail Stations; Bus Main Stations; Airports	Rail Operations and Maintenance; Bus Garages; Ferry Terminals	Cruise Terminals
Waste Management	Sewer Treatment Plants	Sewer Pumps	Official Shelters; Unofficial Shelters
Water	POD; Water Main Office and Repair Yard	Large Grocery Stores; Water Purification; Water Pumps; Water Storage Tanks	Official Shelters; Unofficial Shelters; Hotels; Gas Stations; Small Grocery Stores; Pharmacies; Airports; Cruise Terminals

Microgrid Siting Analysis

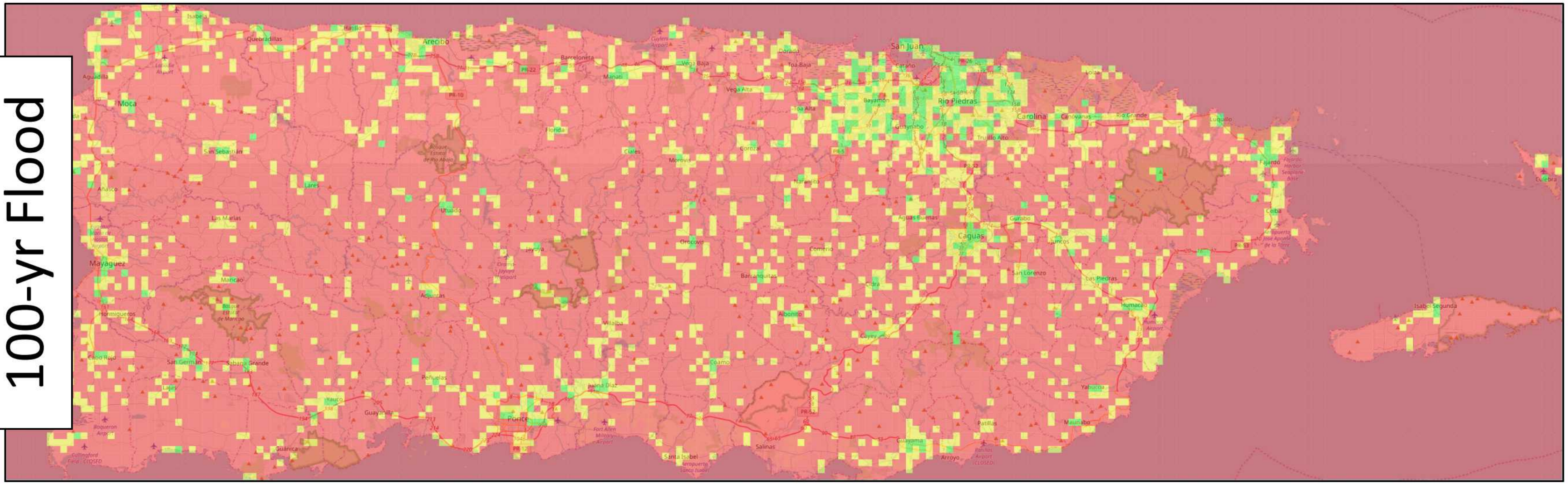
This project improved the ReNCAT tool to identify locations that have high levels of services available based on the threat constraints.



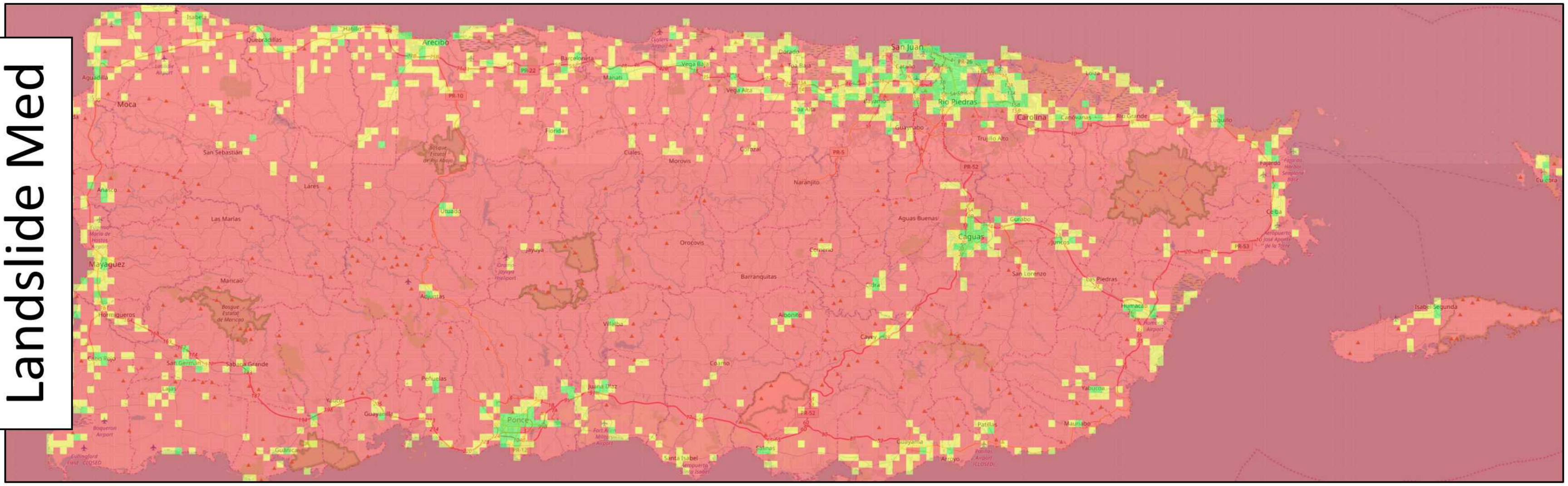
*Pending cost refinement

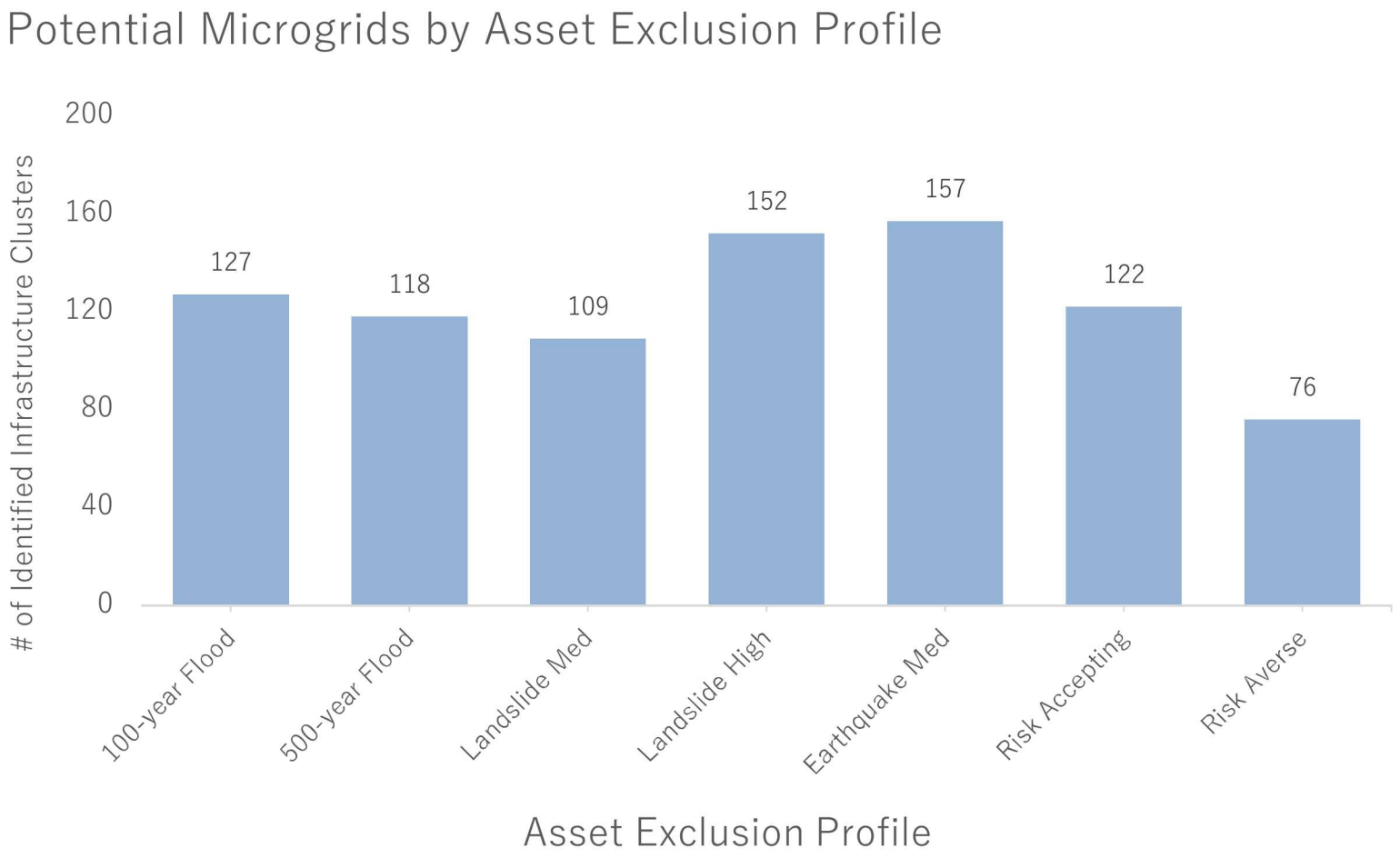
Threat Exclusion Profiles Show Different Results

100-yr Flood



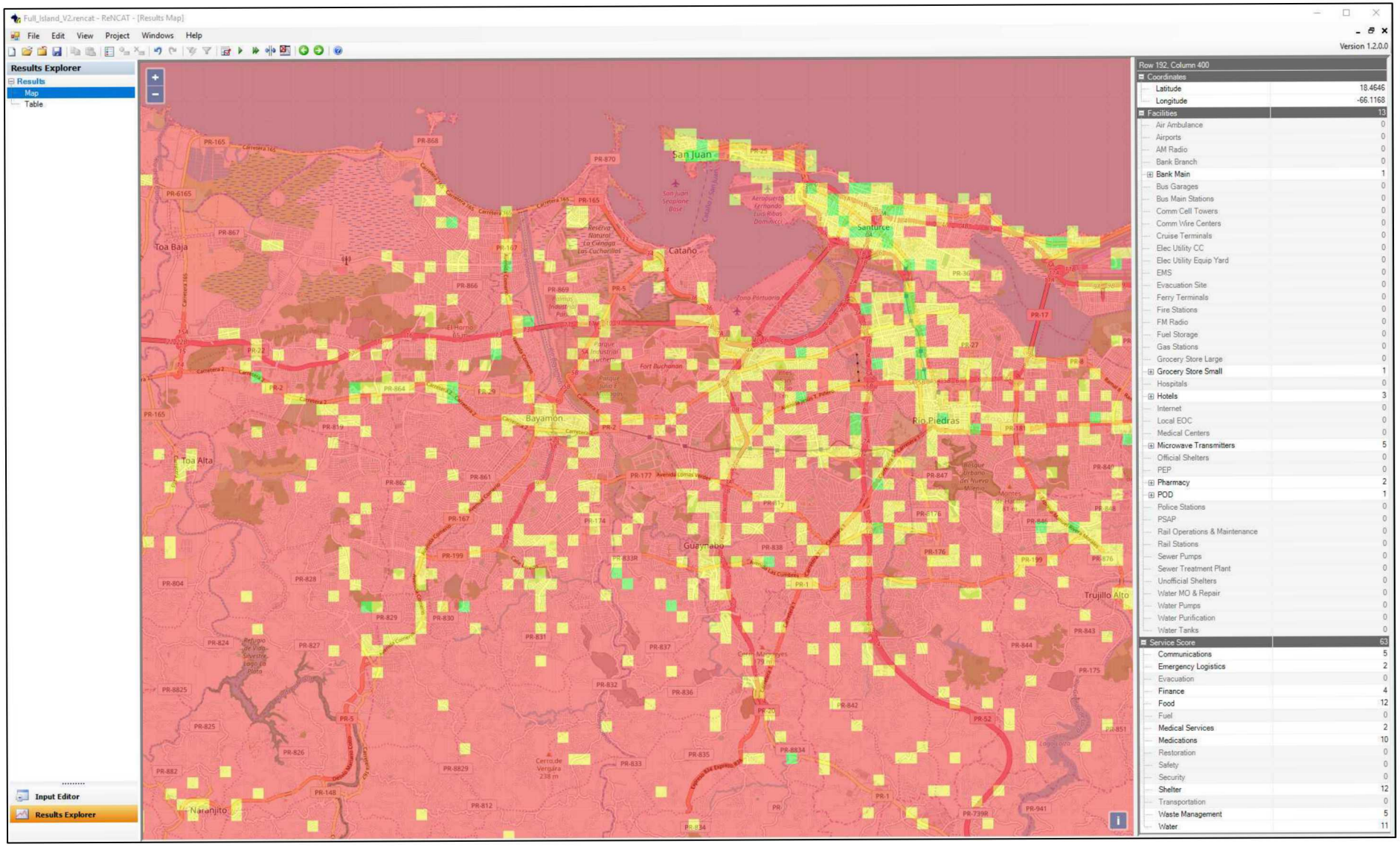
Landslide Med





These ReNCAT runs used 1000x1000ft grid cell and minimum service score of 30

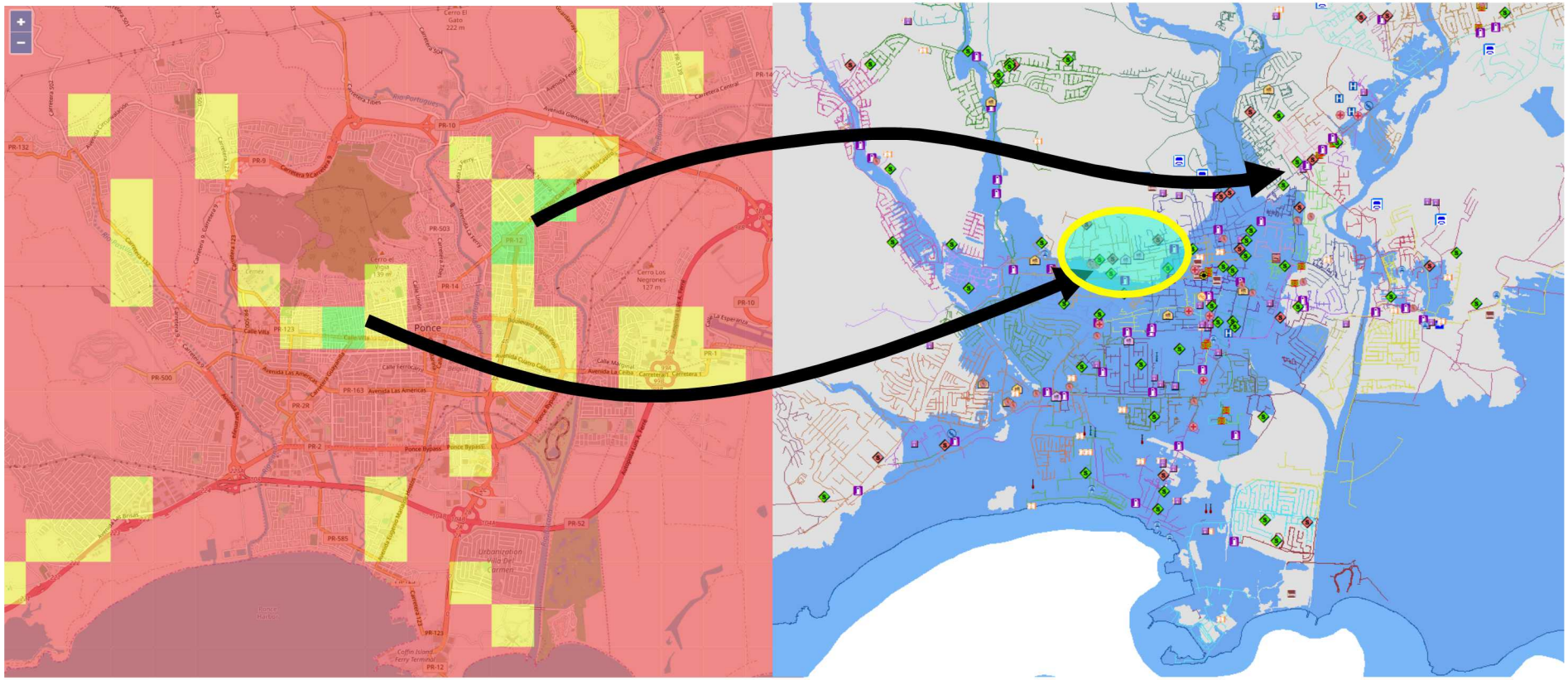
ReNCAT Tool Suggests Locations with High Service Levels



Step 3
Examine Candidate Microgrid Locations

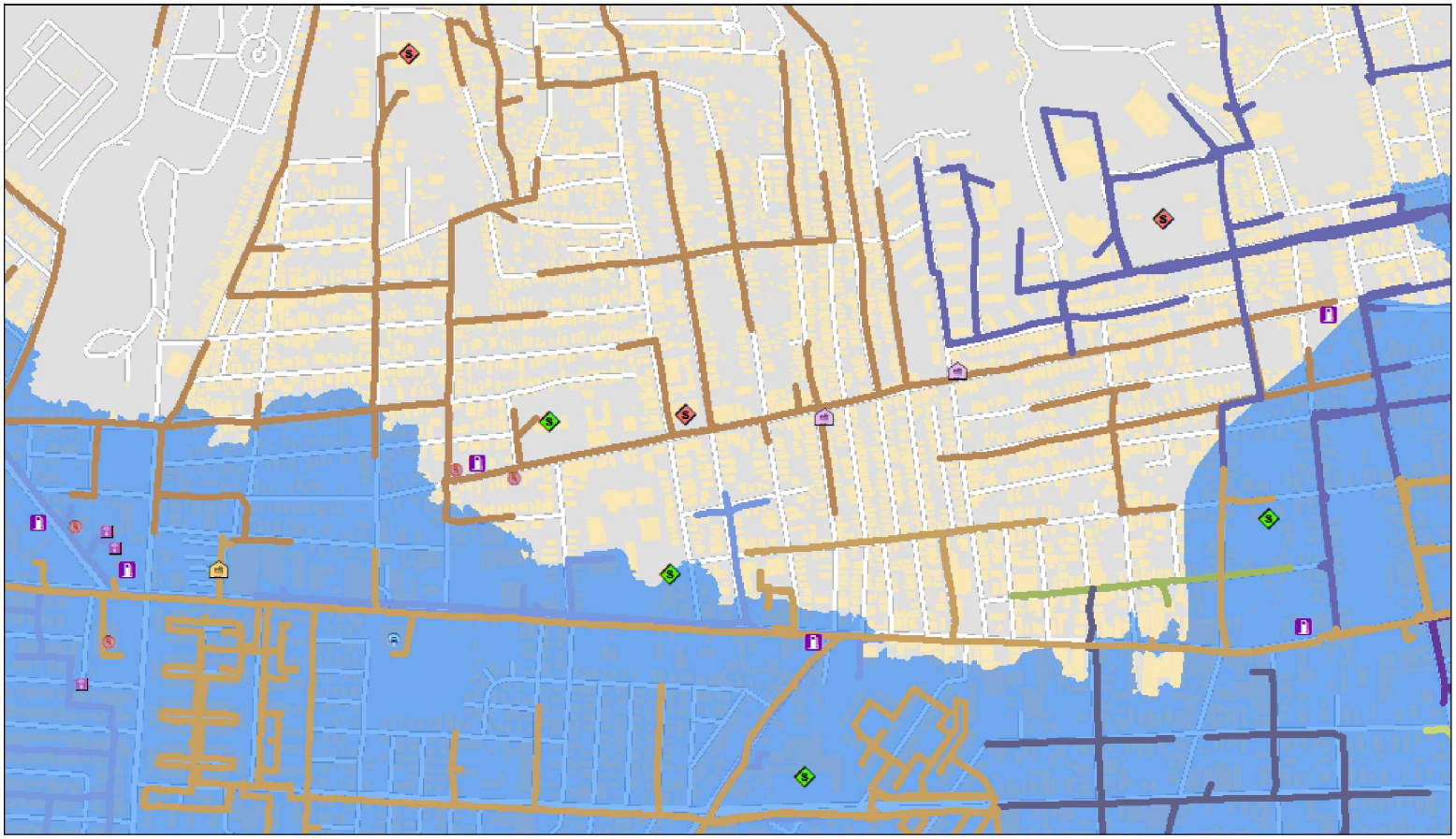
ReNCAT to Microgrids: Ponce Example

Explore the green squares – find high concentration of services outside the hazard zones



ReNCAT to Microgrids: Ponce Example

Find clusters of assets – ideally all on the same feeder - and minimize non-critical load



Legend

infrastructures_ReNCAT_PR_v5_092818

sector

- Air Ambulance
- Bank Branch
- Bank Main
- Comms - PSAP Facility
- Comms - Wire Center/Central Office
- Comms - PEP Transmitter
- Comms - Cell Tower
- Comms - Internet Center
- Comms - Microwave Transmitter
- Comms - AM Radio Station Transmitter
- Comms - FM Radio Station Transmitter
- Electric Utility Control Center
- Electric Utility Equipment Yard
- Emergency Operations Center - State
- EMS
- Evacuation Site
- Fire Station
- Gas Station
- Grocery Store Large
- Grocery Store Small
- Hospital
- Hotels
- Medical Center
- Official Shelter
- Unofficial Shelter
- Point of Distribution (POD)
- Pharmacy
- Police Station
- Refined Fuel Storage
- Trans - Airport
- Trans - Cruise Terminal
- Trans - Ferry Terminal
- Trans - Main Bus Station
- Trans - Bus Garage & Offices
- Trans - Rail Station
- Trans - Rail Operations and Maintenance Yard
- Water Purification - Main Office
- Water Purification - Water Pumps
- Water Purification - Wells
- Water Storage Tanks
- Sewer Treatment Plant
- Sewer Pump
- pr_fema_100yr_flood

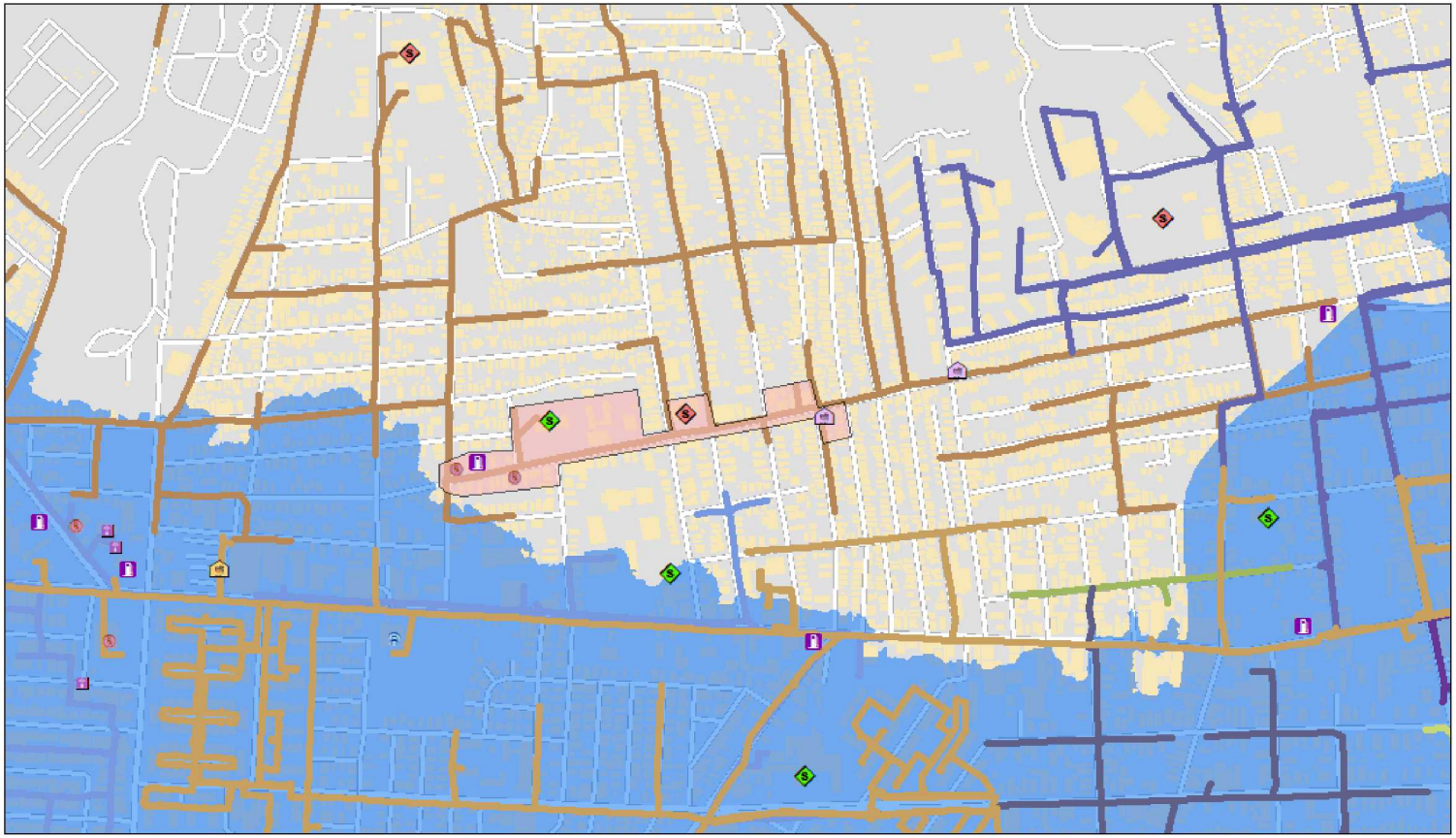
N W E S

0 0.04250.085 0.17 0.255 0.34 Miles

Distribution feeders: PREPA

ReNCAT to Microgrids: Ponce Example

Draw microgrid polygon to balance use of isolation switches vs. acceptance of non-critical load

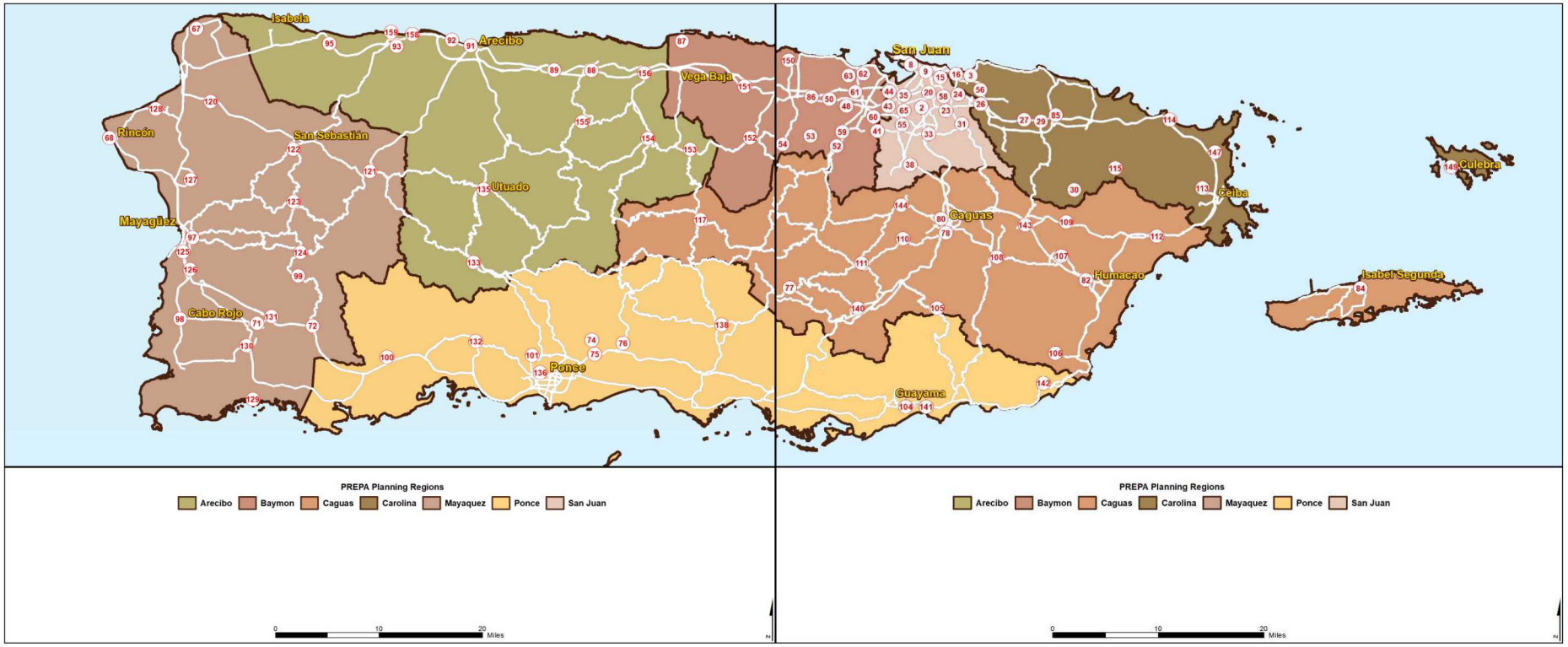


Distribution feeders: PREPA

Step 4
Finalize Candidate Microgrid Locations

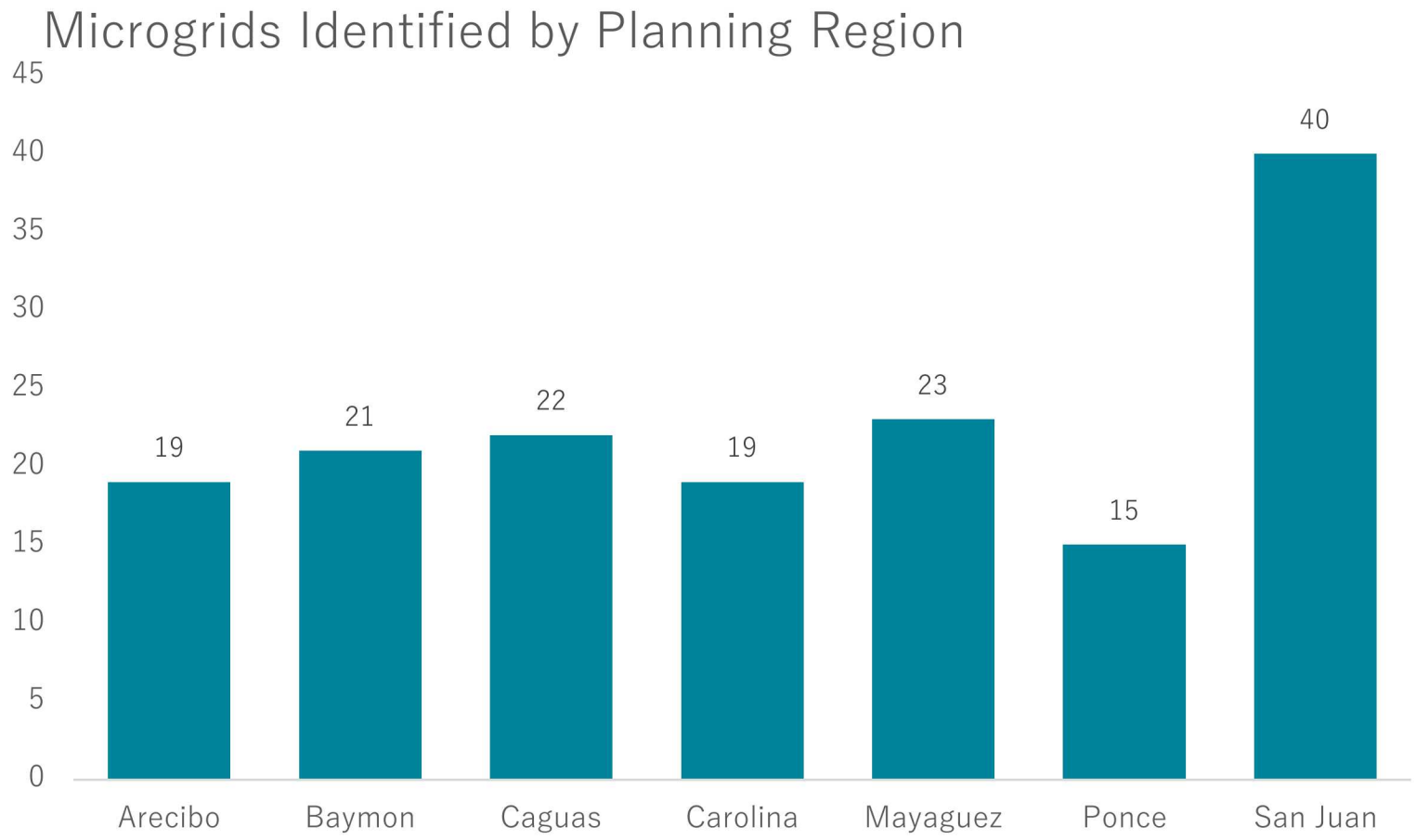
Suggested Microgrid Locations

159 locations in total

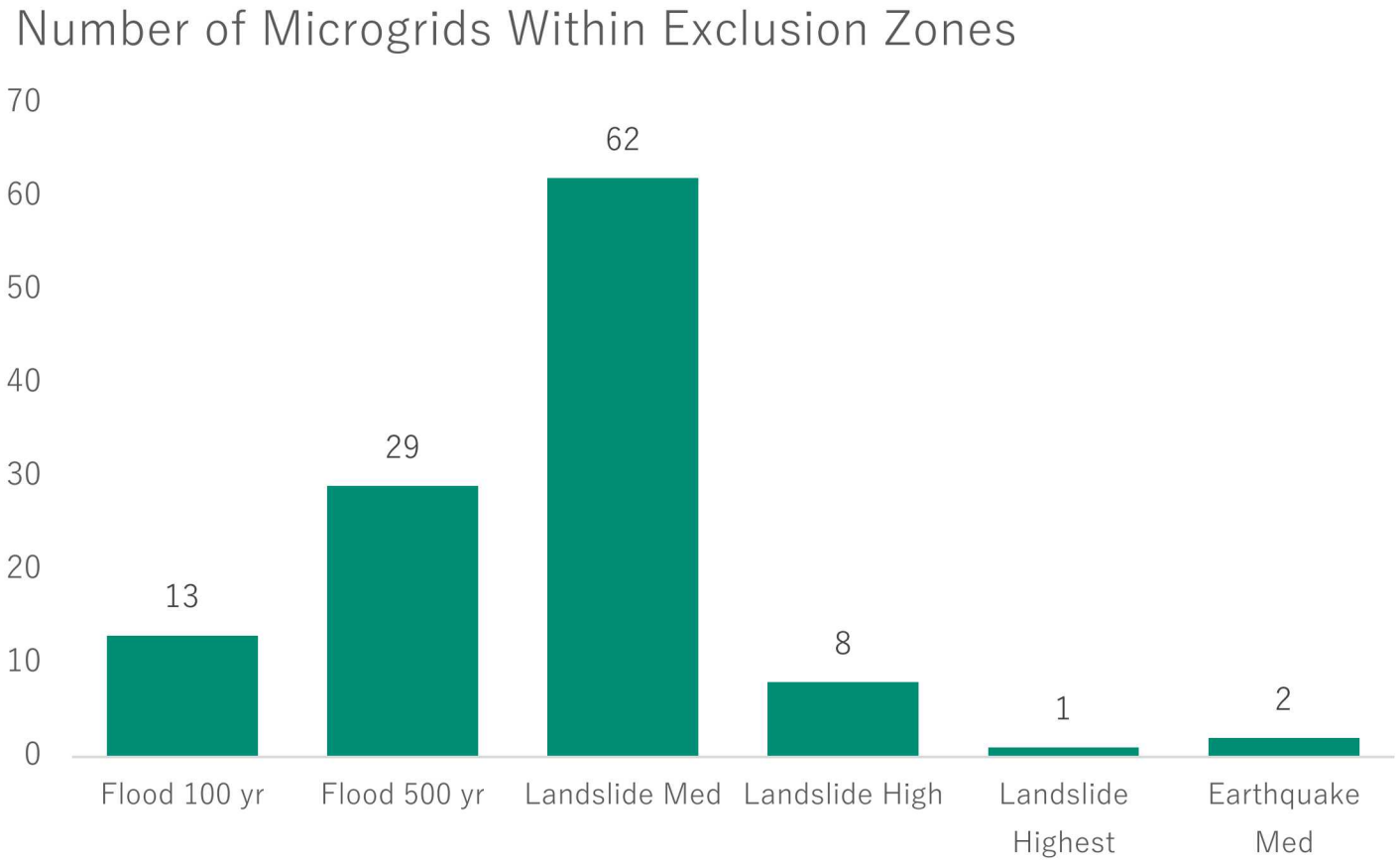


17 microgrids dominated by communications assets (cell towers, microwave transmitters, AM/FM Radio Transmitters):

115, 113, 105, 99, 93, 89, 88, 87, 86, 85, 53, 51, 44, 41, 40, 30, 29

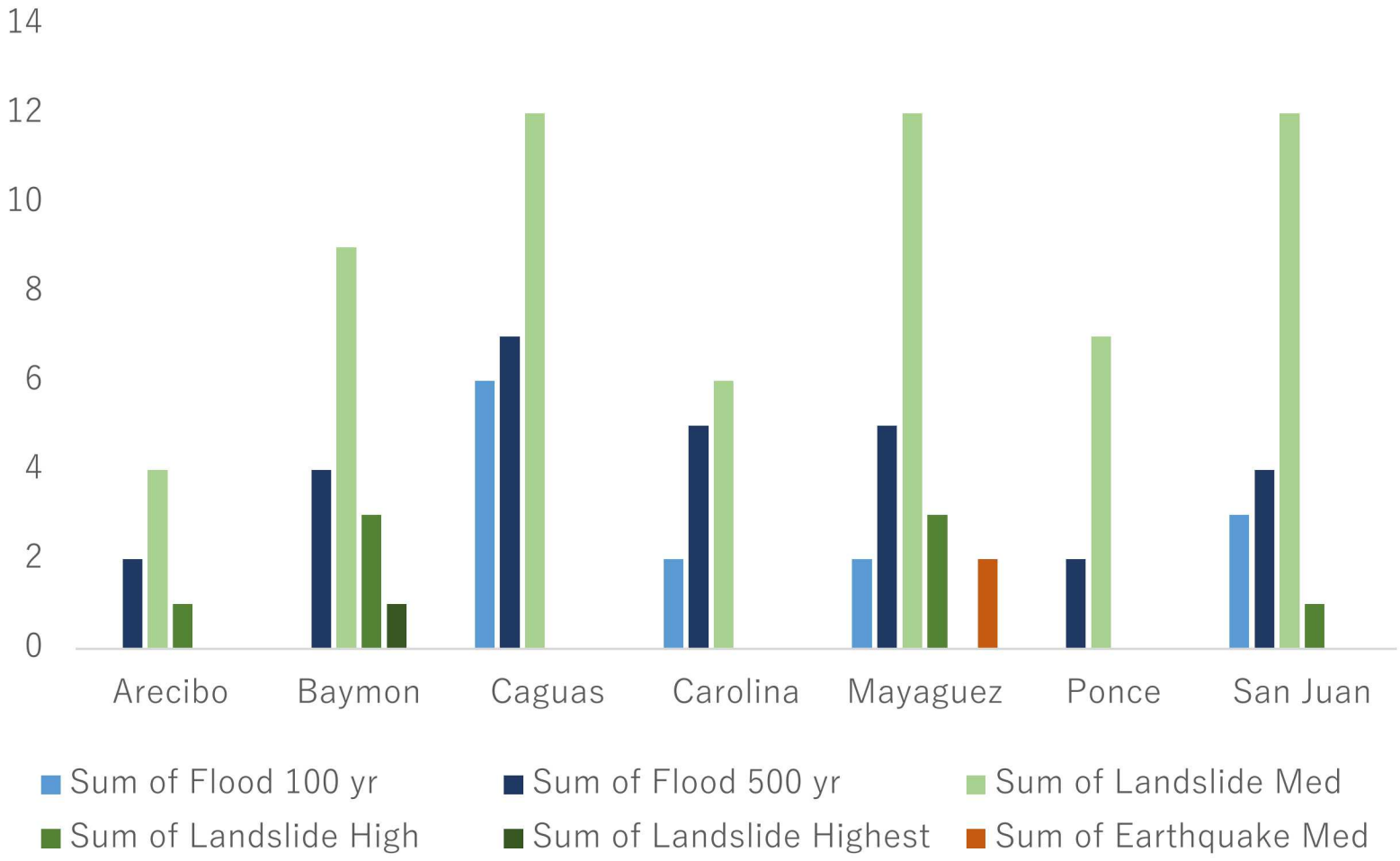


1,128 of 6,643 (17%) infrastructure points are within an identified microgrid

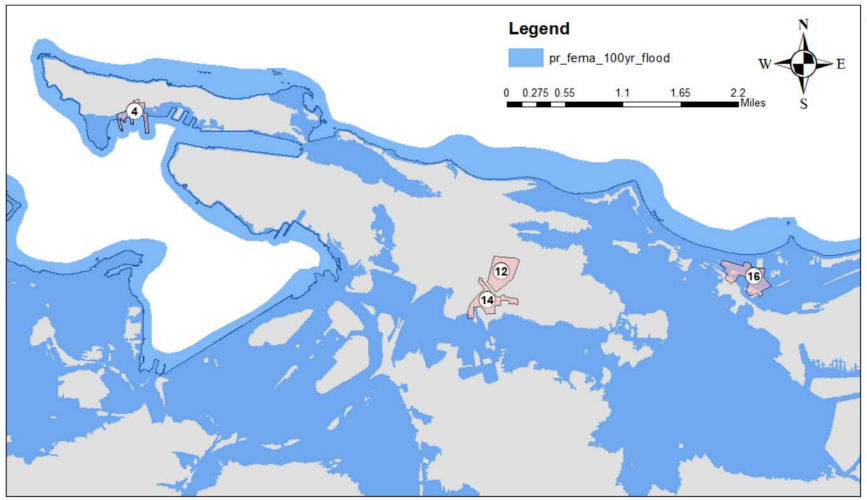


Microgrids with *at least* one asset within an exclusion zone

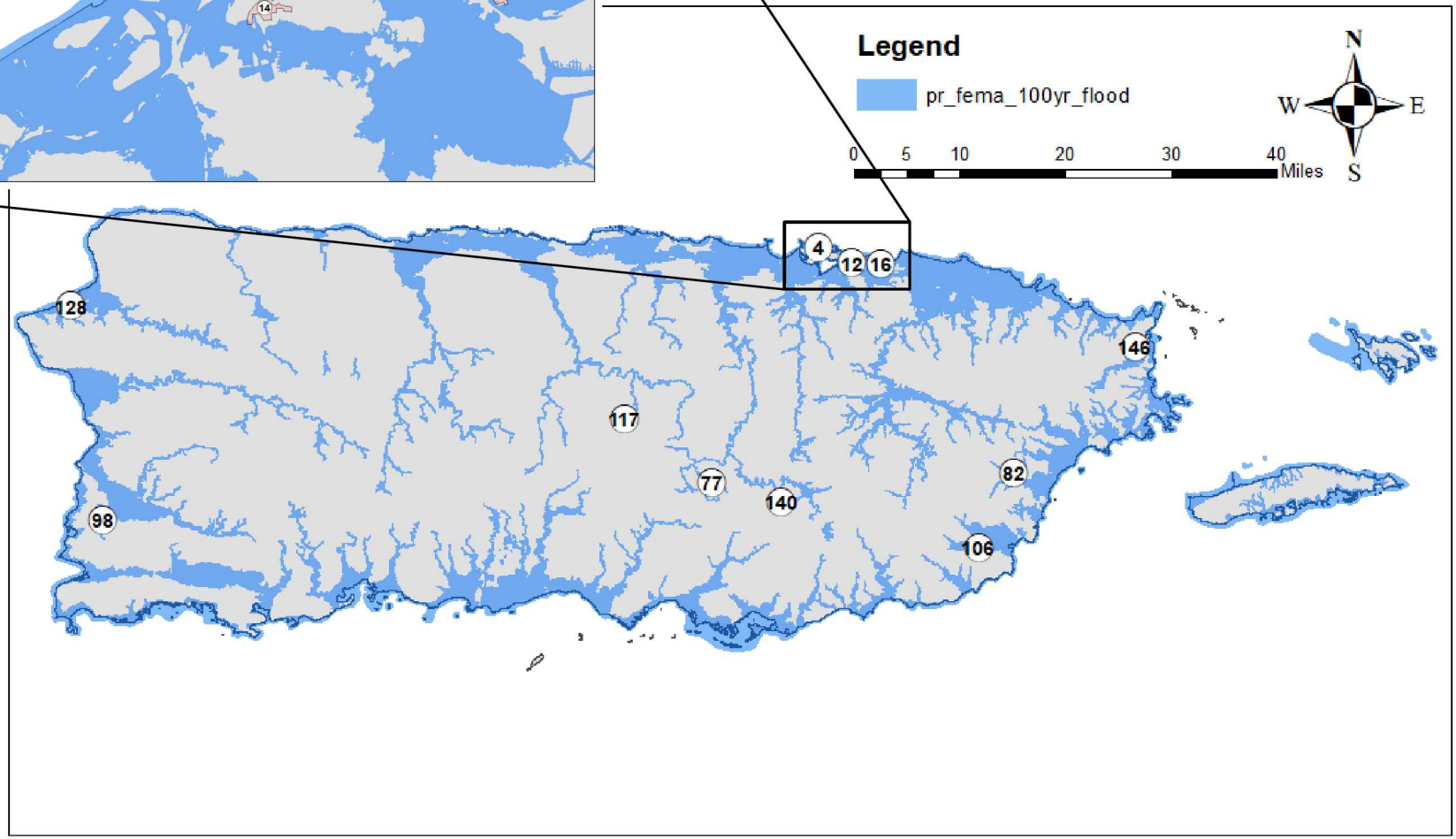
Microgrids Within Exclusion Zones by Region



Microgrids in 100yr Flood Zone

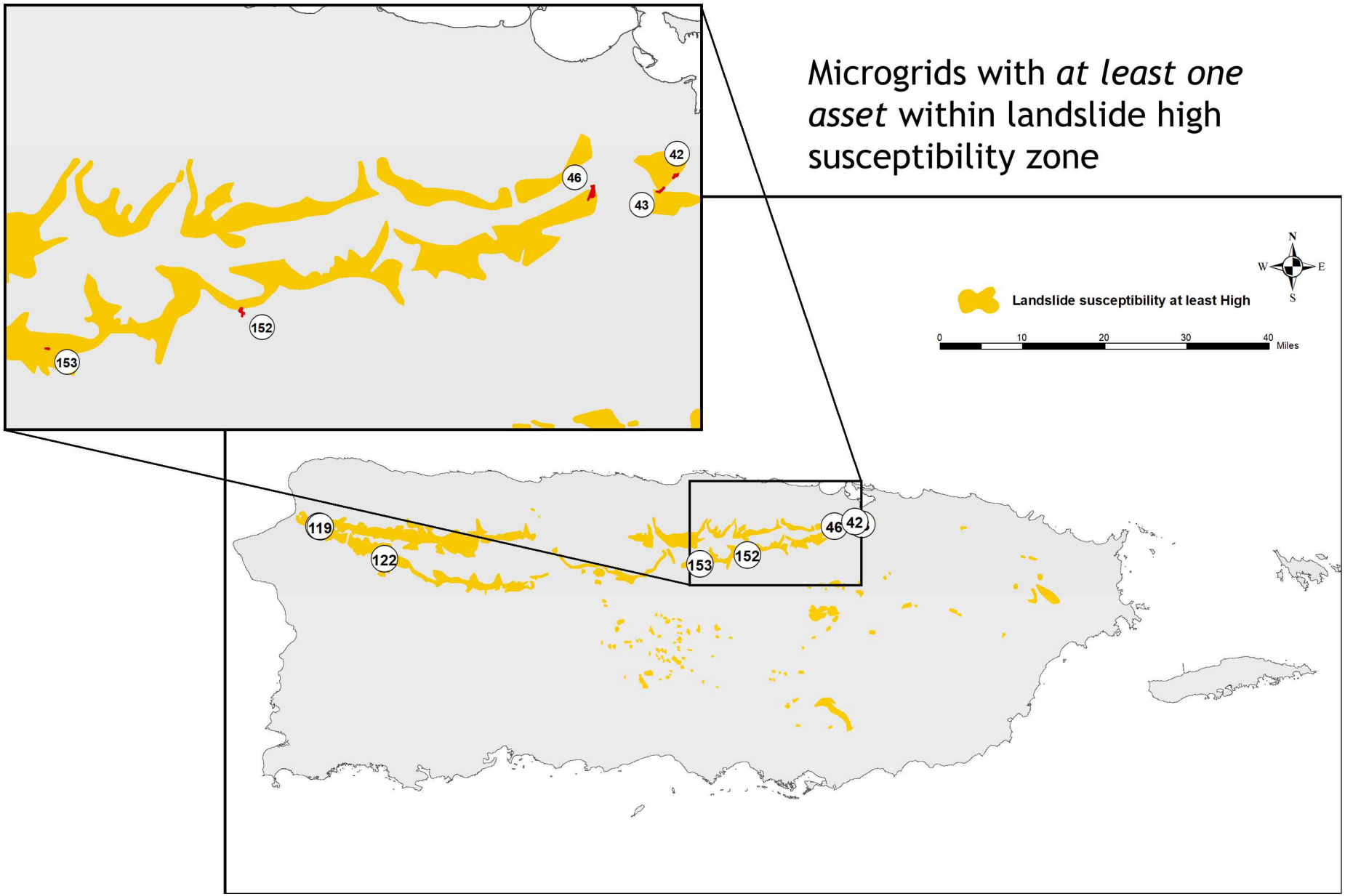


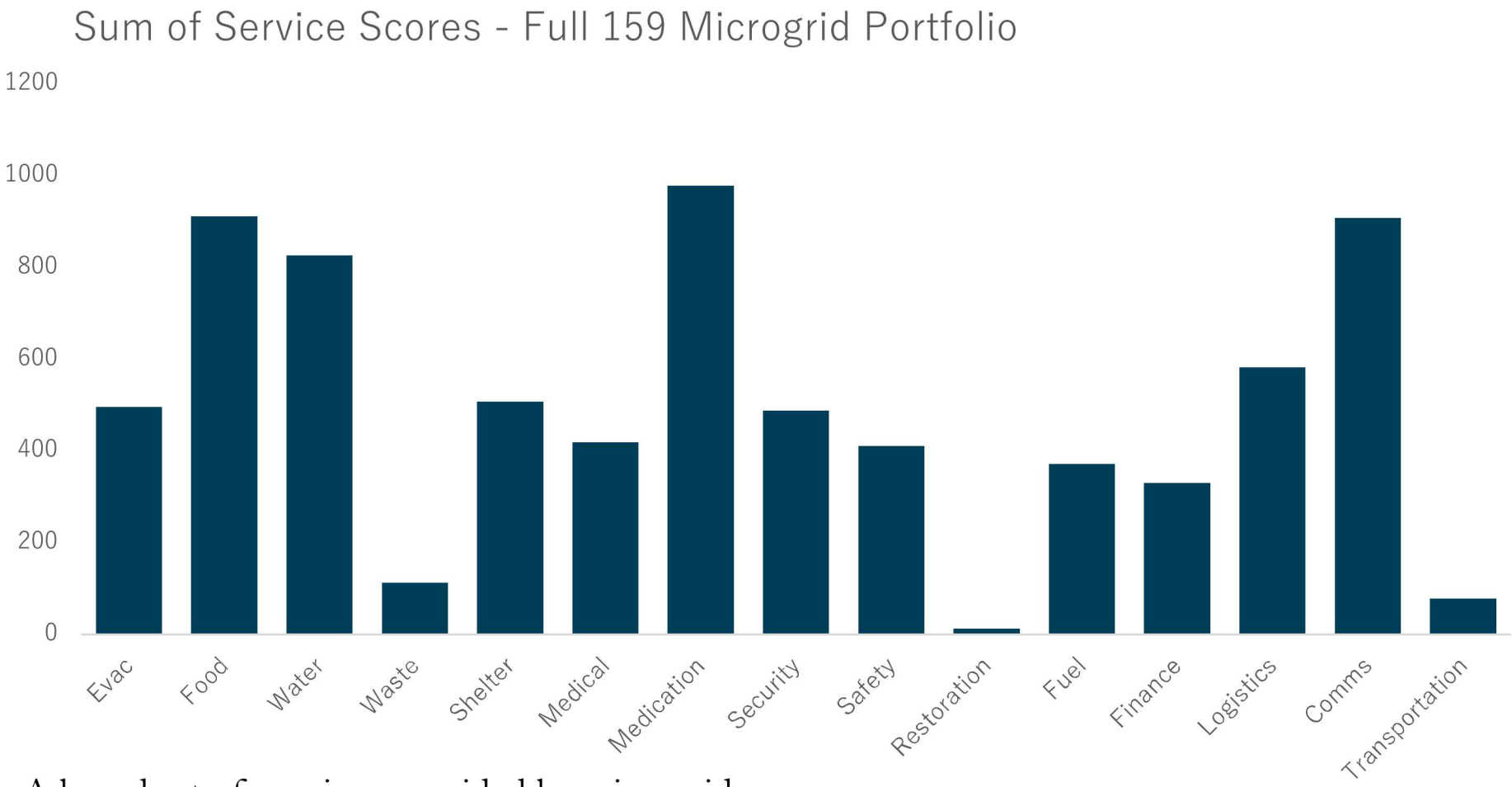
Microgrids with *at least one asset* within 100yr flood zone



Microgrids in Landslide High Susceptibility Zone

Microgrids with *at least one asset* within landslide high susceptibility zone

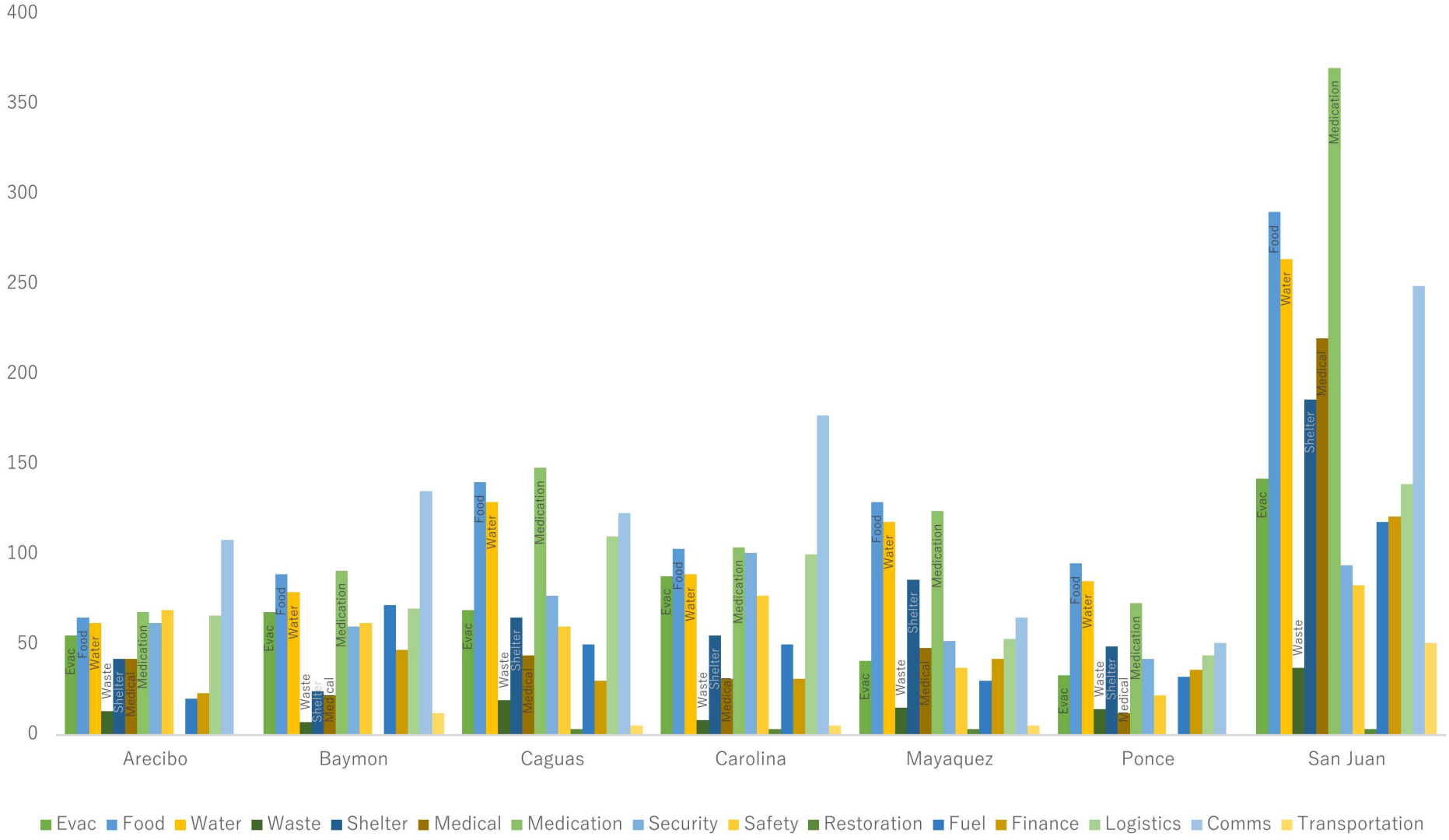




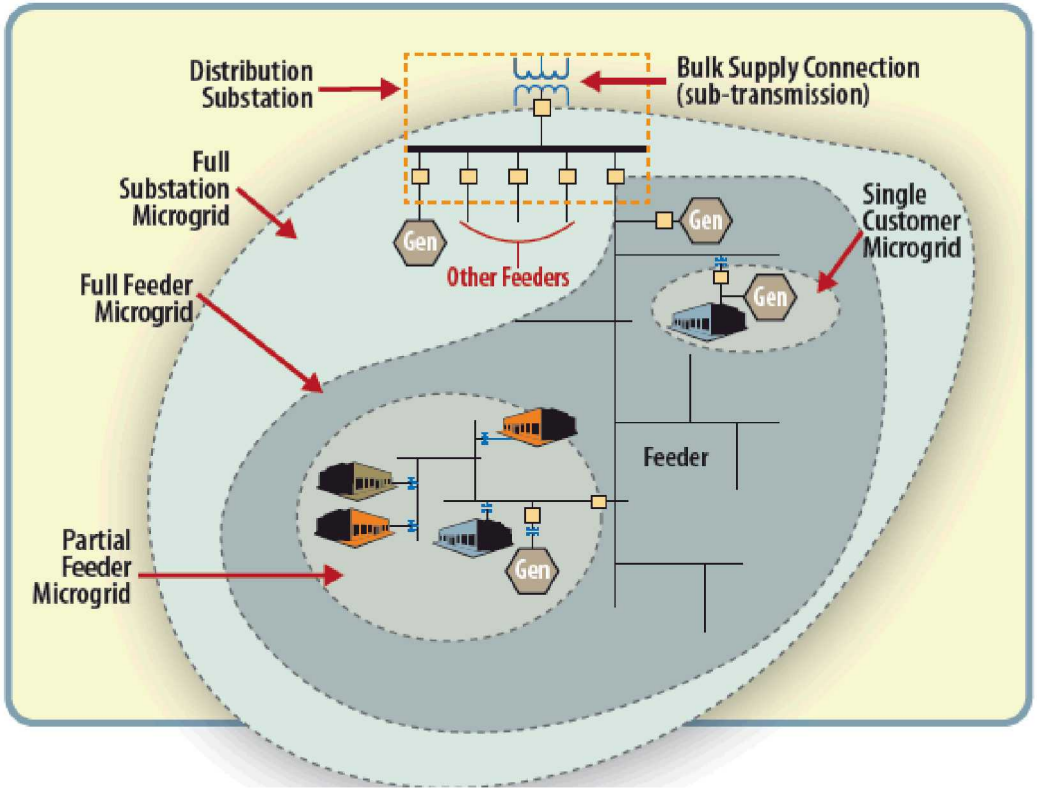
A broad set of services provided by microgrids

The less represented services (waste, grid restoration, transportation) tend to be served by fewer assets

Service Scores for All Microgrids by Planning Region



What is a microgrid



Microgrid Attributes

- Can be sized at full substation, feeder, partial feeder or customer level
- Can operate islanded or grid-tied
- Can integrate distributed and renewable generation, CCHP and manage and control power demand and distributed resource allocation

Blue sky benefits depend on how microgrid can provide revenue streams such as by providing on-going PV and energy storage services to the grid, leveraging CCHP, and providing distribution services such as demand response for peak periods, voltage and Var support, arbitrage, black start, etc.

Microgrid **assessment** and analysis steps following selection of microgrid sites for further design

Initial Assessment

Characterize System and Define Boundaries

- The system to which resilience solutions will be applied

Identify Critical Loads and Infrastructure

- The critical functions that performance must be improved for

Define Design Basis Threats (DBTs)

- Natural and man made threats and power outage durations that performance goals must be designed to address

Define Performance Goals and Objectives

- How system must function to withstand DBT including boundary of critical assets protected, duration of protection, and critical mission energy needs and operations

Microgrid assessment and **analysis** steps following selection of microgrid sites for further design

Analysis

Determine Consequences of Various Threat Scenarios

- including the impacts in terms of power outages in critical assets impacted and durations of impacts; also includes impacts to critical mission functions beyond the specific site itself that impacts safety and personnel

Formulate Solutions

- Range of options include facility hardening to threats, building energy management system improvements, additional redundancy in backup systems, advanced microgrids, including the use of renewables, energy storage and other distributed generation, and increased fuel storage to meet DBTs and improve performance

Evaluate Performance

- Utilize advanced tools like Sandia Microgrid Design Tool (MDT) to evaluate and optimize the most cost effective solutions in terms of performance to meet DBTs

Iterate over Set of Solutions

- Until they meet Performance Goals and Objectives. Compare different solutions in terms of costs and performance benefits to establish system tradeoffs

Implement Solution

- Design and implement set of solutions in terms of cost and performance to improve reliability and resilience of existing system

Step 5
Cost Benefit Tradeoff Analysis

Microgrid Cost

Generation Requirement

- Load estimates for buildings (in terms of kW demand per square footage) using 2012 EIA CBECS building activity
  - Adjusted for climate region
- Open EI building model
- AM & FM transmitters, cell and microgrid towers calculated differently
- Critical and non-critical demand quantified separately

Energy use and peak demand of each building in a microgrid area

Cost Estimation

- Average costs for generation (diesel, PV), points of common coupling, switches, overhead/underground lines
- Every microgrid has same equipment costs – this will be refined as selections are made
  - Four equipment options are considered to give a range, but are applied uniformly across all microgrids

Cost estimate of each microgrid (four cost scenarios for equipment utilization)

Microgrid Benefit

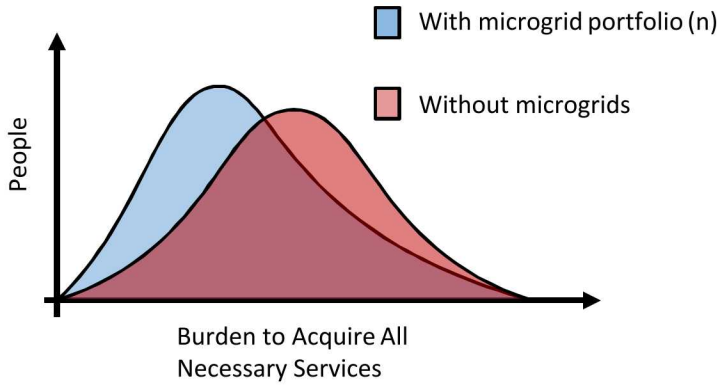
Goal is to:

- Assess microgrid impact resilience
- Choose optimal portfolio of all the potential options

Effort
Average distance traveled to acquire service

Ability
Median household income for census block group

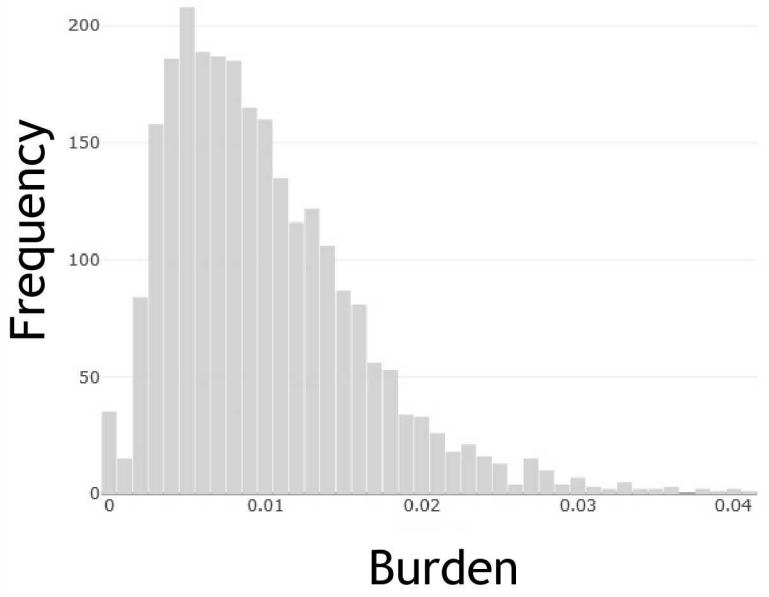
→ **Burden**



Baseline Resilience

Map of Total Burden to Acquire All Services in the Baseline Scenario (No Microgrids Built)

Histogram of Burden to Acquire All Services in the Baseline Scenario



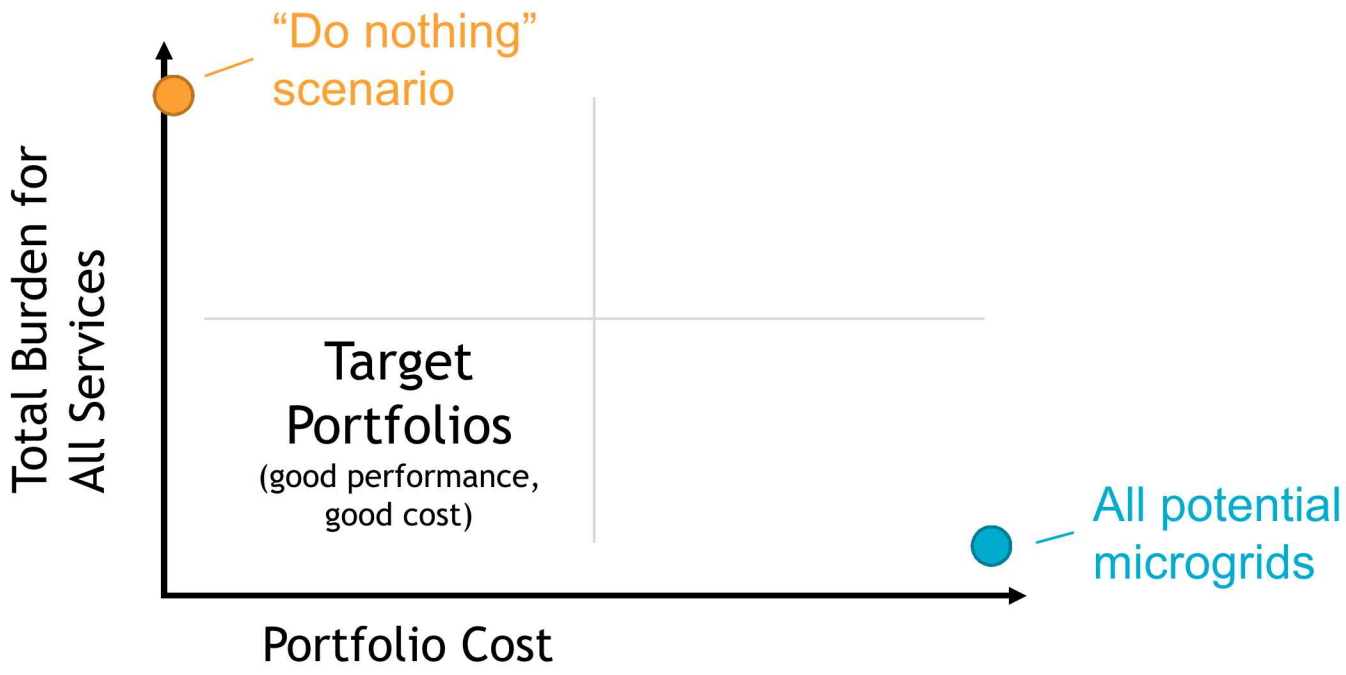
Assumptions

- City-wide blackout
- No infrastructure considered as reliable backup power

Evaluating Burden for Microgrid Portfolios

Recognize complementary nature of certain microgrids

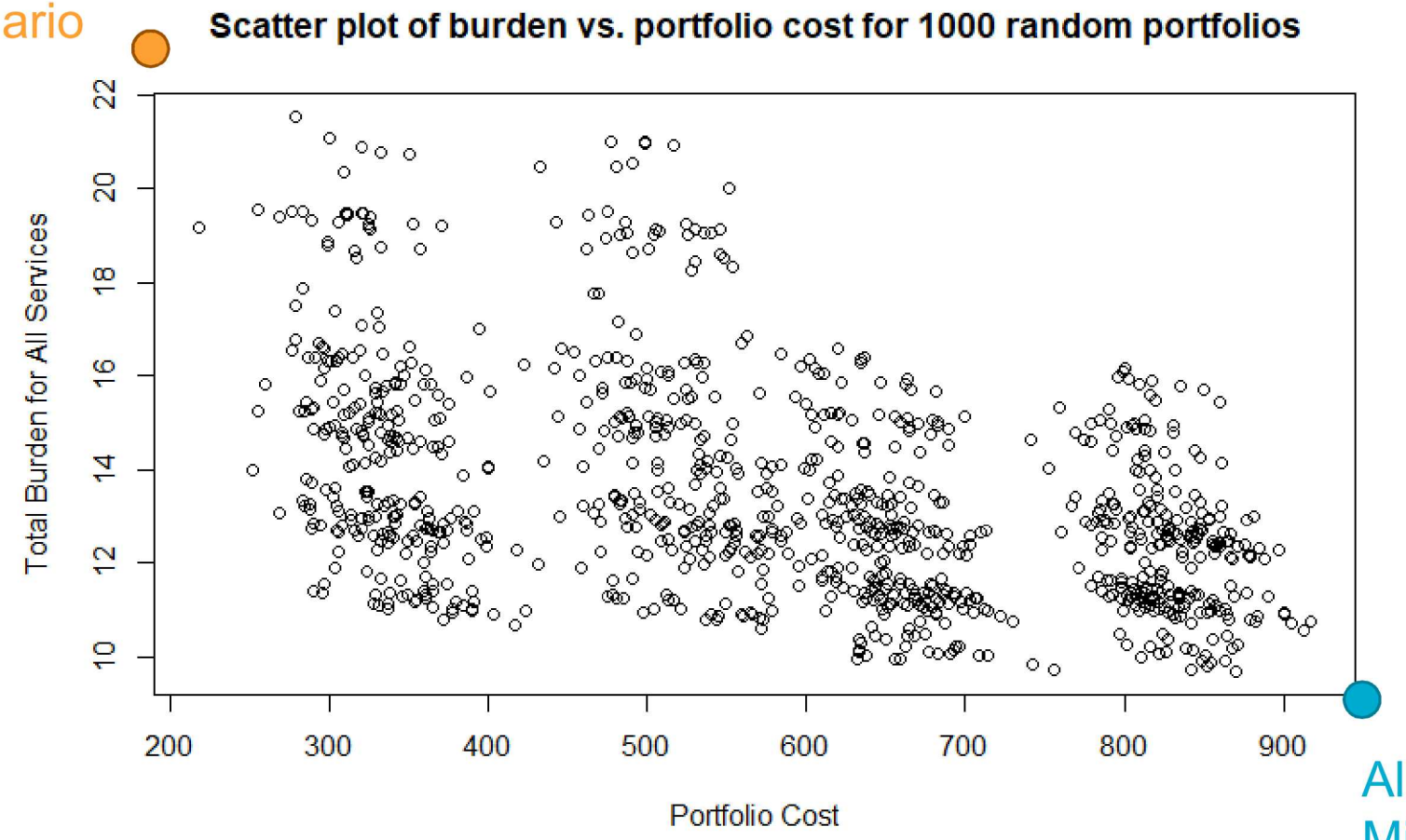
Goal is to design a system of microgrids to decrease overall burden



Step 6
Visualize Metrics and Resiliency Options

Portfolio evaluation

"Do nothing" scenario

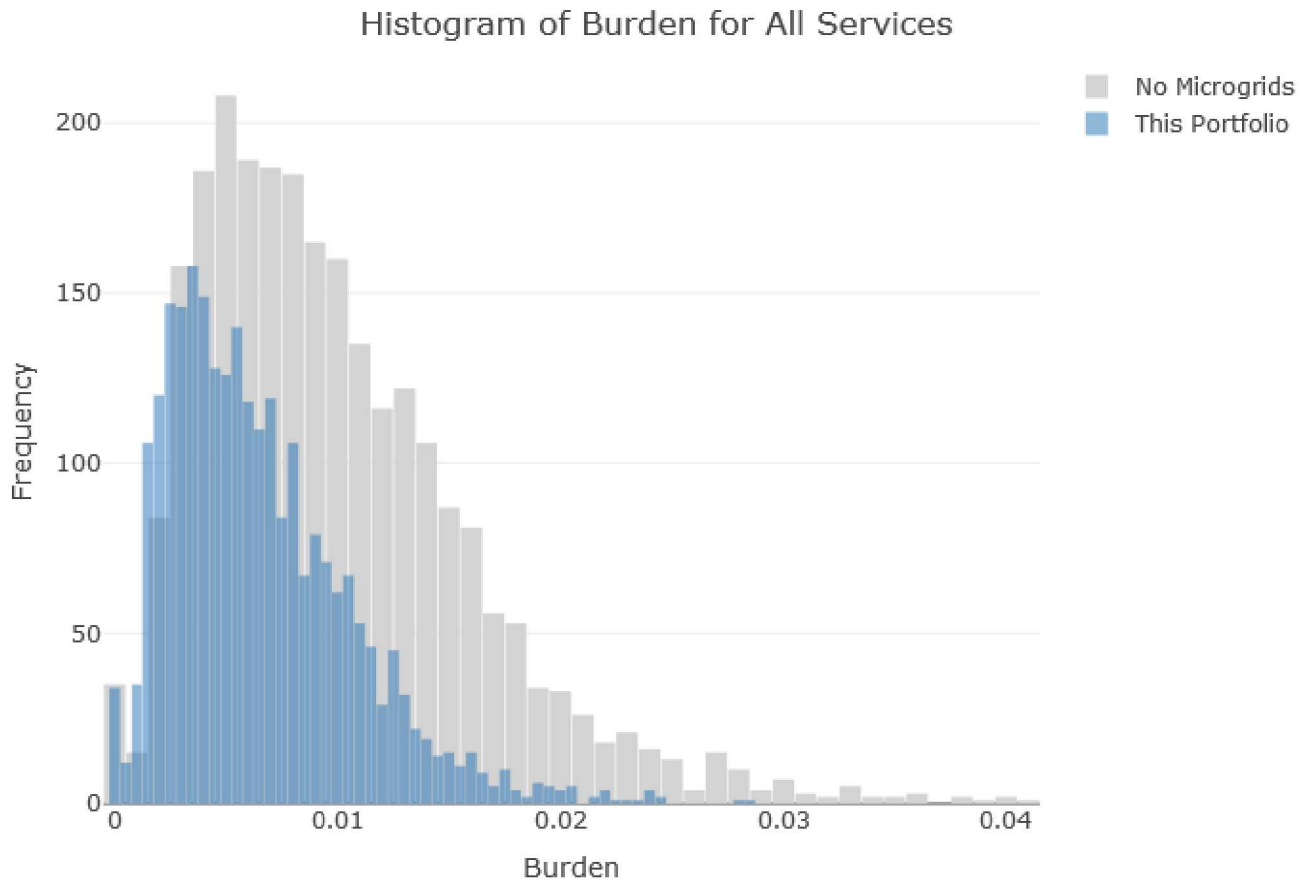


All Microgrids

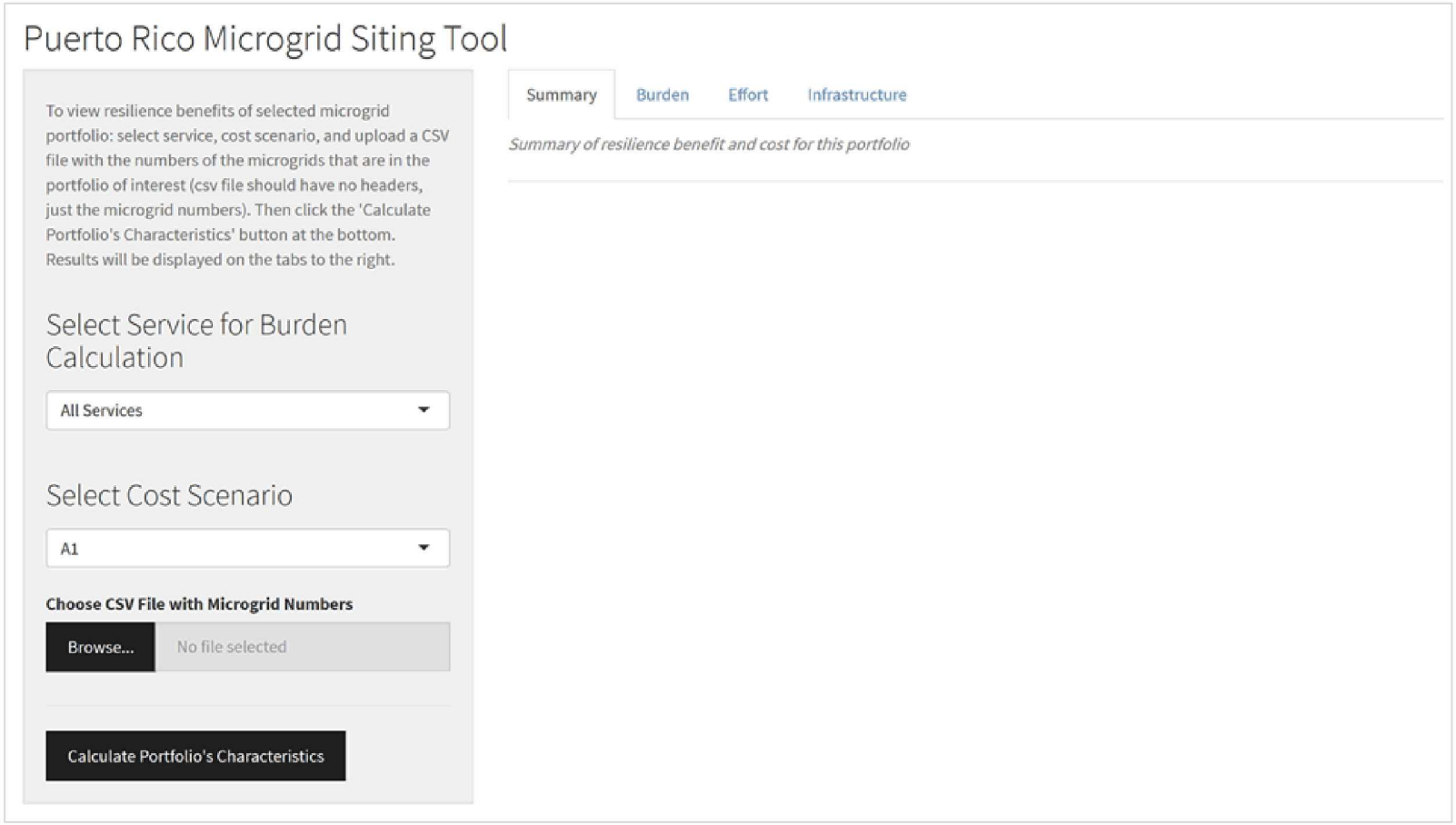
A large decrease in burden can be achieved for relatively low cost compared to all microgrids

Compare Burden Reduction For One Portfolio

Histogram of Burden to Access All Services for One of the Most Cost Effective Portfolios



MPEx Tool for Portfolio Analysis



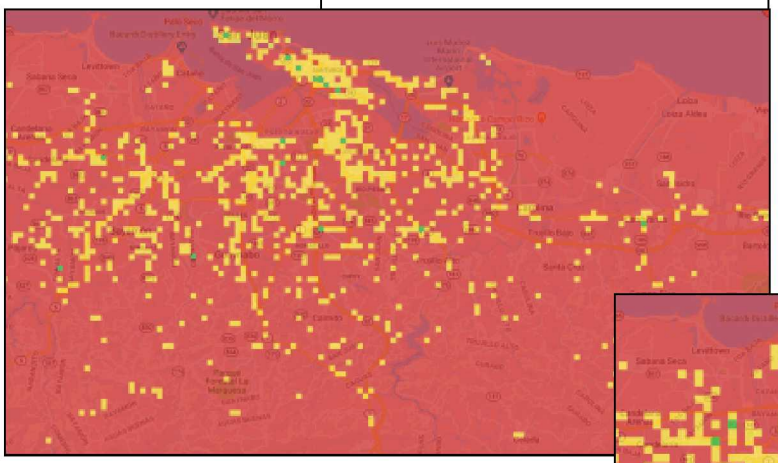
Backup Slides

Additional Assumptions

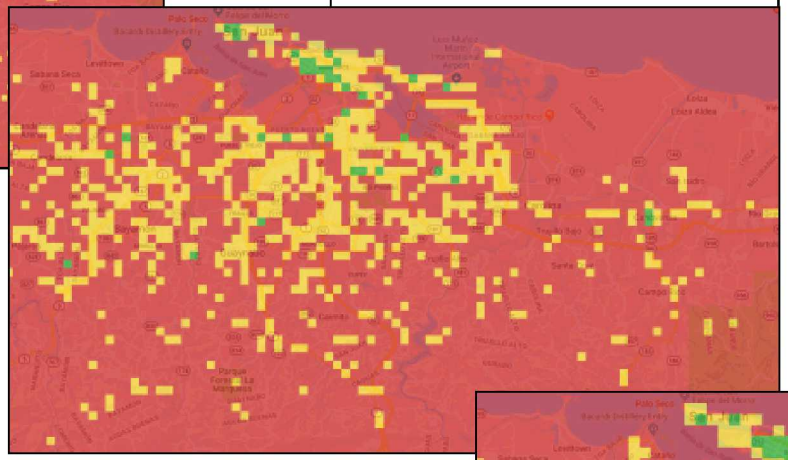
- Assuming no existing reliable backup power
  - Can be revisited if backup generators are known
- Assuming non-power infrastructure is robust to high winds
  - Should be revisited for some infrastructures, e.g. cell towers
- Resilience improvements primarily focus on using microgrids
  - Analysis can suggest locations for localized backup and energy storage
  - E.g. not a feeder hardening study

ReNCAT Results

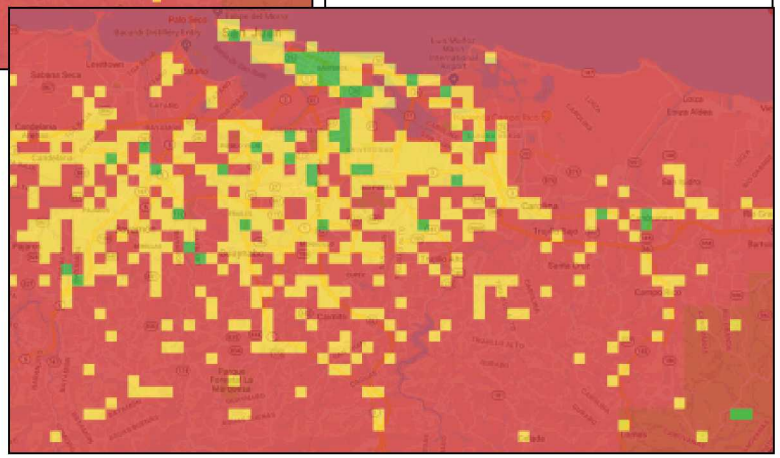
1000ft x 1000ft



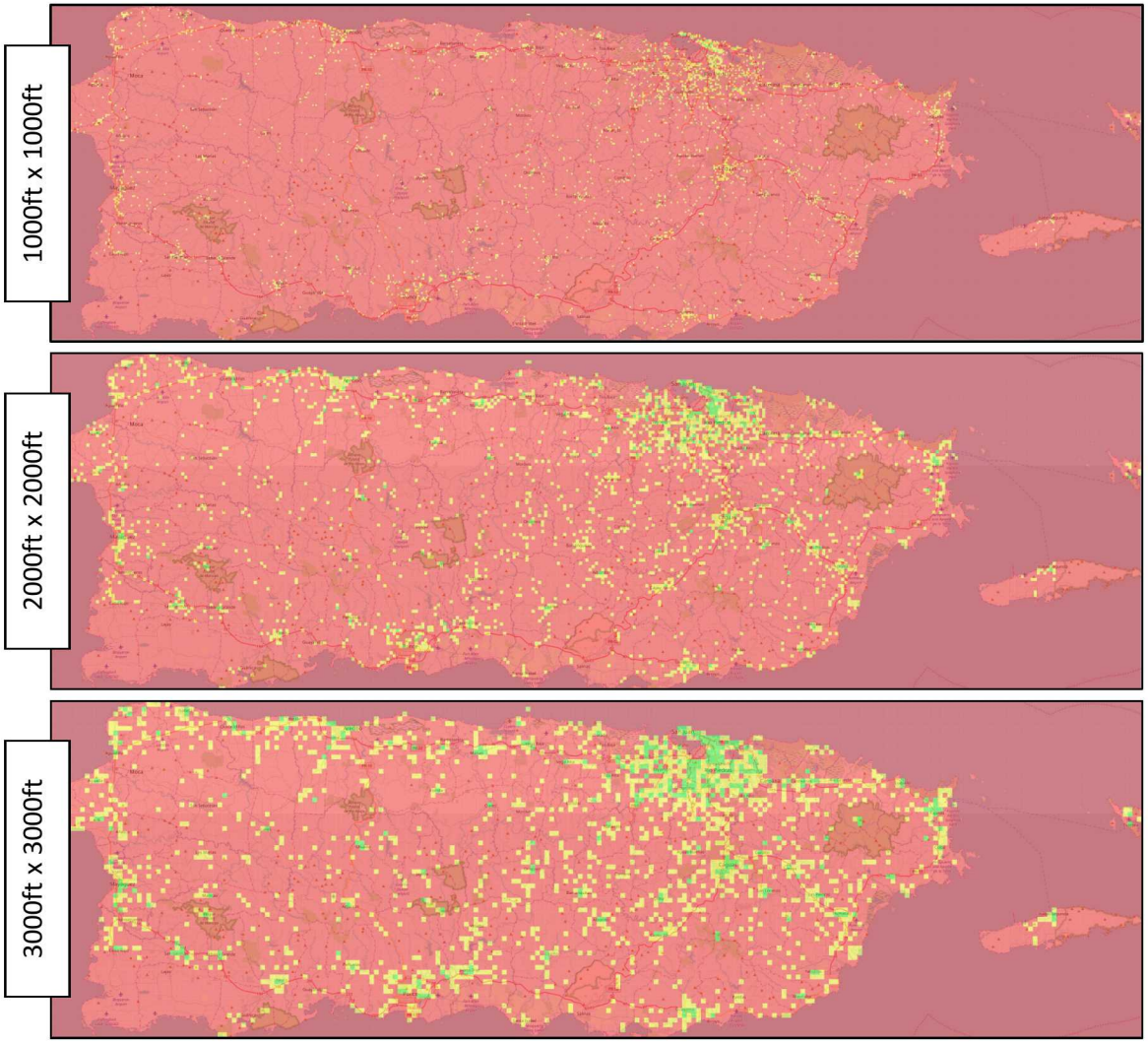
2000ft x 2000ft

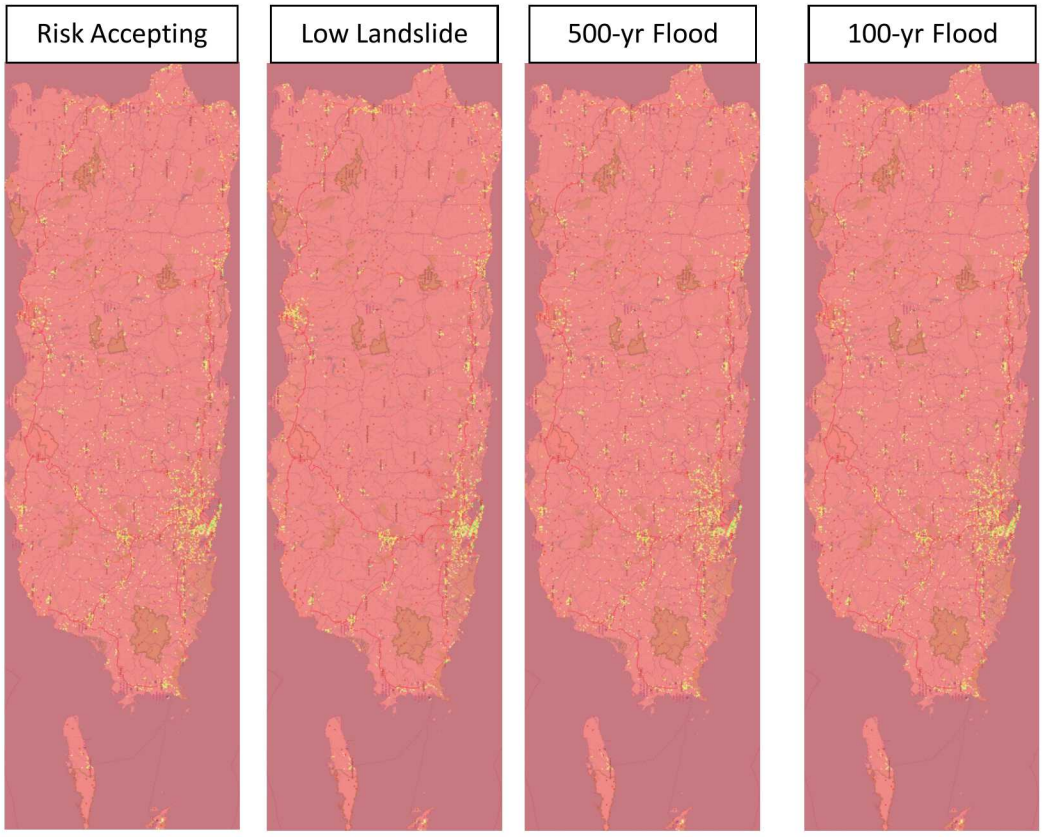


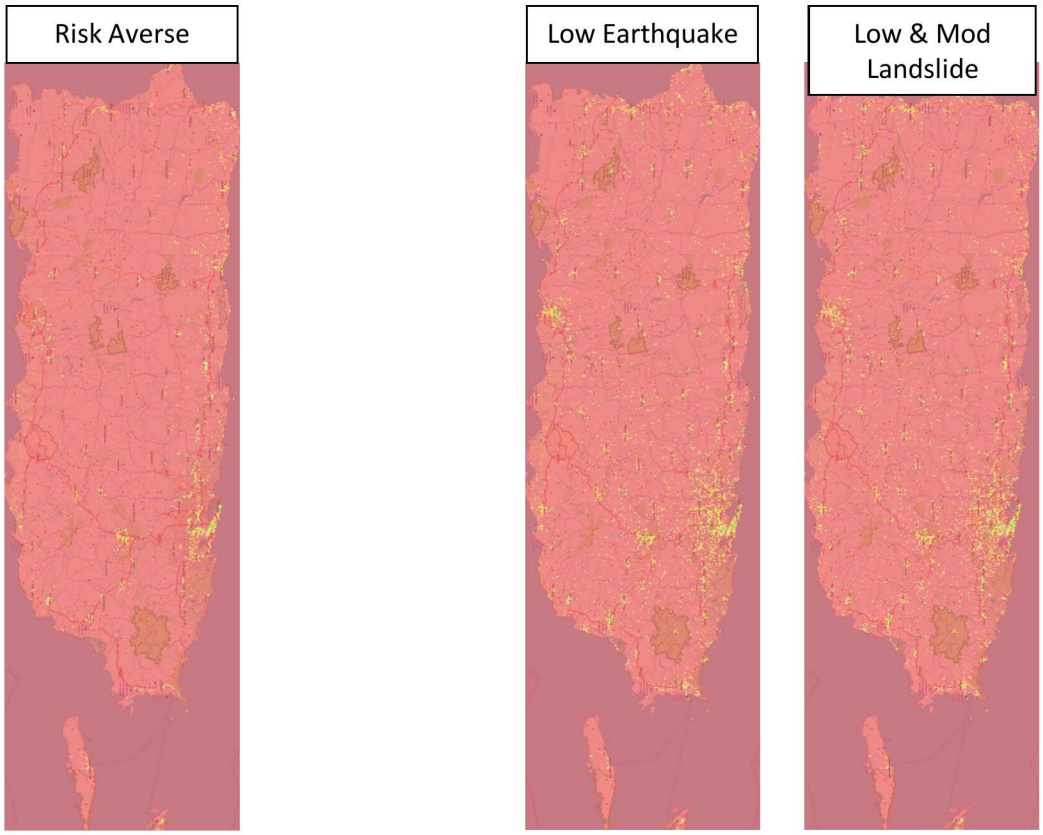
3000ft x 3000ft



Identifying Infrastructure Clusters as a Starting Point for Microgrid Selections







CLASIFICATION LEVEL

Compare Burden Reduction For One Portfolio

If everything gets done, show one portfolio and break down by planning region (one histogram for each region)

Can we break down that portfolio to show which services contribute most to burden?