ND-GAIN

Notre Dame Global Adaptation Initiative

Urban Adaptation Assessment Technical Document

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UNIVERSITY OF NOTRE DAME | RESEARCH

Table of Content

I. Key Terms and Definitions

RISK

Refers to a city's vulnerability to climate change. Vulnerability incorporates the city's exposure, sensitivity and adaptive capacity:

- **Exposure** relates to physical exposure, which means the number of people (individuals) and critical infrastructure exposed *to climate hazard event (e.g. population density in the city, or % of cars in flood zones).* Exposure has a geographic and temporal character.
- For extreme cold, heat, inland flooding and SLR the **sensitivity** refers to the degree to which population of the city are affected by climate hazards. **Adaptive capacity** refers to the city's ability to respond to the negative consequences of climate hazards.
- By way of example, drought **sensitivity** refers to the degree to which economic sectors rely on water-intensive industries (agriculture, water transportation, mining, utilities) and adaptive capacity reflect ability of the city to manage drought through the management plans, or early warning systems.

READINESS

Refers to the capacity of an urban society has to mobilize adaptation investments from private sectors, and to target investments more effectively. Readiness is a function of economic readiness, governance readiness, and social readiness:

- **Economic Readiness:** The economic condition to support adaptation and to attract adaptation investment.
- **Governance Readiness:** The governance support that enables effective use of adaptation investment.
- **Social Readiness:** The social capacity that facilitates the uptake of the benefits brought about through adaptation investment

SOCIAL EQUITY

Rooted in the ideas of distributive justice and fair distribution of adaptation resources, an equitable distribution refers to a situation where there is minimal social exclusion or where local attributes allow participation in economic, political and social activities that influence vulnerability to climate risk.

ADAPTATION

Is an adjustment to the changing climate that minimizes negative effects on human lives and livelihoods. Adaptation includes changing policy, operations and physical assets to modify supply chains, capital projects, community engagements and regulations.

II. Justification: Probability of Hazards

Our estimates of the likelihood of experiencing a particular hazard and the costs associated with that outcome are a result of decisions we made during the development process. For example, climate projections which influence the likelihood of experiencing a hazard range from the RCP 8.5 to the RCP 2.5. In each case these are the average watts per meter squared of energy retained on the earth's surface, but they translate into climate – or at least temperature – projections, most often out to 2100. The difference between these climate modelling scenarios reflects political decisions about how much carbon dioxide will be released into the atmosphere at any given period of time. The worst case scenario – RCP 8.5 – projects emission levels that lead to CO2 concentrations well above 1000 ppm. We currently stand at roughly 400 ppm.

Our choice in generating expected future costs of climate hazards ranged from the most pessimistic (RCP 8.5) to the most optimistic (RCP 2.5). We chose to generate our data based on the climate modeling ensemble RCP 4.5. This is a pretty optimistic expectation given where we stand today with international climate agreements and national level emissions, but we thought it better to base our estimations on optimistic scenarios and let the consumer consider the implications of our collective inability to restrict carbon emission. This leads in many ways to a tougher test of our evaluation tool. If the world misses climate targets that would put us on the RCP 4.5 model, the likely future costs that we estimate will be greater and our consumers should consider this potential outcome. Our estimates are for the year 2040 and in practical terms we will not have a good sense of the future trajectory of climate emissions much before then. The US National Climate Assessment suggests that if we are not on a trajectory for RCP 2.5 by the year 2030, we will have a hard time getting on track to hold temperatures to a global average of 2.5°C.

In keeping with our effort to provide a relatively optimistic evaluation of climate vulnerability we also set a reasonably high bar for experiencing a particular hazard. There were a lot of ways to define the conditions for a heat, cold, flood hazard for a city. We chose to make it reasonably hard to experience such a climate event. For example, for a heat hazard we require six consecutive days above the 90th percentile of a baseline temperature set in the hottest month for a city. This is not an easy threshold to breach. To put it into context, three consecutive days above the 90th percentile followed by one day that dips below, and then four days back above the threshold does not constitute a heat event. It would seem hot and by all accounts it would reflect a heat event, but in our data it would not.

By making the threshold high and the climate projections optimistic we provide something of a vulnerability assessment under the best case scenario. If the conditions generated are worse, then any city could expect more frequent hazards with higher costs. We simply didn't want to present a doom and gloom environment but rather one that could provide insight into city-level vulnerability under short term conditions that hold out hope for adaptation policies. Choosing differently in our analytic strategy would provide for more dire implications, but the further out we get in time the more uncertainty exists in modeling efforts. We would encourage cities to think about potential conditions – or risks – under other climate scenarios and there is no reason that individual cities cannot use our source material to explore these alternative outcomes.

III. Methodology: Probability of Hazards

COLD, HEAT, FLOOD HAZARD PROBABILITY METHODOLOGY

1. Temperature and precipitation data was downloaded from the MACA data portal for all available weather stations for the years 1950-1999 and 2021-2065. The weather station closest to the centroid of each UAA city was selected to represent the city's weather data.

2. Percentiles of precipitation and temperature were calculated for the years 1950-1999 to determine a single baseline threshold for flood, heat and cold hazards in each city.

3. From the baseline threshold, the projected temperature and precipitation data from 2021-2065 were used to determine the number of instances each year where a hazard definition was met. For example, extreme heat is characterized by temperatures that exceed the historical baseline for 6 consecutive days. If this threshold was met, it was counted as one instance of extreme heat. Calculations were made for each day, beginning with day 1-6 of each year, then day 2-7, 3-8, etc. After each year was calculated in this iterative way, the number of extreme heat instances was divided by 365 (or 366 for leap years) to determine the probability of a city experiencing a heat event in 2040. This was repeated for all cities.

DROUGHT HAZARD PROBABILITY METHODOLOGY

1. The UAA used the latitude and longitudes of each city's water withdrawal source. These data were acquired from the Urban Water Blueprint. Not all UAA cities were included in this index, so the remaining were collected by hand by researching the water withdrawals and acquiring the lat/lons via Google Maps. We have all cities except Honolulu, HI. UAA cities have between one and 27 various sources of water (i.e. San Diego).

2. Precipitation data for contiguous 48 states was collected from the MACA data portal and from the ESGF Database for cities outside the continental United States. These data are the same that is used for predictions of future precipitation. The data sets include daily precipitation projections for a specific latitude and longitude.

3. Each UAA city draws water from a variety of water collection points. Using a minimum-distance calculation, each water collection point was assigned precipitation projections from the closest latitude and longitude pair with precipitation data.

4. Daily precipitation projections were aggregated to monthly projections to reflect the time scale of drought occurrences. To determine the expected precipitation for each UAA city, the monthly projected precipitation was averaged across all of a city's water collection points.

5. We calculated a Standard Precipitation Index on a three-month interval (SPI-3). Monthly precipitation data was combined for each two-month trailing period (e.g. January-February-March, February-March-April, etc.)

Data Interpretation

SPI-3 presents a data point's relative rank according to its position within the sample. The calculation compares each three-month, backwards looking segment to all other values of the same three-month span within the distribution. The distribution is converted into a Normal distribution and SPI reports the z-score of each observation. The SPI scores range between -3 and 3, with -3 reflecting severe drought conditions.

SPI-3 was selected for interpretation because it reflects a short- or medium-term look at moisture conditions. Additionally, it is useful for interpreting seasonal data.

Operationally the UAA team measures a drought in relation to the normal expected rainfall for a given city. A city forecast to have rainfall in 2040 that is within ½ a standard deviation less than its historical average or greater is estimated to have a negligible probability of a drought in 2040. Forecasts for lower levels of rainfall are estimated based on the size of the deviation from the historical average with cut points the probability of a drought in 2040 being 6% less than average and above, zero probability of a drought; 6%-13% less rainfall a low probability of drought; 13%-19% less than average forecast rainfall a medium probability, and > 19% precipitation deficit a high probability of a drought in 2040.

SEA LEVEL RISE HAZARD PROBABILITY METHODOLOGY

Probability is set by NOAA's Sea Level Rise Viewer "intermediate" scenario in year 2040.

IV. Methodology: Outcome Data for Hazards

COLD, HEAT, FLOOD HAZARD METHODOLOGY

Data Collection

Storm event data was collected from the NOAA Storm Events Database. The Storm Events Database contains nationwide meteorological records from January 1950 to July 2017 and provides three report formats for each year:

- *Location:* the file includes the location, including geographic coordinates when available, of each storm event reported during the year.
- *Casualties:* the file includes each fatality that results from a storm event in a given year. The location of the fatality and biographical information of the victim are also provided.
- *Details:* the file includes all available information regarding each storm event. These details include: the location of the event; the amount of injuries, fatalities, and monetary damages caused by the storm; the type of storm; and a brief narrative outlining the event.

Data Cleaning

Data entries from individual year files were combined into a single CSV file that contained all records from the period of interest. Records were then categorized by their event type. NOAA categorizes storm events into one of 55 possible storm designations, and these designations served as the basis for the UAA flood, extreme heat, extreme cold, and coastal flood events. The USD/casualties count for the historical average flood events includes both inland flood and coastal flood events. The NOAA designations assigned to each of the UAA events are outlined below:

UAA EVENT	NOAA EVENT NAME
Flood	▪ Flash flood ▪ Flood ▪ Heavy rain ▪ High surf ▪ Hurricane/typhoon ▪ Storm surge/tide ▪ Tropical storm ▪ Coastal flood ▪ Lakeshore flood
Extreme heat	▪ Heat ▪ Excessive heat
Extreme cold	▪ Cold/wind chill ▪ Extreme cold/wind chill ▪ Frost/freeze

Recording Event Instances

Floods

NOAA tracks floods with geographic coordinates that record the beginning and ending location of the flood event. Because no information regarding the path of the flood is available, each flood was assumed to move in a straight line from start point to end point.

A flood event is categorized as occurring within a city if it began, ended, or passed through the city, or if it was entirely contained within the city limits. GIS software was used to create the straight-line path between the beginning and ending location of flood events; if this straight-line path intersected a UAA city, the event was categorized as occurring within that city. In the event the path of a flood intersected multiple cities, the flood was assigned to each of the cities.

The number of flood events occurring within each UAA city was calculated by counting the number of flood events assigned to each city.

Extreme Heat, Extreme Cold, and Coastal Floods

Extreme heat, extreme cold, and coastal flood events are reported according to the National Weather Service (NWS) public forecast zones in which the event occurs. The NWS public forecast zone boundaries frequently overlap with county boundaries. However, for counties where differences in weather are prevalent, forecast zones are broken into subsets of the county.

GIS software was used to determine which UAA cities belonged to each of the forecast zones. Extreme heat, extreme cold, and coastal flood events were categorized as occurring within a UAA city if they occurred in a forecast zone that contains the UAA city. If multiple UAA cities belonged to the forecast zone in which the event occurred, the storm event was recorded as having occurred in each of the cities. For example, a wind chill warning issued for the Cook forecast zone in Illinois would be counted as occurring within both UAA cities within the Cook forecast zone – namely, Chicago and Elgin.

The number of extreme cold, extreme heat, and coastal flood events within each UAA city was calculated by individually counting the number of each type of event that occurred within each city.

Some storm events occurred across a range of forecast zones. In some instances, a UAA city that spans multiple forecast zones would overlap with a storm event that also overlaps multiple forecast zones. For example, Chicago is in both the Cook and Du Page forecast zones. A single cold event that occurs in both forecast zones would be counted in Chicago as two separate extreme cold instances, despite being part of the same event. To avoid this double counting, events were manually cross-referenced. Events that occurred over the same period of time and had the same episode ID were counted only once per city to eliminate double counting of events.

Recording Deaths and Injuries

For storm events with death or injury reports, the deaths and injuries location were recorded with either a known location or an approximate location. A location was known if the event narrative detailed the city in which the death occurred. If the event narrative did not supply this information, the NWS forecast zone associated with the storm event was used as an approximate location.

Flood

NOAA reports death and injury data as either directly or indirectly caused by a storm event. For each UAA city, the total direct and indirect deaths and injuries were calculated by adding together each instance of death/injury within a city. Then, total injury and total death numbers were calculated for each UAA city by adding together indirect and direct injuries, and direct and indirect deaths.

Extreme Heat, Extreme Cold, and Coastal Floods

Some NWS public forecast zones entirely overlap UAA cities. For example, the city of St. Louis has its own NWS public forecast zone. When extreme heat, extreme cold, or coastal flood events caused a death or injury in one of these cities, the deaths/injuries were known to have occurred within these cities.

For events with undetermined death/injury locations, GIS software was used to approximate the death location. If the NWS public forecast zone perfectly aligned with a county, population data from the 2015 Census was collected for the county and any UAA city within the forecast zone. The population of a UAA city was assumed to be evenly distributed across the city. If only part of the city was contained within the forecast zone of interest, the population of the city was assigned to that forecast zone proportional to the percentage of the city's area that is contained within the forecast zone. Then, the percentage of the total population of the county living within a UAA city in the county was calculated.

Deaths and injuries were assigned to UAA cities according to their percentage of the total county population. When this allocation resulted in a non-integer amount of deaths or injuries, the figure was rounded to the nearest whole number.

For events with undetermined death/injury locations and NWS public forecast zones that did not perfectly align with county boundaries, injuries/deaths were assumed to have occurred evenly throughout the forecast zone. Accordingly, deaths/injuries were assigned to UAA cities in proportion to their percentage of the total landmass of the relevant forecast zone.

NOAA reports death and injury data as either directly or indirectly caused by a storm event. For each UAA city, the total direct and indirect deaths and injuries were calculated by adding together each instance of death/injury within a city. Then, total injury and total death numbers were calculated for each UAA city by adding together indirect and direct injuries, and direct and indirect deaths.

Our conservative approach to assigning deaths or injuries lowers our estimated costs and is consistent with our overall approach to adopting an optimistic orientation to assessing city level vulnerability.

Recording Damage

NOAA reports monetary damages for each storm event in two categories: property damage and crop damage. These damage numbers were added together to determine total damage, prior to assigning damage to cities.

Flood

For floods that occurred entirely within a UAA city, any associated damage was known to have occurred within the city.

For floods not entirely contained within a UAA city, the damage caused was assumed to have occurred evenly throughout the straight-line path from the start point to the end point. The percentage of the straight-line path that occurs within a UAA city was calculated, and damage was assigned to the city proportionally. The same process was used for flood events that intersected multiple UAA cities.

Total damage for each city was computed by adding together the damage amounts from each flood in each UAA city.

Extreme Heat, Extreme Cold, and Coastal Floods

Damage caused by extreme heat, extreme cold, or coastal flood events was assumed to have been distributed evenly throughout the NWS forecast zone. Damage was assigned to each UAA city within the relevant forecast zone proportional to its landmass within the forecast zone.

Total damage for each city and storm event was computed by adding together the damage amounts from each event type in each UAA city.

Drought

Data was collected on payment for crop damage in the county, where the UAA city is located from the Sheldus Database. Data varies by year, some cities do no have any data at all and cities that are located in same county have same data.

Data include the following data: Crop Indemnity Payment and number of records. Data are available for year 2010, 2011, 2012, 2013, 2014 (5 year period).

Average historical USD loss attributed to drought event is calculated by Crop Indemnity Payment per event.

Sea Level Rise
Inundation layer from NOAA SLR Viewer downloaded and overlaid with UAA cities. UAA cities are designated as "coastal cities" if they were a UAA city; the city intersected the 1ft SLR inundation layer; and NOAA SLR Viewer had an inundation layer for the city.

Inundation Layer was overlaid with coastal cities. Property parcel data was collected from each city individually, usually through local GIS or assessor department. Parcel data (polygons) were converted to points to cut down on processing time. Median home value at the block group level (American Community Survey) was joined to parcel data. Intersected (GIS function) parcels and inundation layer at 1ft slr. Parcels that intersected had median home value summed to generate economic loss at 1ft slr.

Boston, New Orleans, Brownsville and Baton Rouge parcel data was not converted to points. Because of the size of the parcel file, they were kept in polygon format. Thus, it is likely that more parcel's median home value were summed for these cities compared to other cities that were first converted to points.

Data Presentation

The data was combined into a single document for presentation. This document reports the following elements for each of the UAA cities:

- Latitude and Longitude: the latitude and longitude of the center of the city; to be used for visualizing the data
- State: the state in which the UAA city is located; some UAA cities have the same name, so the state helps to further distinguish the cities
- Instances: for each storm event type, the number of events that occurred within the city
- Indirect, Direct, Total Injuries: for each storm event type, the number of injuries that resulted from storm events within the city
- Indirect, Direct, Total Deaths: for each storm event type, the number of deaths that resulted from storm events within the city
- Damage: for each storm event type, the total amount of damage caused by storm events within the city

V. Methodology: Projection/Modeled Cost of Hazard

We adopted a Confirmatory Factor Analysis approach to modeling risk scores for exposure, sensitivity, adaptive capacity, and readiness scores for economic, social, governance conditions.

Note: the symbol "=~" means regression.

STEP 1: CONFIRMATORY FACTOR ANALYSIS MODEL

The abbreviations used below are:
Expo: exposure
Sens: sensitivity
Adapt: adaptive capacity
Econ: economy

Each model describes the indicators used in the estimation process.

```
heat_model = "
    expo =~ city_pop
    social =~ corruption + civ_engage
    sens =~ alone_65+disability+poverty
    adapt =~ hosp_beds+tree_canopy
    econ =~ debt+bond_worth+incentives_energy
    governance =~ patents+global_warming "

cold_model = "
    expo =~ city_pop
    social =~ corruption + civ_engage
    sens =~ alone_65+out_work+young_5
    adapt =~ hosp_beds+no_heat
    econ =~ debt+bond_worth+incentives_energy
    governance =~ patents+global_warming"

flood_model = "
    expo =~ floodzone_pop+floodzone_build
    social =~ corruption + civ_engage
    sens =~ build_1999+mobile_home
    adapt =~ hosp_beds+water_quality
    econ =~ debt+incentives_energy
    governance =~ patents+global_warming"

drought_model = "
    expo =~ city_pop
    social =~ corruption + civ_engage
    sens =~ Percentage_of_workforce_in_Farming_Fishing_and_Forestry_2015+Percent_of_GDP_
based_on_water_intensive_industries
    adapt =~ Existence_of_drought_management_plans_2015+Existence_of_water_management_
plan_2015
    econ =~ debt+bond_worth+incentives_energy
    governance =~ patents+global_warming"
```

These models were chose because of the fit of the data when compared to alternative models. In effect, these represent the strongest models among competing alternatives.

Note: It is presumed there is no correlation between the categories.

Then the model will generate the scores of each category with vulnerability and readiness for each of the hazards.

STEP 2: Z-TRANSFORMATION THE CATEGORY SCORE

The scores generated by our modeling fall into the range of -5 to 5, by Z-transformation, the scores are converted to a new scale between 0 and 1.

STEP 3: DIRECTION ADJUSTMENT

The direction of each category could be either positive or negative and the theory-based derivation suggests that specific indicators have competing influence on outcomes (e.g. the indicators of one category might contribute oppositely for that category score). To account for this we normalize the direction of causation based on theoretical expectations, such that we minimize the correlation between the risk and readiness scores.

Risk = (Exposure + Sensitivity + 1 - Adaptive Capacity)/3
Readiness = (Social + Economy + Governance)/3

STEP 4: ZERO-INFLATED MODEL FOR THE LOSS PREDICTION

For flood and drought hazards, there are a significant number of cities with zero losses (2011-2015). We use zero-inflated model to predict outcomes from the hazard event; the model is consisted of two layers:

Given hazard event happen once,
1st layer:
Probability of hazard loss is not zero = ~ risk
By logistic regression, the result will give a probability that the loss is not zero.

2nd layer: Given the loss is not zero,
Loss = ~ risk + readiness
By negative binomial regression, the result is the expected loss.

Note: the loss is considered to be a variable ranging from 0 to infinity, and the regression outputs the expected loss value, but by the nature of negative binomial distribution of a variable, it could be any value of integer, with a corresponding probability. We use the average expected loss per incident that is predicted by the model.

VI. Methodology: Risk and Readiness Scores

Given the raw data of the indicators...

STEP 1: Z-TRANSFORMATION

Z-transformation was conducted first.
Then all the inputs were rescaled to between 0 and 1.

Z-transformed indicator= (input - mean)/standard deviation

STEP 2: SHRINK Z-TRANSFORMATION

Shrink the Z-transformed score, make sure the minimum and maximum are 0 and 1 respectively.

Shrinked indicator = (Z-transformed indicator- minimum)/(maximum - minimum)

STEP 3: DIRECTION RECTIFICATION

Based on the categories list provided by UAA, three indicators' directions were rectified:

Water quality, city debt, Total number of federal public corruption convictions by district

The direction rectification is as follow:
New indicator = 1 - Shrinked indicator

Then the new indicator (including three rectified indicator and all other indicators) will be used in the subsequent calculation.

STEP 4: SECTOR CALCULATION

For each sector, the sector score is calculated by average of indicators' scores in that sector.

Heat

Exposure:
- Population density

Sensitivity:
- Percent of population that is 65 years old or older living alone
- Percent of population that is 5 years old or younger
- Percent of buildings built before 1979
- Percent of population spending over 50 percent of income on rent
- Outdoor workers
- Percent of Population in poverty
- Percent of Population with a disability

Adaptive Capacity:
- Number of acute care hospital beds available per 1000 residents
- Percent of population with health insurance
- Percent of land covered by tree canopy

Social:
- Civic Engagement
- General innovation capabilities

Governance:
- Total number of federal public corruption convictions by district
- Percent of population with a 12th grade education or higher
- Estimated percent of adults who think global warming is already harming people in the US now or within 10 years

Economic:
- City debt
- Readiness to accept adaptation investment
- Tax incentives for renewable energy

Cold

Exposure:
- Population density

Sensitivity:
- Percent of population that is 65 years old or older living alone
- Percent of population that is 5 years old or younger
- Percent of buildings built before 1979
- Percent of population spending over 50 percent of income on rent
- Outdoor workers
- Percent of Population in poverty
- Percent of Population with a disability

Adaptive Capacity:
- Number of acute care hospital beds available per 1000 residents
- Percent of population with health insurance
- Percent of houses with heating

Social:
- Civic Engagement
- General innovation capabilities

Governance:
- Total number of federal public corruption convictions by district
- Percent of population with a 12th grade education or higher
- Estimated percent of adults who think global warming is already harming people in the US now or within 10 years

Economic:
- City debt
- Readiness to accept adaptation investment
- Tax incentives for renewable energy

Flood

Exposure:
- Percent of cars in floodzone
- Percent of population in floodzone
- Percent of buildings in floodzone

Sensitivity:
- Percent of area that is impervious surface
- Percent of population residing in the mobile homes
- Percent of population that is 65 years old or older living alone
- Percent of population that is 5 years old or younger
- Percent of households without access to a vehicle
- Percent of buildings built before 1999
- Percent of population spending over 50 percent of income on rent

Adaptive Capacity:
- Number of acute care hospital beds available per 1000 residents
- Percent of population with health insurance
- Water quality

Social:
- Civic Engagement
- General innovation capabilities

Governance:
- Total number of federal public corruption convictions by district
- Percent of population with a 12th grade education or higher
- Estimated percent of adults who think global warming is already harming people in the US now or within 10 years

Economic:
- City debt
- Readiness to accept adaptation investment
- Tax incentives for renewable energy

Drought

Exposure:
- Population density

Sensitivity:
- Baseline water stress
- Percent of workforce in Farming. Fishing and Forestry
- Percent of GDP based on water intensive industries

Adaptive Capacity:
- Existence of drought management plans
- Existence of water management plan

Social:
- Civic Engagement
- General innovation capabilities

Governance:
- Total number of federal public corruption convictions by district
- Percent of population with a 12th grade education or higher
- Estimated percent of adults who think global warming is already harming people in the US now or within 10 years

Economic:
- City debt
- Readiness to accept adaptation investment
- Tax incentives for renewable energy

Sea Level Rise

Exposure:
- Percent of population in 1ft sea level rise zone
- Percent of population in 3ft sea level rise zone

Sensitivity:
- Percent of area that is impervious surface
- Percent of population residing in the mobile homes
- Percent of population that is 65 years old or older living alone
- Percent of population that is 5 years old or younger
- Percent of households without access to a vehicle
- Percent of buildings built before 1999
- Percent of population spending over 50 percent of income on rent

Adaptive Capacity:
- Number of acute care hospital beds available per 1000 residents
- Percent of population with health insurance
- Water quality

Social:
- Civic Engagement
- General innovation capabilities

Governance:
- Total number of federal public corruption convictions by district
- Percent of population with a 12th grade education or higher
- Estimated percent of adults who think global warming is already harming people in the US now or within 10 years

Economic:
- City debt
- Readiness to accept adaptation investment
- Tax incentives for renewable energy

STEP 5: GROUP CALCULATION

For each hazard, the six sector scores: exposure, sensitivity, adaptive capacity, economic, social, governance are calculated by the equation:

Vulnerability = average(sensitivity, 1 - adaptive capacity)
Exposure (in group) = exposure(in sector)
Readiness (in group) = average(economic, social, governance)

STEP 6: CATEGORY CALCULATION

Risk = average (vulnerability, exposure(in group))
Readiness (in category) = Readiness(in group)

STEP 7: CITY SCORE OF THAT HAZARD

City Score = average(1 - Risk, Readiness)

STEP 8: OVERALL SCORE

Overall score = average(city score of each hazard)

VII. City Indicator Definitions, Justification, & Source

We provide a comprehensive description of each of the indicators used to develop our risk and readiness measures for each of our hazards. We present them as a complete list of indicators even though they distribute by specific hazards. In many cases an indicator for vulnerability on one hazard is also an indicator for another hazard.

HAZARD RISK INDICATORS

Exposure Indicators

1. Population Density

Description: Number of people per square kilometer of a city exposed to potential extreme cold hazard.
Rationale: From the exposure point of view, the extreme cold weather potentially impacts all human residents of a city.
Data Source & Collection Notes: Requires GIS. US Census: American Community Survey Table B01003 "Total Population"
Calculation: Total population/sq miles of the city
Years Collected: 2015 ACS 5-year estimates available
Coverage/Scale: City

2. Percent of population living in high risk floodzone

Description: The average number of population, within the administrative boundary of a given city, exposed to potential flood hazard.
Rationale: The amount of the population that could be impacted by flooding is integral information for emergency management and disaster planning (Maantay and Maroko 2009; Cutter et al. 2000). The more people susceptible to damage, displacement, and disease caused by flooding, the more difficult effective adaptation and mitigation are (Cutter et al. 2000).Data Source & Collection Notes: Requires GIS. 1) US Census: American Community Survey Table B01003 "Total Population" 2) FEMA Flood Map Service Center.
Calculation: Overlaid population data with FEMA shapefiles in GIS. Calculated cars in FEMA designated "high risk areas".
Years Collected: 2017 FEMA data; 2015 ACS data
Coverage/Scale: City
Notes: *Missing from national FEMA file were 15 cities. We used preliminary FEMA data for the following cities: Seattle, Pueblo, Portland, Lafayette, Colorado Springs, Provo, West Palm Beach, Brownsville, Naperville, Bellevue, and Kent. Three cities were not included in UAA analysis because no digitized map of the city was available (McAllen, Grand Rapids, Rochester). Midland, Texas created a FEMA map for its city internally, but is not available on the FEMA site. It has three categories of FEMA zones, which roughly translated into the A, AE and AH zones for the 100 year floodplain layer, and X for the 500 year floodplain. We spatially joined population, housing, and registered cars to the FEMA layers.*

3. Number of registered cars in high risk floodzone

Description: Census data on owned vehicles is overlaid with flood zone maps to proxy the number of vehicles on the road affected in the area by floods.
Rationale: The number of vehicles in a floodzone is important information for flood risk management (Kolen et al. 2010; Xia 2011). Firstly, the number of vehicles on roads is essential for planning mass evacuations of flood sensitive areas (Kolen et al. 2010). Secondly, estimating potential property losses such as damage to vehicles is also needed for flood risk management and developing solutions that mitigate as much damage as possible (Xia 2011; Erich 2002).
Data Source & Collection Notes: Requires GIS. 1. Census table: "Aggregated Number of Vehicles in Occupied Housing (includes owner and renter)" 2. FEMA Flood Map Service Center.
Calculation: Overlaid vehicle data with FEMA shapefiles in GIS. Calculated cars in FEMA designated "high risk areas".
Years Collected: 2017 FEMA data; 2015 ACS data
Coverage/Scale: City, Specific Roads

Notes: *Missing from national FEMA file were 15 cities. We used preliminary FEMA data for the following cities: Seattle, Pueblo, Portland, Lafayette, Colorado Springs, Provo, West Palm Beach, Brownsville, Naperville, Bellevue, and Kent. Three cities were not included in UAA analysis because no digitized map of the city was available (McAllen, Grand Rapids, Rochester). Midland, Texas created a FEMA map for its city internally, but is not available on the FEMA site. It has three categories of FEMA zones, which roughly translated into the A, AE and AH zones for the 100 year floodplain layer, and X for the 500 year floodplain. We spatially joined population, housing, and registered cars to the FEMA layers.*

4. Percent of housing units in high risk floodzone

Description: The average number of buildings, within the administrative boundary of a given city, exposed to potential flood hazard.
Rationale: A fundamental part of risk management is understanding the "vulnerability of the elements at risk, which includes people as well as their properties" (Erich 2002). This is especially important for buildings, as they are immovable pieces of property and susceptible to costly damages; understanding the potential hazards and potential amount of resources needed for reconstruction after floods are necessary to flood planning (Erich 2002). Risk assessment like this informs well-founded solutions to adaptation and mitigation in floodzones (Erich 2002; Xia 2011).
Data Source & Collection Notes: Requires GIS. 1) US Census: American Community Survey Table B25001: "Housing Units" 2) FEMA Flood Map Service Center
Calculation: Overlaid population data with FEMA zone using GIS. Calculated percent housing units in FEMA designated "high risk areas".
Years Collected: 2017 FEMA data; 2015 ACS data
Coverage/Scale: City
Notes: *Missing from national FEMA file were 15 cities. We used preliminary FEMA data for the following cities: Seattle, Pueblo, Portland, Lafayette, Colorado Springs, Provo, West Palm Beach, Brownesville, Naperville, Bellevue, and Kent. Three cities were not included in UAA analysis because no digitized map of the city was available (McAllen, Grand Rapids, Rochester). Midland, Texas created a FEMA map for its city internally, but is not available on the FEMA site. It has three categories of FEMA zones, which roughly translated into the A, AE and AH zones for the 100 year floodplain layer, and X for the 500 year floodplain. We spatially joined population, housing, and registered cars to the FEMA layers.*

Sensitivity Indicators

1. Percent of buildings built before 1979

Description: The percent of buildings in a city built before 1979.
Rationale: Buildings with higher energy efficiency tend to be more resistant to extreme temperatures. Due to increased regulation, new buildings tend to be more energy efficient than older buildings (Jens Lausten 2008). More energy efficient buildings are better able to tolerate extreme heat events without fluctuation in indoor temperature (Jens Lausten 2008). While there is no national building code, states choose to adopt outside building codes and many tended to adopt energy efficiency codes in the 1970s, possibly due to the oil crisis around that time (Jens Lausten 2008) As it is hard to estimate local adoption of energy efficiency codes (Cort and Butner 2012) state adoption may be an appropriate proxy as local building ages reflect building energy efficiency. Thus, this is an indicator of a city's resilience to extreme heat. (See Appendix B for more information)
Data Source & Collection Notes: US Census: American Community Survey B25034 "Year Structure Built"

Calculation:

COLUMN	COLUMN ID	DESCRIPTION
A	HD01_VD01	Estimate; Total: (Total Buildings)
B	HD01_VD11	Estimate; Total: -Built 1939 or earlier
C	HD01_VD10	Estimate; Total: -Built 1940 to 1949
D	HD01_VD09	Estimate; Total: - Built 1950 to 1959
E	HD01_VD08	Estimate; Total: - Built 1960 to 1969
F	HD01_VD07	Estimate; Total: - Built 1970 to 1979
Calculation	**[(B+C+D+E+F)/A] *100**	

Years Collected: 2015 5-Yr Estimate
Coverage/Scale: City

2. Percent of buildings built before 1979

Description: Percent of households in which the only householder is over 65 and lives alone.
Rationale: One consequence of social isolation is the limited acquisition of disaster information and the failure to recognize the impact of upcoming risks (Health Canada, 2012). In addition, limited flexibility and less enthusiasm to engage in the pre- and post- aid programs are other possible contributors to the vulnerability of the socially-isolated elderly (Sharkey, 2007; Ngo, 2001; Klinenberg, 2015). Limited or impaired mobility associated with aging (Gamble et al., 2013; Fernandez et al., 2002) also complicates evacuation during events like floods and can restrict one's ability to find cover and shelter (Fernandez et al., 2002). In addition, limited mobility also is one of the reasons that some elderly (approximately 4% in the US) elderly choose to live in nursing homes or continuous care communities (US Census Bureau, 2017). However, dependency on caregivers in an institutional settings, especially for those that are confined to beds, sometimes exacerbates vulnerability to extreme events (Staffoggia et al., 2006) due to multiple reasons such as lack of public assistance (Saliba et al., 2004).
Data Source & Collection Notes: US Census: American Community Survey: Table B09020
Calculation:

COLUMN	COLUMN ID	DESCRIPTION
A	HD01_VD15	Estimate: In households: in nonfamily households: householder: male: living alone
B	HD01_VD18	Estimate: In households: in nonfamily households: householder: female: living alone
C	HD01_VD01 (from table B19058)	Total: Households –(Estimate)
Calculation	**[(A+B)/C] *100**	

Years Collected: 2015 5-Yr Estimate
Coverage/Scale: Nationwide at city level

3. Percent of the renting population that spends over 50% of income on rent

Description: The percent of renters in a city who spend over 50% of their income on their rent payments.
Rationale: : A proxy of risk of homelessness, according to definition of housing instability that is measured by spending more than 50% of household income on housing (Kushel et al. 2006; Ma et al. 2007). Such burdening housing costs and housing instability are higher risk factors for homelessness (Kushel et al. 2006; Shinn et al. 1998; Wood et al. 1990). The homeless population and marginal population are most vulnerable to temperature and weather effects, and struggle most to recover from being displaced/harmed (Wisner 1998; Morrow 1999). Emergency planners should identify and locate high risk sectors, as "effective disaster management calls for aggressively involving these neighborhoods and groups at all levels of planning and response," and mitigation efforts must "address the root causes of vulnerability" (Morrow 1999).
Data Source & Collection Notes: US Census: American Community Survey Table B25070 "Gross Rent as a Percentage of Household Income in the Past 12 Months"
Calculation:

COLUMN	COLUMN ID	DESCRIPTION
A	HD01_VD01	Estimate; Total: (total renting)
B	HD01_VD10	Estimate; Total: - 50.0 percent or more
Calculation	**(B/A) *100**	

Years Collected: 2015 5-Yr Estimate
Coverage/Scale: Nationwide at city level

4. Percent of population that is outdoor workers

Description: The percent of the workforce that has an occupation that requires primarily outdoor work, making them vulnerable to heat.
Rationale: : Those who work outdoors are vulnerable to heat stress, which can cause decrease in productivity and induce health risks such as dehydration, heat stroke, and long-term damage to major organs and physiological functions (Parsons 2003; Bridger 2003; Kjellstrom et al. 2010). Climate change will increase both the intensity of heat exposure and the amount of areas vulnerable to it (Kjellstrom et al. 2010).
Data Source & Collection Notes: US Census: American Community Survey Table S2401 "Occupation by Sex for the Civilian Employed Population 16 Years and Over". Based on the definition of each occupation in Bureau of Labor Statistics 2010 Standard Occupational Classifications, the following occupation groups are outdoor, based on typical work performed by the majority of workers in the group's. These occupations are: Building and Grounds Cleaning and Maintenance; Farming, Fishing, and Forestry; Construction and Extraction; Material Moving.

Calculation:

COLUMN	COLUMN ID	DESCRIPTION
A	HC01_EST_VC01	Total; Estimate; Civilian employed population 16 years and over
B	HC01_EST_VC36	Total; Estimate: Production, transportation, and material moving occupations: - Material moving occupations
C	HC01_EST_VC31	Total; Estimate: Natural resources, construction , and maintenance occupations: - Construction and extraction occupations
D	HC01_EST_VC30	Total; Estimate: Natural resources, construction, and maintenance occupations: - Farming, fishing and forestry occupations
E	HC01_EST_VC24	Total; Estimate: Service occupations: - Building and grounds cleaning and maintenance occupations
Calculation	**[(B+C+D+E)/A] *100**	

Years Collected: 2015 5-Yr Estimate
Coverage/Scale: Nationwide at the city level

5. Percent of population under 5 years old

Description: The percent of population that is under 5 years old in the city.
Rationale: During the mass displacement of people that occurs during serious flooding or other hazard events, child protection and health service systems are disrupted, and parents/guardians may be lost, leaving children vulnerable to not just the environmental and health dangers but also to neglect, abuse, and exploitation (UNICEF 2015; IDMC/NRC 2015).
Data Source & Collection Notes: U.S. Census: American Community Survey: Table S0101: Age and Sex
Calculation:

COLUMN	COLUMN ID	DESCRIPTION
A	HC01_EST_VC03	Total: Estimate: Age-Under 5 years (percent)
Calculation	**N/A**	

Years Collected: 2015 5-Yr Estimate
Coverage/Scale: Nationwide at city level

6. Percent of population with a disability

Description: Percent of the population that have one of six categorized disabilities including:
- Hearing difficulty: deaf or having serious difficulty hearing
- Vision difficulty: blind or having serious difficulty seeing, even when wearing glasses
- Cognitive difficulty: Because of a physical, mental, or emotional problem, having difficulty remembering, concentrating or making decisions
- Ambulatory difficulty: Having serious difficulty walking or climbing stairs

- Self-care difficulty: Having difficulty bathing or dressing
- Independent living difficulty: Because of a physical, mental or emotional problem, having difficulty doing errands alone such as visiting a doctor's office or shopping

Rationale: People with disabilities are among the most vulnerable in an emergency, sustaining disproportionately higher rates of morbidity and mortality, and at the same time being among those least able to access emergency support. When an emergency hits they may have difficulty reaching safe areas or accessing vital emergency information.
Data Source & Collection Notes: US Census: American Community Survey: Table S1810: Disability
Calculation:

COLUMN	COLUMN ID	DESCRIPTION
A	HC03_EST_VC01	Percent with a disability: Estimate: Total civilian noninstitutionalized population
Calculation	**N/A**	

Years Collected: 2015 5-Yr Estimate
Coverage/Scale: Nationwide at city level

7. Percent of households receiving public assistance

Description: The percent of households receiving public assistance of food stamps in the last 12 months. Cash public assistance can be from the Federal program, Temporary Assistance for Needy Families (TANF), or various state-level cash assistance programs. It does not include separate payments received for hospital or other medical care (vendor payments) or SSI or noncash benefits such as the Supplemental Nutrition Assistance Program. The Supplemental Nutrition Assistance Program, or SNAP, (formerly known as food stamps), provides benefits to those who are unemployed, have no or low incomes, are elderly, are disables with low incomes, or are homeless. The income threshold for SNAP varies with household size and other factors. SNAP benefits can be used to purchase grocery items such as breads, cereals, fruits, vegetables, meats and dairy products. ("Facts about SNAP", 2015)
Rationale: The number of households receiving public assistance are indicative of households living in poverty or with insufficient resources. Lack of financial resources makes households in poverty more vulnerable to natural disasters. This is due to inadequate housing, social exclusion, and an inability to relocate or evacuate. Inadequate shelter exposes occupants to increased risk from storms, floods, fire and temperature extremes (Wilkinson and Marmot, 2003). Low-income residents are less likely to have adequate property insurance, so they may bear an even greater burden from property damage due to natural hazards (Wilkinson and Marmot, 2003).
Data Source & Collection Notes: US Census: American Community Survey: Table B19058
Calculation:

COLUMN	COLUMN ID	DESCRIPTION
A	HD01_VD02	Estimate: Total: (households) with cash public assistance or Food Stamps/SNAP
B	HD01_VD01	Estimate: Total (households)
Calculation	**(A/B) *100**	

Years Collected: 2015 5-Yr Estimate
Coverage/Scale: Nationwide at city level

8. Percent of area that is impervious surface

Description: The percent of areas that are impervious surfaces.
Rationale: Higher amounts of impervious surfaces are strongly correlated with higher amounts of surface water runoff, which can exacerbate flooding (Zahran et al. 2008).
Data Source & Collection Notes: https://www.mrlc.gov/index.php
Calculation: This dataset consists of a single layer, percent impervious surface, with file pixel values ranging from 0 to 100 percent, with each individual value representing the area or proportion of that 30m cell covered by developed imperviousness. Each pixel represents impervious surface.
GIS Analysis:

- A python script was written to mosaic individual raster data for HI, AK, PR and the Contiguous US and iterated the process for all 3 years
- UAA city boundary and the rasters were projected to the same projection system for spatial analysis
- A model builder was constructed in the ArcGIS to iterate through all city to compute zonal statistics-- to count all pixel value (i.e, percent tree canopy) within the city boundary and calculate an average value per city.

Years Collected: 2011
Coverage/Scale: Nationwide

9. Percent of buildings built before 1999

Description: The percent of buildings in a city built before 1999.
Rationale: : Based on National Flood Insurance Program and building code flood provision adoptions (ASCE 24). ASCE 24 was first published in 1998, outlining flood provisions for inclusion in building codes. Furthermore, model codes (i.e. International Code Council (ICC) – widely used in US) began adopting flood provision in 2000. After this point, building codes began adopting provisions. Building codes are widely adopted across the US, in many cases statewide. The building codes require inspections to ensure compliance, while the National Flood Insurance Program (NFIP) only recommends inspections. Thus, cities with a larger percentage of buildings built before 1999 without flood provisions are at risk for more flood damage to buildings.
Data Source & Collection Notes: US Census: American Community Survey Table B25034 "Year Structure Built"
Calculation:

COLUMN	COLUMN ID	DESCRIPTION
A	HD01_VD01	Estimate; Total: (Total Buildings)
B	HD01_VD02	Estimate; Total:- Built 2014 or later
C	HD01_VD03	Estimate; Total:-Built 2010-2013
D	HD01_VD04	Estimate; Total: - Built 2000-2009
Calculation	**100% - (A+B+C+D)**	

Years Collected: 2015 ACS 5-Yr Estimate
Coverage/Scale: Nationwide at the city level

10. Percent of households without access to a vehicle

Description: Measures the percent of workers 16 years and over in households without access to a vehicle.
Rationale: Failure to safely evacuate is a large cause of flood injury and access to a personal vehicle provides more reliable evacuation options (Colten 2006). Thus, access to a car is an indicator commonly included when examining vulnerability of urban populations to flooding (Kazmierczak and Cavan 2011; Peacock et al. 2010). This indicator also reveals the economic resilience of an area after disasters, as access to vehicles allows commuting to return to normal more quickly (Peacock et al. 2010; Tierney 2009).
Data Source & Collection Notes: U.S. Census: American Community Survey: Table DP04: Select Housing Characteristics
Calculation:

COLUMN	COLUMN ID	DESCRIPTION
A	HC03_VC85	Percent; Vehicles Available—Occupied Housing units—no vehicle
Calculation	**N/A**	

Years Collected: ACS 2015 5-Yr Estimate
Coverage/Scale: Nationwide at city level

11. Percent of households receiving public assistance

Description: Based on the estimates by the American Community Survey, this indicator measures the percent of housing units that are considered mobile homes.
Rationale: Mobile homes are more subject to flooding than regular homes and are structurally unsafe to stay in during extreme weather events (Baker 1991). Because of this, a greater percentage of mobile home occupants evacuate than occupants of other housing (Baker 1991). Additionally, they are more easily damaged than other homes (Cutter and Shirley 2003) making them less resilient to flood events. Therefore, this indicator is important for evacuation planning and risk/damage management.
Data Source & Collection Notes: US Census: American Community Survey Table DP04 "Selected Housing Characteristics"
Calculation:

COLUMN	COLUMN ID	DESCRIPTION
A	HC03_VC21	Percent; UNITS IN STRUCTURE – Total housing units-Mobile Homes
Calculation	**N/A**	

Years Collected: 2015 5-Yr Estimate
Coverage/Scale: Nationwide at city level

12. Percent of households receiving public assistance

Description: The ratio of total annual withdrawal to average annual available blue water, which is an indicator of water demand. **Rationale:** This indicator measures the level of fresh water consumption vis-à-vis the amount of freshwater available, to identify regions experiencing water stress. Water stress and scarcity affect both the environmental and economic health of a region. It serves as the baseline measure of how water scarce is the city compared to its demand. and thus to predict the pressures a drought could intensify for the city (Berrittella et al. 2007; Estrela and Vargas 2012).
Data Source & Collection Notes: Per the stress levels defined by the data source, indicator values above 20% show some risks from stress, while values above 40% show severely water-stressed conditions. The Aqueduct Water Risk Atlas does not have data specific for states, cities or counties. Instead, to analyze a location, a specific address must be entered. This can be done by typing the address or by entering coordinates, as well as clicking in the map. Entering coordinates is the easiest and most precise way of getting data.
Calculation: Baseline Water Stress measured from 1-5; 5 being most stressed.

- The Aqueduct Water Risk Atlas does not have data specific for states, cities or counties. Instead, to analyze a location, a specific address must be entered. This can be done by typing the address or by entering coordinates, as well as clicking in the map.
- To get an approximation of the city coordinates, we downloaded a file with a list of all cities in the US and their corresponding ZIP codes, each with coordinates.

Example:

CITY	STATE	LATITUDE	LONGITUDE
Aaronsburg	PA	40.89869	-77.4562
Abbeville	SC	34.21571	-82.4463
Abbeville	GA	31.97705	-83.3725
Abbeville	AL	31.5594	-85.223
Abbeville	MS	34.47194	-89.4475

- After this, we matched each of the UAA's cities with a pair of coordinates (this was done by coding it in VBA).
- Once each city had its coordinates, we uploaded a file with this information to the website.

Years Collected: 2014
Coverage/Scale: Nationwide at city level

13. Percent of GDP based on water intensive industries
Calculation: Sum A-E:

A. Percent of GDP based on agriculture, fishing and hunting
Description: The percentage of a city's economy that is based on the agriculture, fishing, and hunting industries. This is an indicator of how much a city depends economically on the agriculture industry.
Rationale: Industries bearing bigger impacts from short-term drought tend to be those more reliant on water and environmental health (Badjeck et al. 2010; Toulmin 1986; Heathcote 1969). Thus, the higher degree of dependence on these industries, the more sensitive is the city's economy to drought.
Data Source & Collection Notes: BEA. Industry Classification Number: 11. All cities have a corresponding metropolitan area.
Calculation: The 'Agriculture, forestry, fishing and hunting' industry GDP was divided by the total GDP of all industries.
Years Collected: 2015
Coverage/Scale: Metropolitan Area
Notes: *No data for cities in Puerto Rico. The dataset includes the values (D) and (L). (D) indicates data suppression to prevent the disclosure of confidential information. 52 cities have no data.*

B. Percent of GDP based on water transportation
Description: The percentage of a city's GDP that is based on the water transportation industry. This is anindicator of how much a city depends economically on the water transportation industry.
Rationale: The industry of water transportation can be economically impacted by medium-term droughts; droughts increase shipping costs, decrease productivity, and raise prices for consumers (Heinz 2012; Heathcote 1969).
Data Source & Collection Notes: BEA. Industry Classification Number: 483. All cities have a corresponding metropolitan area.
Calculation: The water transportation industry GDP was divided by the total GDP of all industries.
Years Collected: 2015; if 2015 data not available, 2014
Coverage/Scale: Metropolitan Area
Notes: *No data for cities in Puerto Rico. The dataset includes the values (D) and (L). (D) indicates data suppression to prevent the disclosure of confidential information. 156 cities have no data.*

C. Percent of GDP based on mining
Description: The percentage of a city's GDP that is based on the mining industry. This is an indicator of how much a city depends economically on the mining industry.
Rationale: Mining is a water intensive industry. It depends on maintaining the proper water balance, therefore, droughts could have severe consequences for mining industries and economies that rely heavily on them (Kelley 1954; Climate Change Business Journal).
Data Source & Collection Notes: BEA. Industry Classification Number: 21. All cities have a corresponding metropolitan area.
Calculation: The mining industry GDP was divided by the total GDP of all industries.
Years Collected: 2015; if 2015 data not available, 2014
Coverage/Scale: Metropolitan Area
Notes: *No data for cities in Puerto Rico. The dataset includes the values (D) and (L). (D) indicates data suppression to prevent the disclosure of confidential information. 55 cities have no data.*

D. Percent of GDP based on utilities

Description: The percentage of a city's GDP that is based on the utilities industry. This is an indicator of how much a city depends economically on the utilities industry.
Rationale: Utilities can be impacted by drought in many aspects: loss of water supply, poor water quality, increased costs and reduced revenues due to drought response, and increased demand that may be difficult to meet (EPA 2016). Thus, the more the economy of a city depends on utilities, the more vulnerable it is to drought.
Data Source & Collection Notes: BEA. Industry Classification Number: 22. All cities have a corresponding metropolitan area.
Calculation: The utilities industry GDP was divided by the total GDP of all industries.
Years Collected: 2015
Coverage/Scale: Metropolitan Area
Notes: *No data for cities in Puerto Rico. The dataset includes the values (D) and (L). (D) indicates data suppression to prevent the disclosure of confidential information. 66 cities have no data.*

E. Percent of GDP based on manufacturing

Description: The percentage of a city's GDP that is based on the manufacturing industry. This is an indicator of how much a city depends economically on the manufacturing industry.
Rationale: The industry of manufacturing can be heavily impacted by droughts because its high demand of water for various commercial processes (Heathcote 1969; Alliance For Water Efficiency).
Data Source & Collection Notes: BEA. Industry Classification Number: 31-33. All cities have a corresponding metropolitan area.
Calculation: The manufacturing industry GDP was divided by the total GDP of all industries.
Years Collected: 2015
Coverage/Scale: Metropolitan Area
Notes: *No data for cities in Puerto Rico. The dataset includes the values (D) and (L). (D) indicates data suppression to prevent the disclosure of confidential information. 15 cities have no data.*

Puerto Rico Notes: : PR does not produce GDP by county.

- Here is a link to the latest GDP tables.
- Table 9 includes GDP for Puerto Rico by industry, including GDP for agriculture, mining, utilities and manufacturing.
- County Business Patterns was used to create ratios that can approximate the extent to which each PR municipality's GDP is composed from these industries.
- For example, we took the total Manufacturing GDP for Puerto Rico and use a ratio of (Manufacturing employment for Bayamon / Manufacturing employment in all of Puerto Rico) to approximate how much of the overall Manufacturing GDP can be attributed to Bayamon.

14. Percent of workforce in farming, fishing and forestry

Description: The percent of the workforce that has an occupation in the farming, fishing and forestry industry.
Rationale: Based on the BLS Classifications as water intensive industries, these industries are especially water intensive. The livelihood of workers in the farming, fishing, and forestry industry are especially vulnerable to the effects of droughts, as these industries are dependent on rain, water levels, and water quality (Toulmin 1986; Badjeck 2010; Heathcote 1969).
Data Source & Collection Notes: US Census American Community Survey, Table S2401: "Occupation by Sex for the Civilian Employed Population 16 Years and Over" using ACS 5-year estimates
Calculation:

COLUMN	COLUMN ID	DESCRIPTION
A	HC01_EST_VC30	Total; Estimate, Natural resources, construction, and maintenance occupations: - Farming, fishing and forestry occupations
B	HC01_EST_VC01	Total; Estimate; Civilian employed population 16 years and over
Calculation	**(A/B) *100**	

Years Collected: 2015 5-Yr Estimate
Coverage/Scale: Nationwide at city level
Notes: *Workforce indicators are not included for the other drought sensitive industries (see above) because the data on those specific industries is not available from the Census.*

15. Percent of households without access to a vehicle

Description: Measures the percent of workers 16 years and over in households without access to a vehicle.
Rationale: Failure to safely evacuate is a large cause of flood injury and access to a personal vehicle provides more reliable evacuation options (Colten 2006). Thus, access to a car is an indicator commonly included when examining vulnerability of urban populations to flooding (Kazmierczak and Cavan 2011; Peacock et al. 2010). This indicator also reveals the economic resilience of an area after disasters, as access to vehicles allows commuting to return to normal more quickly (Peacock et al. 2010; Tierney 2009).
Data Source & Collection Notes: U.S. Census: American Community Survey: Table DP04: Select Housing Characteristics
Calculation:

COLUMN	COLUMN ID	DESCRIPTION
A	HC03_VC85	Percent; Vehicles Available—Occupied Housing units—no vehicle
Calculation	**N/A**	

Years Collected: ACS 2015 5-Yr Estimate
Coverage/Scale: Nationwide at city level

Adaptive Capacity Indicators

1. Percent of housing with heating fuel available

Description: The percent of housing units with available for heating the home.
Rationale: In the event of an extreme cold weather, residents rely on home heating; thus, the percentage of homes with heating is an indication of coping capacity as a city faces during cold weather events (Curriero et al. 2002). Those withheating are less vulnerable to cold-induced negative health effects(Conlon et al. 2011).
Data Source & Collection Notes: US Census: American Community Survey Table DP04"House Heating Fuel" The data of interest is the "no fuel used" data under "House Heating Fuel."
Calculation:

COLUMN	COLUMN ID	DESCRIPTION
A	HC03_VC101	Percent; HOUSE HEATING FUEL-Occupied housing units-No fuel used
Calculation	**100%-A= Percent with heating fuel**	

Years Collected: 2015 5-Yr Estimate
Coverage/Scale: Nationwide at the city level

2. Percent of the population with health insurance

Description: The percent of the un-institutionalized population with health insurance.
Rationale: During natural disasters such as floods, people without health insurance can "experience higher morbidity and mortality," and after disasters, "lack of access to routine health care is a leading cause of mortality" (Mensah et al. 2005). The more of the population with health insurance, the less people exposed to this higher risk during disasters. Insurance provides a safety net and allows populations to recover more quickly after disasters (Cutter, 2000; Masozera et al. 2006).
Data Source & Collection Notes: US Census: American Community Survey Table S2701 "Selected Characteristics of Health Insurance Coverage in the United States"
Calculation:

COLUMN	COLUMN ID	DESCRIPTION
A	HC03_EST_VC01	Percent Insured; Estimate: Civilian noninstitutionalized population
Calculation	**N/A**	

Years Collected: 2015 5-Yr Estimate
Coverage/Scale: Nationwide at the city level

3. Number of acute care hospital beds per 1,000 residents

Description: The number of acute care hospital beds available per 1,000 residents in hospital referral areas.

Rationale: Lack of acute care hospital beds has been identified as the greatest impediment to efficiency of patient treatment and outflow and the biggest cause of overcrowding in hospitals (Trzeciak 2003; Bullard, 2009; Moskop 2009). Overcrowding in hospitals, especially in the emergency department, "threatens public health by compromising patient safety and jeopardizing the reliability of the entire US emergency care system" (Trzeciak 2003; Bullard, 2009; Moskop 2009). This is an even greater threat during disasters; the less acute care beds available, the less equipped a hospital is to deal with the impacts of a natural disaster (Trzeciak 2003; Milsten 2000).
Data Source & Collection Notes: Homeland Infrastructure Foundation-Level Data (HIFLD). The feature class/shapefile contains locations of Hospitals for 50 US states, Washington D.C, US territories of Puerto Rico. The dataset only includes hospital facilities based on data acquired from various state departments or federal sources. Hospital facilities which do not occur in these sources will not be present in the database. The database does not contain nursing homes or health centers. Hospitals have been categorized into children, chronic disease, critical access, general acute care, long term care, military, psychiatric, rehabilitation, special and women based on the range of available values from the various sources after removing similarities. For the purpose of UAA's calculation, psychiatric and rehabilitation type hospitals were removed from the database, as they did not fit into our definition of acute care facilities.
Calculation: Hospital facilities hospital beds were aggregated at the city level, and we calculated the number of hospital beds in a city per 1,000 residents. For cities that had no hospital facility located within its boundaries (10 cities), we included hospitals that were within 5 miles from the city centroid. At city level, the calculation was number of beds from applicable hospital facilities within city boundary (or within buffer zone) divided by the population of the city, multiplied by 1,000 to obtain beds/1,000 residents. At the sub-city level, we only list number of beds per census; where we divide the city population by the census population and multiply the bed count to obtain a weighted distribution of beds.
Years Collected: 2017
Coverage/Scale: Nationwide at the city level
Notes: *Arvada and Surprise were the two remaining cities that do not have an applicable hospital facility within their city boundaries, or within 5 miles from the city centroid.*

5. Percent land covered by tree canopy

Description: The percent of land covered by tree canopy. Tree canopy is the outer layer of mature leaves and trees.
Rationale: Green spaces provide passive cooling to mitigate the impact of extreme heat (Gentry et al. 2014; Bowler et al. 2010). Increased tree canopy and vegetative cover can "reduce the impacts of biophysical hazards in cities, including heat stress related to elevated temperatures, air pollution and associated public health effects" (Solecki 2005; Stone et al. 2014). Furthermore, the demand for air-conditioning related energy production can be decreased economically and effectively by expanding the amount of tree canopy in a given area (Solecki 2005; Stone et al. 2014).
Data Source & Collection Notes: Requires GIS. This dataset consists of a single layer, percent tree canopy cover, with file pixel values ranging from 0 to 100 percent, with each individual value representing the area or proportion of that 30m cell covered by tree canopy.
Calculation: Raster, 30-meter resolution. Each pixel represents tree canopy. GIS Analysis:

- A python script was written to mosaic individual raster data for HI, AK, PR and the Contiguous US and iterated the process for all 3 years
- UAA city boundary and the rasters were projected to the same projection system for spatial analysis
- A model builder was constructed in the ArcGIS to iterate through all city to compute zonal statistics--to count all pixel value (i.e, percent tree canopy) within the city boundary and calculate an average value per city.

Years Collected: 2011
Coverage/Scale: Nationwide

6. Water quality enforcement

Description: The number of fiscal quarters in which the city had a drinking water quality violation in the past 3 years.
Rationale: The availability of safe drinking water is one of the most important factors in whether epidemics break out after floods (Watson et al. 2007). Higher numbers of drinking water safety violations, magnitude of violations, and low solution capability would increase the risk of contamination, and this risk must be considered in planning the protection of drinking water (Marsalek and Rochfort 2004).
Data Source & Collection Notes: EPA Enforcement and Compliance History Online (ECHO).

- Matched the UAA cities with the available data, but only some cities had an exact match (based on the pws the city serves). Many pws had multiple cities so there was no way to match this directly. For the missing cities, filter the pws by state and determine which one served the city (based on the pws name).

Calculation: Count number of violations
Years Collected: 2015-2017
Coverage/Scale: City. Nationwide. Years cannot be disaggregated at mass-download level (i.e. cannot find out in which years each violation occurred without clicking on each individual city page).

7. Existence of drought management plan

Description: This is a binary indicator: 1 means that a city has a drought management plan and 0 means that a city does not.
Rationale: As drought episodes and widespread drought conditions occur more and more, they are posing increasingly larger economic, social, and environmental challenges (Estrela and Vargas 2012; Hayes et al. 2000). Drought management plans can strategically provide warnings and better impact mitigation, and have become "a principal tool of states and other levels of governments to improve their response to droughts" (Estrela and Vargas 2012; Hayes et al. 2000).
Data Source & Collection Notes: City government materials. Each city website was searched individually.
Calculation: Enter the name of the city and the state initials and add 'drought plan' into Google. For example "Oakland CA drought plan." Most of the time this yields immediate results if the city does have a plan. We then searched the city name followed by 'water management plan' or 'water conservation plan' which would again yield almost immediate results. For all searches, we keyword searched the word 'drought' to see where/ if the document discussed drought. Next, we looked for any auxiliary documents/ websites/groups who worked with drought in / for the city.
Years Collected: 2017
Coverage/Scale: Nationwide at the city level

8. Existence of water management plan

Description: This is a binary indicator: 1 means that a city has a water management plan and 0 means that a city does not.
Rationale: "Water is a strategic resource for economic, social, and environmental development," and is becoming an increasingly scarce resource with increasing droughts (Estrela and Vargas 2012). To mitigate the vulnerability of a city to drought, a city can implement water management plans with measures such as improving the operational capabilities of their water systems in general, including water supply monitoring and conservation (Wilhite et al. 2006).
Data Source & Collection Notes: City government materials. Each city website was searched individually.

Calculation: Enter the name of the city and the state initials and add 'drought plan' into Google. For example "Oakland CA drought plan." Most of the time this yields immediate results if the city does have a plan. We then searched the city name followed by 'water management plan' or 'water conservation plan' which would again yield almost immediate results. For all searches, we keyword searched the word 'drought' to see where/ if the document discussed drought. Next, we looked for any auxiliary documents/ websites/groups who worked with drought in / for the city.
Years Collected: 2017
Coverage/Scale: Nationwide at the city level

READINESS INDICATORS

Economic Readiness

1. Bond worthiness

Description: The creditworthiness of the city as measured by general obligation bond ratings.
Rationale: Cities can issue bonds as one way to solve financial challenges for funding large-scale adaptation projects. Bond worthiness measures the attractiveness of the city to potential buyers and the likeliness of investment in a city (Kosinova et al. 2014; Sinclair 2008).
Data Source & Collection Notes: Moody's bond ratings.
Calculation: To download data...

1. Go to moodys.com
2. Log in to get access to bond ratings (it is free to create an account, and this can be done in a few minutes).
3. Use the search bar to look for a city. The name of the city must follow the following format: Los Angeles (City of) CA
4. Click the ratings tab.
5. Look for the most recent "General Obligation" bond. (In the table there is a column called "Security Type"). If there are multiple types of ratings for the bond (underlying, enhanced, insured) use the most recent one.
6. Some cities haven't had a General Obligation bond in years, or don't have records of any at all.
7. Record the most recent rating (record most recent rating if given the choice between General Obligation and General Obligation Limited Tax). The following scale was used to record the ratings:
8. If a general obligation has two ratings, and the same dates corresponding to those ratings, choose insured instead of underlying.

To translate the letters into numerical scores:

Aaa	21	Baa1	14	B2	7
Aa1	20	Baa2	13	B3	6
Aa2	19	Baa3	12	Caa1	5
Aa3	18	Ba1	11	Caa2	4
A1	17	Ba2	10	Caa3	3
A2	16	Ba3	9	Ca	2
A3	15	B1	8	C	1
				WR	0

Years Collected: Varies by city
Coverage/Scale: City governments

2. Tax incentives for renewable energy

Description: The number of tax incentive programs a city provides for renewable energy initiatives
Rationale: Cities can attract direct investment as one way to solve financial challenges for funding adaptation actions. Economic incentives for adaptation encourage actions and technological innovation that drive sustainable development (Johnstone et al. 2010). It also indicates the local government is prioritizing adaptive actions and has sustainability goals (Saha and Paterson 2008). With no direct measure of incentive for adaptation, indicator related to renewable energy is indicative of an investment environment that encourages businesses that seek to address issues related to climate change.
Data Source & Collection Notes: Database of State Incentives for Renewables and Efficiency (DSIRE) Different tax incentive programs are given different codes; the final score was a count of how many programs are associated with a certain city; data was from December of 2016 and April of 2017. Each of the UAA cities was matched with its respective DSIRE city ID, and the tables were merged to get the total count of tax incentive programs.
Calculation: To download data…

1. Go to Database of State Incentives for Renewables and Efficiency website
2. Downloaded the zip file
3. Opened the "program_city file" to get a list of all programs and in which cities they can be found
4. Get the frequency of each program-city pair (we did this by creating a pivot table, with the cities as rows and program frequency (count values).
5. Compared their cities to our cities by assigning a city_id to each of our cities (based on the "city" file)
6. Used a vlookup to get the number of programs per city

Years Collected: 2016, 2017 (DSIRE only posts the most recent five months)
Coverage/Scale: City-level

3. Debt per resident

Description: A city's debt per resident
Rationale: The deficit measure supplements the revenue measure to proxy the financial capacity that a city government has. A deficit measure is important to understand the current expense hence to predict the room left to ramp up expenditure on extra adaptation efforts (Pagano and Johnston 2000).
Data Source & Collection Notes: City-data.com Advanced U.S. city search
Calculation: Collect parenthetical value under Debt: "Beginning Outstanding Unspecified public use"category using the values in parenthesis (per resident). For cities collected in a year earlier than 2004 (see below in Notes) collect "Beginning Outstanding: NEC".
Years Collected: 2006
Coverage/Scale: City-level
Notes: *These cities have data for 2002 only: Temecula, CA; Victorville, CA; Miramar, FL; Columbia, SC; McKinney, TX. These cities have data for 2004 only: Lubbock, TX; Austin, TX; Norman, OK; Reno, NV; Henderson, NV; Wilmington, DE. Data for Puerto Rican cities is unavailable.. Data for Columbus, GA, Frisco, TX and Miami Gardens, FL is unavailable.*

Governance Readiness

1. Estimated percent of adults who think global warming is already harming people in the U.S. now or within 10 years

Description: The estimated percent of a county that believes that global warming will harm people in the US.

Rationale: Those who believe they and others around them are already experiencing global warming and its' impacts have a higher risk perception of climate change; this affects people's attitudes towards preparations for climate change (Akerlof et al. 2013). Risk perception is a large determinant in whether people will act preemptively and make or accept changes to their lifestyles in order to adapt to situations such as climate change (Slovic and Peters 2006; Leiserowitz 2006). Additionally, the risk perception of climate change strongly influences policy support and advocacy (Leiserowitz 2006).
Data Source & Collection Notes: Yale Project on Climate Change Communication
Years Collected: 2014
Coverage/Scale: Nationwide at the county level

2. Total number of federal public corruption convictions

Description: The total number of federal public corruption convictions.
Rationale: Corruption convictions are indicative of a local government's transparency and accountability (Goel and Nelson 2007; Alt and Lassen 2008), which would negatively impact the efficient use of funds for actions that do not have immediate payoff such as climate change adaptation.
Data Source & Collection Notes: Table III: Federal Public Corruption Conviction by District Over the Past Decade. Click in each of the reports from years 2007-2015, go to page 72/77 and then sum total convictions. When a city is in several counties in different districts the average is used (Carrollton, TX). To find the district corresponding to each city, go to the city or county website.
Calculation: Sum total convictions
Years Collected: 2005-2013
Coverage/Scale: Data available by district of the US Attorney's Office, by district

3. Percent of Population with a 12th grade education or higher

Description: Percent of population over the age of 25 that completed the 12th grade or higher levels of education.
Rationale: Education helps reduce vulnerability to disasters and enhances adaptation to climate change (Ecology and Society 2014). High school completion is used as a proxy for overall socioeconomic circumstances. Lack of education is strongly correlated with poverty and poor health. A study in California found the lack of a high school degree was the factor most closely related to social vulnerability to climate change. (Cooley, 2012)
Data Source & Collection Notes: US Census: American Community Survey: Table B15002: Educational Attainment
Calculation:

COLUMN	COLUMN ID	DESCRIPTION
A	HD01_VD03	Male: No schooling completed
B	HD01_VD04	Male: Nursery to 4th grade
C	HD01_VD05	Male: 5th and 6th grade
D	HD01_VD06	Male: 7th and 9th grade
E	HD01_VD07	Male: 9th grade
F	HD01_VD08	Male: 10th grade

COLUMN	COLUMN ID	DESCRIPTION
G	HD01_VD09	Male: 11th grade
H	HD01_VD20	Female: No schooling completed
I	HD01_VD21	Female: Nursery to 4th grade
J	HD01_VD22	Female: 5th and 6th grade
K	HD01_VD23	Female: 7th and 8th grade
L	HD01_VD24	Female: 9th grade
M	HD01_VD25	Female: 10th grade
N	HD01_VD26	Female: 11th grade
O	HD01_VD01	Total population 25 years and over
Calculation	**=100% - Sum(A:N) / O**	

Years Collected: 2015 5-Yr Estimate
Coverage/Scale: Nationwide at the city level

Social Readiness

1. General innovation capabilities

Description: The patent count per capita of the county a city belongs to.
Rationale: Patents require creativity and resources, both of which enable better disaster response, and importantly, a better leverage of investment for better results (Cooke et al. 1997). Therefore, a high number of patents is one signal that a society will have the resilience to effectively encounter change. (Patenting and Innovation in Metropolitan America, 2013). In addition, patents are a commonly used measure for technological innovation, which to achieving long term sustainability (Johnstone 2010).
Data Source & Collection Notes: United States Patent and Trademarks Office; County Population: US Census: American Community Survey Table B01003 "Total Population"
Calculation: Sum patents per county year 2015 and divide by the county population of the same year. All UAA cities in the same county receive the same score.
Years Collected: 2015
Coverage/Scale: Nationwide at the county level

2. Civic engagement

Description: Voter turnout in federal general elections.

Rationale: Democracy is considered better than the non-democracies to protect the rights and basic needs of groups most at risk from climate-induced threats (Burnell, 2012), hence a measure of democracy is an indicator of governance readiness for adaptation. The overall citizen participation in elections is a general measure of democracy (Gerken, 2009). Voter turnout can be used as a proxy of the extent to which citizens are engaged in decision-making process of public issues like climate change adaptation. commonly used measure for technological innovation, which to achieving long term sustainability (Johnstone 2010).
Data Source & Collection Notes: National 2008 Precinct Map from Stanford's Spatial Social Science Lab.
Calculation: Data for votes cast per precinct in the 2008 election came from the national precinct map provided by Stanford's Spatial Social Science Lab. However, the map did not include the state of Oregon. We collected individual county data for the UAA cities that were located in Oregon, obtaining precinct data from Marion, Multnomah and Lane County. All precinct data was aggregated at city level. Because the Stanford Spatial Social Science Lab precinct map did not include number of registered voters, we could not calculate voter turnout. Instead, we estimated turnout by calculating number of voters divided by the population of the city over the age of 18. Calculation is thus the summed precinct votes for each city divided by the population of the city over the age of 18.
Years Collected: The precinct voter data was based on the 2008 election.
Coverage/Scale: National precincts aggregated at city level
Notes: For Puerto Rico Election data & Eligible Voters:

- Visit: http://eleccionespuertorico.org/datos/2008/
- Use ACS 2010 Census 5-year estimate, Table: S1501, sum of columns D + AH
- Calculation: Votes from election data divided by eligible voters

VIII. Sub-City Indicators

1. Median Household Income

Description: Estimated value of median household income in census tract. For households and families, the median income is based on the distribution of the total number of households and families including those with no income. The median income for households is computed on the basis of a standard distribution.
Rationale: Low income is one of the strongest predictors for compromised health and ability to recover from disruptions. This is true across many types of risk, including general health as well as risks from extreme weather, climate change and environmental stresses. Natural disasters disproportionately impact the poor because of factors such as inadequate housing, social exclusion, a diminished ability to evacuate, lack of property insurance, and more acute emotional stress. Low income people are also more likely to be overlooked during emergency response following disaster.
Data Source & Collection Notes: US Census: American Community Survey: Table B19013
Column ID: B19013e1: Median Household Income in the Past 12 Months (In 2015 Inflation-Adjusted Dollars): Total: Households—(Estimate)
Years Collected: 2015 5-Yr Estimate
Coverage/Scale: Nationwide at census tract level

2. Percent of limited English speaking households/ Linguistic Isolation

Description: Percent of households in which no member 14 years old and over (1) speaks only English or (2) speaks a non-English language and speaks English "very well."
Rationale: A person's ability to take action during an emergency is compromised by language and cultural barriers. Poor English skills can make it harder to follow directions or interact with agencies.
Data Source & Collection Notes: US Census: American Community Survey: Table B16002: Language Spoken at Home
Calculation:

COLUMN	COLUMN ID	DESCRIPTION
A	B16002e13	Household Language by Household: Limited English Speaking Status: Other languages: Limited English speaking household: Households—(Estimate)
B	B16002e4	Household Language by Household: Limited English Speaking Status: Spanish: Limited English speaking household: Households—(Estimate)
C	B1101e1	Total: Households—(Estimate)
Calculation	**(A+B)/C *100**	

Years Collected: 2015 ACS 5-Yr Estimate
Coverage/Scale: Nationwide at census tract level
Notes: This indicator is not relevant (does not speak to social vulnerability) for majority Spanish speaking cities including those in Puerto Rico and for some cities in Florida.

3. Percent of the population without health insurance

Description: The percent of the un-institutionalized population with health insurance.
Rationale: During natural disasters such as floods, people without health insurance can "experience higher morbidity and mortality," and after disasters, "lack of access to routine health care is a leading cause of mortality" (Mensah et al. 2005). The more of the population with health insurance, the less people exposed to this higher risk during disasters. Insurance provides a safety net and allows populations to recover more quickly after disasters (Cutter, 2000; Masozera et al. 2006).
Data Source & Collection Notes: US Census: American Community Survey Table S2701 "Selected Characteristics of Health Insurance Coverage in the United States"
Calculation:

COLUMN	COLUMN ID	DESCRIPTION
A	HC03_EST_VC01	Percent Insured; Estimate: Civilian noninstitutionalized population
Calculation	**100%-A**	

Years Collected: 2015 5-Yr Estimate
Coverage/Scale: Nationwide at census tract level

4. Percent of single mother households

Description: Percent of households that have single, female householder (no husband present) in family
Rationale: Traditionally, more women lead single-parent homes than men, and when families split up during disasters children often end up with the mothers. Extra responsibilities can increase the challenges that single mother households face during climate hazards.
Data Source & Collection Notes: US Census: American Community Survey Table B09005 "HOUSEHOLD TYPE FOR CHILDREN UNDER 18 YEARS IN HOUSEHOLDS"
Calculation:

COLUMN	COLUMN ID	DESCRIPTION
A	HD01_VD01	Estimate; Total: (total households)
B	HD01_VD10	Estimate; In family households: - In female householder, no husband present, family
Calculation	**(B/A) *100**	

Years Collected: 2015 5-Yr Estimate
Coverage/Scale: Nationwide at census tract level

5. Percent of the renting population that spends over 50% of income on rent

Description: The percent of renters in a city who spend over 50% of their income on their rent payments.
Rationale: A proxy of risk of homelessness, according to definition of housing instability that is measured by spending more than 50% of household income on housing (Kushel et al. 2006; Ma et al. 2007). Such burdening housing costs and housing instability are higher risk factors for homelessness (Kushel et al. 2006; Shinn et al. 1998; Wood et al. 1990). The homeless population and marginal population are most vulnerable to temperature and weather effects, and struggle most to recover from being displaced/harmed (Wisner 1998; Morrow 1999). Emergency planners should identify and locate high risk sectors, as "effective disaster management calls for aggressively involving these neighborhoods and groups at all levels of planning and response," and mitigation efforts must "address the root causes of vulnerability" (Morrow 1999).
Data Source & Collection Notes: US Census: American Community Survey Table B25070 "Gross Rent as a Percentage of Household Income in the Past 12 Months"
Calculation:

COLUMN	COLUMN ID	DESCRIPTION
A	HD01_VD01	Estimate; Total: (total renting)
B	HD01_VD10	Estimate; Total: - 50.0 percent or more
Calculation	**(B/A) *100**	

Years Collected: 2015 5-Yr Estimate
Coverage/Scale: Nationwide at census tract level

6. Percent of population living in high risk floodzone

Description: The average number of population, within the administrative boundary of a given city, exposed to potential flood hazard.
Rationale: The amount of the population that could be impacted by flooding is integral information for emergency management and disaster planning (Maantay and Maroko 2009; Cutter et al. 2000). The more people susceptible to damage, displacement, and disease caused by flooding, the more difficult effective adaptation and mitigation are (Cutter et al. 2000).
Data Source & Collection Notes: Requires GIS. 1) US Census: American Community Survey Table B01003 "Total Population" 2) FEMA Flood Map Service Center
Calculation: Overlaid population data with FEMA shapefiles in GIS
Coverage/Scale: City
Notes: Missing from national FEMA file were 15 cities. We used preliminary FEMA data for the following cities: Seattle, Pueblo, Portland, Lafayette, Colorado Springs, Provo, West Palm Beach, Brownsville, Naperville, Bellevue, and Kent. Three cities were not included in UAA analysis because no digitized map of the city was available (McAllen, Grand Rapids, Rochester). Midland, Texas created a FEMA map for its city internally, but is not available on the FEMA site. It has three categories of FEMA zones, which roughly translated into the A, AE and AH zones for the 100 year floodplain layer, and X for the 500 year floodplain. We spatially joined population, housing, and registered cars to the FEMA layers.

7. Percent of area that is impervious surface

Description: Percent of areas that are impervious surfaces.
Rationale: Higher amounts of impervious surfaces are strongly correlated with higher amounts of surface water runoff, which can exacerbate flooding (Zahran et al. 2008).
Data Source & Collection Notes: https://www.mrlc.gov/index.php
Calculation: This dataset consists of a single layer, percent impervious surface, with file pixel values ranging from 0 to 100 percent, with each individual value representing the area or proportion of that 30m cell covered by developed imperviousness. Each pixel represents impervious surface.
GIS Analysis:

- A python script was written to mosaic individual raster data for HI, AK, PR and the Contiguous US and iterated the process for all 3 years
- UAA city boundary and the rasters were projected to the same projection system for spatial analysis
- A model builder was constructed in the ArcGIS to iterate through all city to compute zonal statistics--to count all pixel value (i.e, percent tree canopy) within the city boundary and calculate an average value per city.

Coverage/Scale: Nationwide

8. Percent Land Covered by Tree Canopy

Description: The percent of land covered by tree canopy. Tree canopy is the outer layer of mature leaves and trees.
Rationale: Green spaces provide passive cooling to mitigate the impact of extreme heat (Gentry et al. 2014; Bowler et al. 2010). Increased tree canopy and vegetative cover can "reduce the impacts of biophysical hazards in cities, including heat stress related to elevated temperatures, air pollution and associated public health effects" (Solecki 2005; Stone et al. 2014). Furthermore, the demand for air-conditioning related energy production can be decreased economically and effectively by expanding the amount of tree canopy in a given area (Solecki 2005; Stone et al. 2014).
Data Source & Collection Notes: Requires GIS. This dataset consists of a single layer, percent tree canopy cover, with file pixel values ranging from 0 to 100 percent, with each individual value representing the area or proportion of that 30m cell covered by tree canopy.

Calculation: Raster, 30-meter resolution. Each pixel represents tree canopy.
GIS Analysis:

- A python script was written to mosaic individual raster data for HI, AK, PR and the Contiguous US and iterated the process for all 3 years
- UAA city boundary and the rasters were projected to the same projection system for spatial analysis
- A model builder was constructed in the ArcGIS to iterate through all city to compute zonal statistics--to count all pixel value (i.e, percent tree canopy) within the census tract boundary and calculate an average value per census tract.

Years Collected: 2011
Coverage/Scale: Nationwide

9. Percent of buildings built before 1999

Description: The percent of buildings in a city built before 1999.
Rationale: Based on National Flood Insurance Program and building code flood provision adoptions (ASCE 24). ASCE 24 was first published in 1998, outlining flood provisions for inclusion in building codes. Furthermore, model codes (i.e. International Code Council (ICC) – widely used in US) began adopting flood provision in 2000. After this point, building codes began adopting provisions. Building codes are widely adopted across the US, in many cases statewide. The building codes require inspections to ensure compliance, while the National Flood Insurance Program (NFIP) only recommends inspections. Thus, cities with a larger percentage of buildings built before 1999 without flood provisions are at risk for more flood damage to buildings.
Data Source & Collection Notes: US Census: American Community Survey: Table B25034: Housing Characteristics
Calculation:

COLUMN	COLUMN ID	DESCRIPTION
A	B25034e11	Year Structure Built: 1939 or earlier
B	B25034e10	Year Structure Built: 1940-1949
C	B25034e9	Year Structure Built: 1950-1959
D	B25034e8	Year Structure Built: 1960-1969
E	B25034e7	Year Structure Built: 1970-1979
F	B25034e6	Year Structure Built: 1980-1989
G	B25034e5	Year Structure Built: 1990-1999
H	B25034e1	Total Housing Units
Calculation	**(A+B+C+D+E+G)/H *100**	

Years Collected: 2015 5-Yr Estimate
Coverage/Scale: Nationwide at census tract level

10. Percent of buildings built before 1979

Description: The percent of buildings in a city built before 1979.
Rationale: Buildings with higher energy efficiency tend to be more resistant to extreme temperatures. Due to increased regulation, new buildings tend to be more energy efficient than older buildings (Jens Lausten 2008). More energy efficient buildings are better able to tolerate extreme heat events without fluctuation in indoor temperature (Jens Lausten 2008). While there is no national building code, states choose to adopt outside building codes and many tended to adopt energy efficiency codes in the 1970s, possibly due to the oil crisis around that time (Jens Lausten 2008) As it is hard to estimate local adoption of energy efficiency codes (Cort and Butner 2012) state adoption may be an appropriate proxy as local building ages reflect building energy efficiency. Thus, this is an indicator of a city's resilience to extreme heat. (See Appendix B for more information)
Data Source & Collection Notes: US Census: American Community Survey: Table B25034: Housing Characteristics
Calculation:

COLUMN	COLUMN ID	DESCRIPTION
A	B25034e11	Year Structure Built: 1939 or earlier
B	B25034e10	Year Structure Built: 1940-1949
C	B25034e9	Year Structure Built: 1950-1959
D	B25034e8	Year Structure Built: 1960-1969
E	B25034e7	Year Structure Built: 1970-1979
H	B25034e1	Total Housing Units
Calculation	**(A+B+C+D+E)/H *100**	

Years Collected: 2015 5-Yr Estimate
Coverage/Scale: Nationwide at census tract level

11. Percent of total housing units that are mobile homes

Description: Measures the percent of housing units that are considered mobile homes.
Rationale: Mobile homes are more subject to flooding than regular homes and are structurally unsafe to stay in during extreme weather events (Baker 1991). Because of this, a greater percentage of mobile home occupants evacuate than occupants of other housing (Baker 1991). Additionally, they are more easily damaged than other homes (Cutter and Shirley 2003) making them less resilient to flood events. Therefore, this indicator is important for evacuation planning and risk/damage management.
Data Source & Collection Notes: US Census: American Community Survey: Table B25024: Housing Characteristics

Calculation:

COLUMN	COLUMN ID	DESCRIPTION
A	B25024e10	Units in Structure: Mobile Home: Housing Units
B	B25024e1	Units in Structure: housing Units: Total
Calculation	**A/B (*100)**	

Years Collected: 2015 5-Yr Estimate
Coverage/Scale: Nationwide at census tract level

12. Percent of workers in households without access to a vehicle

Description: The percent of workers 16 years and over in households with no vehicles available.
Rationale: Failure to safely evacuate is a large cause of flood injury and access to a personal vehicle provides more reliable evacuation options (Colten 2006). Thus, access to a car is an indicator commonly included when examining vulnerability of urban populations to flooding (Kazmierczak and Cavan 2011; Peacock et al. 2010). This indicator also reveals the economic resilience of an area after disasters, as access to vehicles allows commuting to return to normal more quickly (Peacock et al. 2010; Tierney 2009).
Data Source & Collection Notes: US Census: American Community Survey: Table B08014: Commuting
Calculation:

COLUMN	COLUMN ID	DESCRIPTION
A	B08014e3	Sex of workers by vehicle available: Workers 16 years and over in households: No vehicles available
B	B08014e1	Sex of workers by vehicle available: workers 16 years and over in households: Total
Calculation	**A/B (*100)**	

Years Collected: 2015 5-Yr Estimate
Coverage/Scale: Nationwide at census tract level

13. Percent of households with person over 65 years or older living alone

Description: Percent of households in which the only householder is over 65 and lives alone.
Rationale: One consequence of social isolation is the limited acquisition of disaster information and the failure to recognize the impact of upcoming risks (Health Canada, 2012). In addition, limited flexibility and less enthusiasm to engage in the pre- and post- aid programs are other possible contributors to the vulnerability of the socially-isolated elderly (Sharkey, 2007; Ngo, 2001; Klinenberg, 2015). Limited or impaired mobility associated with aging (Gamble et al., 2013; Fernandez et al., 2002) also complicates evacuation during events like floods and can restrict one's ability to find cover and shelter (Fernandez et al., 2002). In addition, limited mobility also is one of the reasons that some elderly (approximately 4% in the US) elderly choose to live in nursing homes or continuous care communities (US Census Bureau, 2017).

However, dependency on caregivers in an institutional settings, especially for those that are confined to beds, sometimes exacerbates vulnerability to extreme events (Staffoggia et al., 2006) due to multiple reasons such as lack of public assistance (Saliba et al., 2004).
Data Source & Collection Notes: US Census: American Community Survey: Table B09020: Children_ Household_Relationship
Calculation:

COLUMN	COLUMN ID	DESCRIPTION
A	B09020e18	In households: In nonfamily households: Householder: Male: Living alone: Population 65 years and over – (Estimate)
B	B09020e15	In households: in nonfamily households: Householder: Male: Living alone: Population 65 years and over—(Estimate)
C	B11001e1	Household Type (Including Living Alone): Total: Households –(Estimate)
Calculation	**A +B / C (*100)**	

Years Collected: 2015 5-Yr Estimate
Coverage/Scale: Nationwide at census tract level

14. Percent of population with a disability

Description: Percent of the population that have one of six categorized (ACS) disabilities including:

- Hearing difficulty: deaf or having serious difficulty hearing
- Vision difficulty: blind or having serious difficulty seeing, even when wearing glasses
- Cognitive difficulty: Because of a physical, mental, or emotional problem, having difficulty remembering, concentrating or making decisions
- Ambulatory difficulty: Having serious difficulty walking or climbing stairs
- Self-care difficulty: Having difficulty bathing or dressing
- Independent living difficulty: Because of a physical, mental or emotional problem, having difficulty doing errands alone such as visiting a doctor's office or shopping

Rationale: People with disabilities are among the most vulnerable in an emergency, sustaining disproportionately higher rates of morbidity and mortality, and at the same time being among those least able to access emergency support. When an emergency hits they may have difficulty reaching safe areas or accessing vital emergency information.
Data Source & Collection Notes: US Census: American Community Survey: Table B18101: Disability
Calculation:

COLUMN	COLUMN ID	DESCRIPTION
A	B18101e4	Male: under 5 years: with a disability
B	B18101e7	Male 5-17: with a disability
C	B18101e10	Male 18-34: with a disability

COLUMN	COLUMN ID	DESCRIPTION
D	B18101e13	Male 35-64: with a disability
E	B18101e16	Male 65-74: with a disability
F	B18101e19	Male 75 and over: with a disability
G	B18101e23	Female Under 5 years: with a disability
H	B18101e26	Female 5-17: with a disability
I	B18101e29	Female: 18-34: with a disability
J	B18101e32	Female: 35-64: with a disability
K	B18101e35	Female: 65-74: with a disability
L	B18101e38	Female: 75 and over: with a disability
M	B01001e1	Total: Total Population
Calculation	**=Sum(A:L)/M (*100)**	

Years Collected: 2015 5-Yr Estimate
Coverage/Scale: Nationwide at the city level

IX. References

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