GREENBELT ALLIANCE

Technical Memorandum

Bay Area Resilience Hotspots

Summer 2023

Background and Purpose

The Bay Area Resilience Hotspots project is a multiphase project led by Greenbelt Alliance to identify high-priority locations for nature-based resilience through spatial analysis, local engagement efforts (including interviews, events, and other meeting formats), and supportive qualitative and quantitative research efforts. This memorandum describes the methodology, data, and approach that Greenbelt Alliance undertook to complete the spatial analysis portion of this project.

Project Beginnings

Greenbelt Alliance has long been a trusted source of land use analyses, especially given our past *At Risk* report that incorporated mapping and original research to identify the Bay Area lands at risk of sprawl development.

The Resilience Hotspots project is our newest iteration of *At Risk* that incorporates not only conservation priorities and sprawl risk, but also climate hazards and social vulnerability factors. Greenbelt Alliance partnered with design and planning firm, Wallace Roberts and Todd (WRT) in 2021 to lead the first phase of development focused on data refinement, methodology development, and consultation with technical advisors. These advisors included the following people: Anna Lang (Zylient), Jack Hogan (Arup), Koshy Thomas (Urban Footprint), Ben Botkin from Metropolitan Transportation Commission (MTC), Michael Germeraad (MTC), Robin Grossinger (Second Nature, formerly SFEI), Todd Hallenbeck from Bay Conservation and Development Commission (BCDC), Tom Robinson (Together Bay Area).

In collaboration with WRT and advisors, Greenbelt Alliance produced an initial Bay Area Resilience Hotspots map that combined flood and wildfire hazard data, social vulnerabilities, and sprawl and conservation priorities into one map through a data prioritization process.

Subsequent Phases and Where the Project is Today

After the initial phase of the Resilience Hotspots Project, Greenbelt Alliance sought review from partner organizations and experts to gain further insight into how this product would advance measurable resilience outcomes in the Bay Area. As a result, Greenbelt Alliance made adjustments to the project scope to include local input and allow us to identify hotspots through separate analyses for flooding, wildfire, and extreme heat. These subsequent phases of work (see timeline detail left), include stakeholder feedback, updates to the methodology for the spatial analysis, identification of hotspots areas of opportunity, engagement of community partners, production of Community Resilience Profiles, project launch, and action implementation.

Throughout this process, Greenbelt Alliance engaged technical advisors, peer organizations, and subject-matter experts to help with development of the data analyses and the next project phases. The following people participated as technical advisors during this phase of the project: Carrie Schloss (The Nature Conservancy), Tom Robinson (Together Bay Area), Adam Garcia (APG Consulting), Cristina Bejarano and Beth Houser (WRT), Terilyn Chan (Asian Pacific Environmental Network), Sneha Ayyagari and Nicole Wong (Greenlining), Lisa Michelli (Pepperwood), Dana Brechwald and Todd Hallenbreck (BCDC), and Michael Germeraad (MTC/ABAG). These advisors provided invaluable input on data and methodology during one-on-one consultations or larger meetings, but ultimately, Greenbelt Alliance made all final decisions.

For more detail on the Bay Area Resilience Hotspots Project, see the project website at greenbelt.org/hotspots.

Memo Purpose

This memorandum is intended to detail the data and methodology used to produce Hotspots maps. This memo does not include information on Greenbelt Alliance's Wildfire-Specific Social Vulnerability Index, which was produced as part of this project. Further detail on this data layer will be released Summer 2023.

This memo is organized by Hotspot maps and their themes and thus includes data and methodologies for flooding and sea level rise Hotspots, wildfire hotspots, and extreme heat Hotspots.

Data, Logic, and Methodology

Approach

The goal of this spatial analysis phase of the Resilience Hotspots Project is to use data to inform local outreach and engagement. In particular, Greenbelt Alliance is focused on working in places that have potential for nature-based infrastructure and land management strategies that build resilience and serve climate-vulnerable communities. These values greatly influenced how the methodology was developed and the data that was included. The graphic below shows the multi-phase approach for the Resilience Hotspots Project, starting with data analysis. In particular it should be noted that this data analysis and data-informed process was only one aspect of the Resilience Hotspots Project, which aims to balance data with community partnership, stories of lived experiences, and locally appropriate context and action.

Unit of Analysis

In choosing a unit of analysis, we considered (1) the scale that would be most appropriate for the actions and projects we want to inform, (2) the benefits of working within natural boundaries versus jurisdictional boundaries, and (3) data granularity and availability. In light of these considerations, we decided to use a standardized unit of analysis by creating tessellations. To do this we used the Generate Tessellation geoprocessing tool in Esri's ArcGIS Pro (a desktop GIS mapping software) to create equal-sized hexagons to cover the nine-county Bay Area. We chose to make each hexagon 1.79 square miles because that is an appropriate scale for understanding neighborhood-level data necessary for this analysis. All data was summarized into these standardized hexagons by using either average or sum, depending on the data.

How We Combined the Data

In order to combine multiple risk factors for each of our **three Hotspots Maps** and determine where there are the highest vulnerability levels, we created indexes that quantified the vulnerability level of each tessellation unit to a particular risk. We then merged these indices together using ArcGIS Pro to create sets that showed the prevalence of multiple risk factors in an area. This allowed us to produce Hotspots maps through a stepwise process that allowed for adjustment at each level of data combination. The result is a tessellated map for each Hotspot type that is ranked to reveal the highest priority locations for further data analysis and research. The following sections further detail the data included in each Hotspot Map (**Flooding and Sea Level Rise, Wildfire, and Extreme Heat**) and the methodology for combining the data, which differs amongst the three maps.

Flooding and Sea Level Rise

When seeking to identify flooding Hotspots, Greenbelt Alliance took care to produce a map output that identified the highest risk areas for flooding that overlapped or were adjacent to climate-vulnerable communities and provided opportunities for nature-based solutions due to their proximity to high-value unprotected natural lands. As seen in the logic diagram below, data was combined to separately understand the "Land Vulnerability" and "Community Vulnerability." In understanding these two aspects independently, the team was then able to combine the data in multiple ways to understand how the two compiled layers were interacting and where there may be areas of opportunity for nature-based resilience and where there were intersections between vulnerable communities and vulnerable lands.

Data Considerations and Data Used in Analysis

Data was selected based on regional availability, trusted data sources, and granularity. The intention of this project is not to create yet another data source or mapping tool, but instead, to combine existing data resources in a way that is meaningful and action-oriented. BCDC's Adapting to Rising Tides project is an invaluable resource for our region because it provides inundation and flood layers that account for the unique hydrology of the Bay. Additionally, we are using NOAA and FEMA data to fill in the gaps for inland and coastal (outside San Francisco Bay) flood and sea level rise risks.

A key piece of data missing from this analysis is shallow groundwater. This is a fundamental part of understanding high priority locations for flood resilience, but due to the timeline of data production and the lack of coverage for the nine-county Bay Area, we were unable to incorporate the data in this analysis. However, to account for the unique vulnerability posed by the overlap of sea level rise and flooding with unstable lands, a risk that is further exacerbated by shallow groundwater conditions, we added liquefaction data to this analysis.

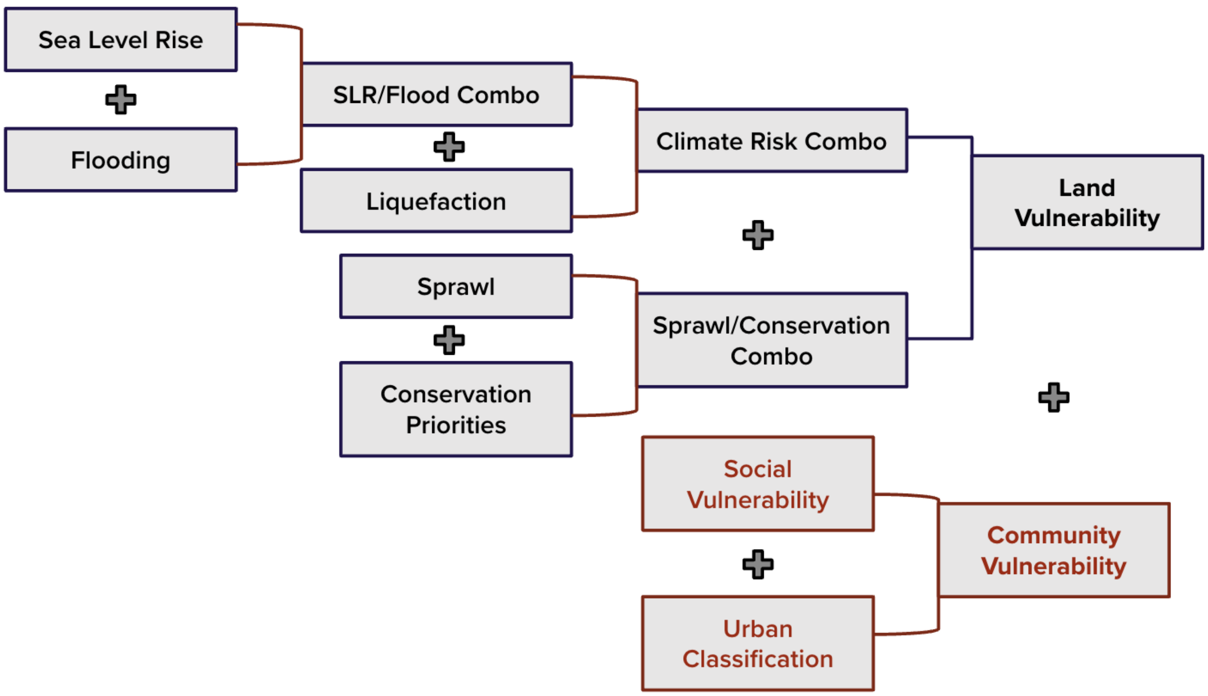
BCDC's Community Vulnerability layer was selected after careful consideration of the available data on social vulnerability for the region. We considered MTC's Equity Priority Communities, California's Low-Income and Disadvantaged Communities, and the CDC's Social Vulnerability Index data. Ultimately we chose to use BCDC's layer because of its regional specificity and focus on climate vulnerabilities.

Finally, we incorporated the Conservation Lands Network (CLN)'s essential and important lands data, which is a Bay Area-specific data set that identifies priorities for conservation through an extensive data analysis and partner feedback process. We combined this with Greenbelt Alliance's 2017 At Risk dataset which identifies lands at risk of sprawl development. Together, these datasets provide a solid foundation for assessing where there are gaps in protection and critical habitat and conservation needs. The following table details the data layers used in the analysis.

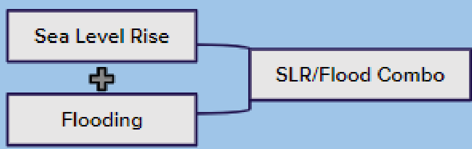
Category	Data Layer	Source	Year
SF Bay Sea Level Rise	Adapting to Rise Tides	BCDC	2017
Coastal Sea Level Rise	SLR Inundation 2 - 9 Feet	NOAA	2017
Flooding	Flood Risk	FEMA	2017
Liquefaction	Liquefaction Susceptibility (high and very high)	USGS, AGOL	2006
Social Vulnerability	ART Community Vulnerability	BCDC	2020
Sprawl	At Risk	Greenbelt Alliance	2017
Conservation	Essential and Important Lands	Conservation Lands Network 2.0	2019

Flooding Hotspots Data Logic

This data was combined using the following logic, further detailed in the descriptions and indices below.



Combining the Data



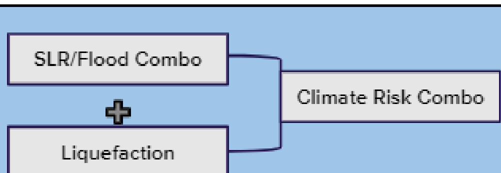
Description

BCDC's ART inundation data provides polygons of inundated areas at various water levels. We combined all water level scenarios and used those predicted water levels to rank the severity of sea level rise impacts. Polygons showing inundation with 0 – 24 inches of sea level rise were given the highest rank, while polygons showing inundation with over 108 inches of sea level rise were given a lower ranking.

In using FEMA flood data, we used FEMA's existing classifications, "outside flood zone," "500-year flood," "100-year flood," and "floodway" to classify the severity of flood impacts. Index A shows how these two data sets were combined to result in a layer with the highest impact areas as a result of both sea level rise and flooding.

Index

Flooding	Sea Level Rise				
	Above 108"	**72" – 108"**	**48" – 72"**	**24 " – 48"**	**0 – 24"**
Outside Flood Zone	1	2	3	4	5
500-year Flood Zone	2	2	3	4	5
100-year Flood Zone	3	3	4	4	5
Floodway	5	5	5	5	5

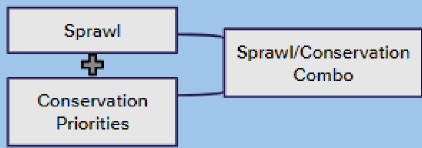


Description

The resulting ranked polygons from the combination of BCDC data and FEMA data were then combined with liquefaction data from USGS. We used the USGS classifications of liquefaction risk, ranging from "very low" to "very high," to classify risk.

Index

Liquefaction	SLR/ Flood Combo				
	Rank 1	Rank 2	Rank 3	Rank 4	Rank 5
Very Low	1	2	3	4	5
Low	1	2	3	4	5
Moderate	2	2	3	4	5
High	4	4	4	4	5
Very High	5	5	5	5	5



Description	Index

Greenbelt's At Risk 2017 data categorizes all parcels of the Bay Area by high, medium, and low risk of sprawl based on growth policies in place, existing zoning, and other factors. We combined this data with the Conservation Lands Network's "essential" and "important" lands that are high priority places for conservation and linkages.

We assigned lands that were either permanently protected or urban/developed in nature a ranking of zero as a way to prioritize unprotected important lands in this analysis. We acknowledge that more action and resources are needed beyond permanent protection, but understanding management type was beyond the scope of this work.

Conservation Lands Network

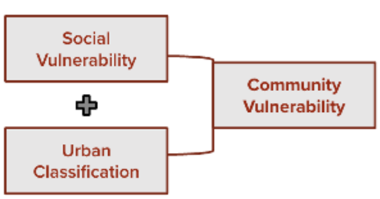
At Risk 2017	No Data	Essential	Important
Permanent Protection	0	0	0
Urban/ No Data	0	0	0
Low Risk	0	1	1
Medium Risk	2	2	2
High Risk	3	4	4

Description	Index

After combining these data sources together to create ranked polygons, we then combined the sprawl/ conservation priorities layer with the sea level rise/ flood/liquefaction layer. The outcome is the final score for community vulnerability.

Climate Risk Combo

Sprawl/Conservation Combo	Rank 1	Rank 2	Rank 3
Rank 1	1	2	4
Rank 2	2	4	5
Rank 3	2	5	5



Description	Index

We used BCDC's Social Vulnerability Index, which uses a variety of indicators to map areas of highest social vulnerability for Bay Area census tracts. To be in the "Highest" Risk category for BCDC's SVI, a census tract had to have either 8 or more indicators with rates in the 70th percentile relative to the 9-county Bay Area or have 6 or more indicators in the 90th percentile. To be in the "High" category, tracts that don't meet criteria for "Highest" had to have either 6 – 7 indicators in the 70th percentile or 4-5 indicators in the 90th percentile. In order to prioritize urban areas, we combined BCDC data with urbanization data from CLN. This lets us know which urban areas have the highest areas of social vulnerability.

		Social Vulnerability Index (BCDC)			
		Outside Area	Moderate Risk	High Risk	Highest Risk
Urban Areas (CLN)	Outside Urban Area	1	3	4	5
	Urban/ Developed Area	2	3	4	5

Putting It All Together

To combine the Land and Community sides (as shown in the logic diagram above), we used both an index and a gradient to create (1) ranked areas where there were high overlapping vulnerabilities and (2) a gradient showing where there are areas of high social vulnerability that are adjacent to areas needing climate resilience investments. This approach lets us see a more nuanced understanding of the landscape of risk and resilience opportunities.

Index

		LAND			
		Rank 1	Rank 2	Rank 4	Rank 5
COMMUNITY	Rank 1	1	1	2	3
	Rank 2	1	2	3	3
	Rank 3	2	3	4	4
	Rank 4	2	3	5	5
	Rank 5	2	3	5	5

Gradient

		LAND			
		Rank 1	Rank 2	Rank 4	Rank 5
COMMUNITY	Rank 1	1	3	6	9
	Rank 2	2	5	8	11
	Rank 3	4	7	10	12

Wildfire

When seeking to identify wildfire Hotspots, Greenbelt Alliance took care to produce a map output that identified the highest risk areas for wildfire that overlapped or were adjacent to climate-vulnerable communities and had opportunities for nature-based solutions due to their proximity to high-value unprotected natural lands. As seen in the logic diagram below, data was combined to understand the "Land Vulnerability" and "Community Vulnerability." In understanding these two aspects separately, the analysis team was then able to combine the data in multiple ways to understand how the two compiled layers were interacting and where there may be areas of opportunity for nature-based resilience and where there were intersections between vulnerable communities and vulnerable lands.

Data Considerations and Selected Data

Data was selected based on regional availability, trusted data sources, and granularity. The intention of this project is not to create yet another data source or mapping tool, but instead, to combine existing data resources in a way that is meaningful and action-oriented.

In selecting wildfire risk data, we considered multiple datasets including CalFire's fire hazard severity zones, historic fire perimeters, WUI data from the Forest Service, fire probability from Michael Mann, and ladder fuel density data from the Forest Observatory. Ultimately we chose to use Michael Mann wildfire data because it included risks as a result of human factors and development context as well as vegetation and topography. Landslide data was also included in the analysis due to the exacerbated risk that wildfire poses to landslide risk.

When assessing the risk to community, we sought to understand social and economic factors that make it challenging for a community to both respond and recover from a wildfire event as well as the number of homes impacted by wildfire risk. To do this we combined housing unit density data with development of a wildfire-specific social vulnerability index.

Greenbelt Alliance created a wildfire-specific Social Vulnerability Index after assessing available options and determining that other available datasets did not adequately account for the unique risks posed by wildfire and/or were not specific to the Bay Area region. We considered MTC's Equity Priority Communities, California's Low-Income and Disadvantaged Communities, BCDC's Community Vulnerability Layer, and the CDC's Social Vulnerability Index data. More detail on the development of Greenbelt's SVI layer will be released in Summer 2023, via greenbelt.org/hotspots.

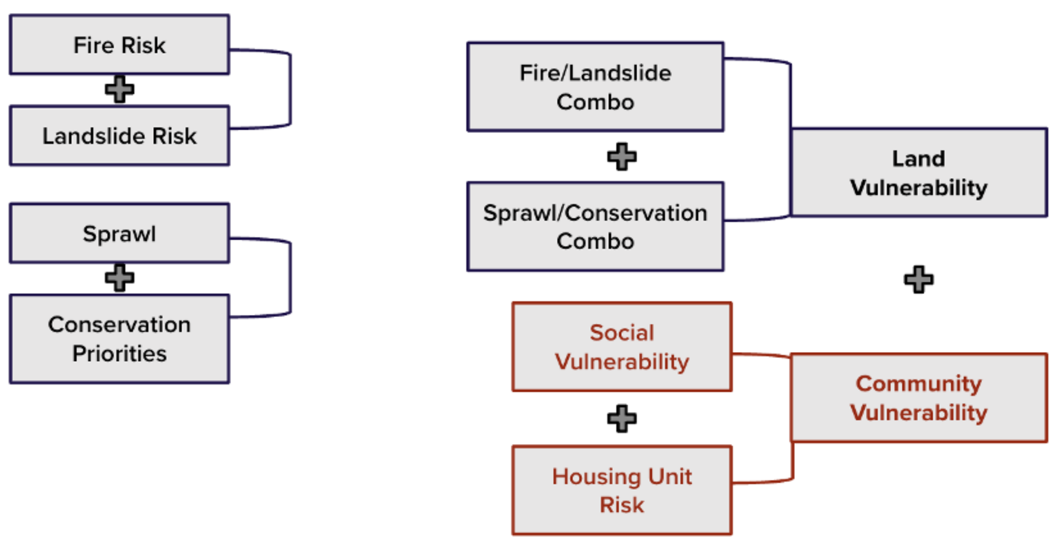
Finally, we incorporated the Conservation Lands Network (CLN)'s Essential and Important Lands Data, which is a Bay Area-specific data set that identifies priorities for conservation through an extensive data analysis and partner feedback process. We combined this with Greenbelt Alliance's 2017 At Risk dataset which identifies lands at risk of sprawl development. Together, these datasets provide a solid foundation for assessing where there are gaps in protection and critical habitat and conservation needs.

The following table details the data layers used in the wildfire hotspots analysis.

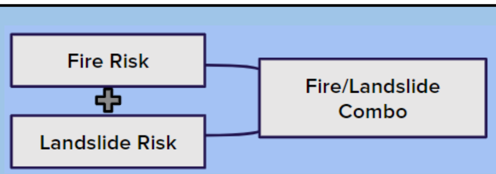
Category	Data Layer	Source	Year
Wildfire Risk	Michael Mann Fire Probability	Mann et al.	2016
Landslide	Landslide Susceptibility based on Rock Strength and Slope Steepness	California Geological Survey	2011
Social Vulnerability	Wildfire-Specific Social Vulnerability Index	Greenbelt Alliance	2023
Liquefaction	Liquefaction Susceptibility (high and very high)	USGS, AGOL	2006
Housing Unit Density	Housing Unit Density (HUDen)	US Forest Service	2021
Sprawl	At Risk	Greenbelt Alliance	2017
Conservation	Essential and Important Lands	Conservation Lands Network 2.0	2019

Wildfire Hotspots Data Logic

This data was combined using the following logic, further detailed in the descriptions and indices below.



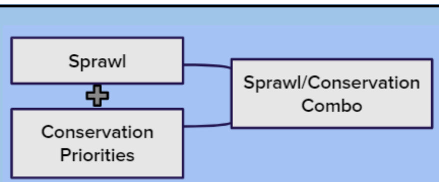
Combining the Data



Description	Index

Landslide Risk Rank directly from USGS classification and Wildfire Probability levels from Michael Mann. Ranking was influenced by expert input on the impact of land stability in adding to wildfire risk.

Wildfire Probability	Landslide Risk 0 – 6	7	8	9	10
0 – 10%	1	2	2	2	2
11 – 20	3	3	3	4	4
21 – 30%	4	4	4	4	5
31 – 40%	5	4	5	5	5
41 – 50%	5	5	5	6	5

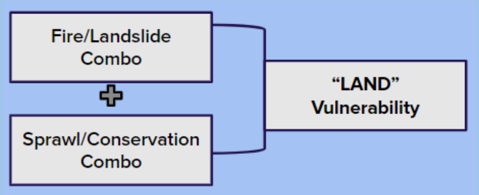


Description	Index

Greenbelt's At Risk 2017 data categorizes all parcels of the Bay Area by high, medium, and low risk of sprawl based on growth policies in place, existing zoning, and other factors. We combined this data with the Conservation Lands Network's "essential" and "important" lands that are high priority places for conservation and linkages.

We assigned lands that were either permanently protected or urban/developed in nature a ranking of zero as a way to prioritize unprotected important lands in this analysis. We acknowledge that more action and resources are needed beyond permanent protection, but understanding management type was beyond the scope of this work.

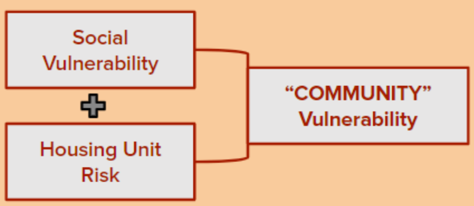
At Risk 2017	Conservation Lands Network: No Data	Essential	Important
Permanent Protection	0	0	0
Urban/ No Data	0	0	0
Low Risk	0	1	1
Medium Risk	2	2	2
High Risk	3	4	4



Description	Index
The two combination layers were then combined to result in the rankings of Land vulnerability.	See Fire/ Landslide Combo table below

Fire/ Landslide Combo

Sprawl/ Conservation Combo	Rank 1	Rank 2	Rank 3	Rank 4	Rank 5
Rank 1	1	1	2	3	4
Rank 2	1	2	3	4	5
Rank 3	2	3	4	5	5



Description	Index
Social vulnerability data was averaged within the hexagon and the rank was determined by binning outcomes. Housing Unit Risk data was a raster dataset that was summarized into tessellated geometry the mean for each hexagon. Then the means were ranked as follows: 1 = (under 1,000), 2 = (1,000-10,000), 3 = (over 10,000).	See Social Vulnerability table below

Social Vulnerability

Housing Unit Risk	Rank 1	Rank 2	Rank 3	Rank 4	Rank 5
Rank 1	1	1	2	2	2
Rank 2	1	2	3	4	5
Rank 3	2	3	4	5	5

Putting it all together

To combine the Land and Community sides (as shown in the logic diagram above), we used both an index and a gradient to create (1) ranked areas where there were high overlapping vulnerabilities, and (2) a gradient showing where there are areas of high social vulnerability that are adjacent to areas needing climate resilience investments. This approach lets us see a more nuanced understanding of the landscape of risk and resilience opportunities.

Index	Gradient

Index

		LAND					
		Rank 1	Rank 2	Rank 3	Rank 4	Rank 5	Rank 6
COMMUNITY	Rank 1	1	1	1	1	1	1
	Rank 2	1	1	1	2	2	3
	Rank 3	1	1	2	3	4	5
	Rank 4	1	1	3	4	5	5
	Rank 5	1	1	3	4	5	5

Gradient

		COMMUNITY			
		Rank 1/2	Rank 3	Rank 4	Rank 5/6
LAND	Rank 1	1	3	6	10
	Rank 2	2	5	9	13
	Rank 3	4	8	12	15
	Rank 4/5	7	11	14	16

Extreme Heat

When seeking to identify Extreme Heat Hotspots, Greenbelt Alliance took care to produce a map output that identified the highest risk areas for extreme heat, based on social factors, built environment factors, and heat models. Unlike the other Hotspots Maps, we sought to focus on the heat risk present in urban environments where heat is most deadly. To do so, we built out rankings for heat, social factors, and built environment factors, then combined those ranked scores together to create the final map. The following table details the data layers used in the extreme heat hotspots analysis.

Category	Data Layer	Source	Year
Urban Heat Island Effect	Urban Heat Island Effect	UC Berkeley, Bay Area Greenprint	2019
Extreme Heat Days	Average Number of Extreme Heat Days (2099) (CanESM2, MICROC5, HadGEM2-ES, CNRM-CM5) with RCP 85	Cal Adapt	2015-2018 (depending on model)
Housing Unit Age	Housing Unit Age, Table B25034	American Community Survey, 5-year survey	2021
Social Vulnerability	ART Community Vulnerability	BCDC	2020
Impervious Surfaces	Percent Impervious Surfaces	Climate Change & Health Vulnerability Indicators for California (CCHVIs)	2016
Tree Canopy	Land Cover	CDPH/National Land Cover Database	2011

How we Selected this Data

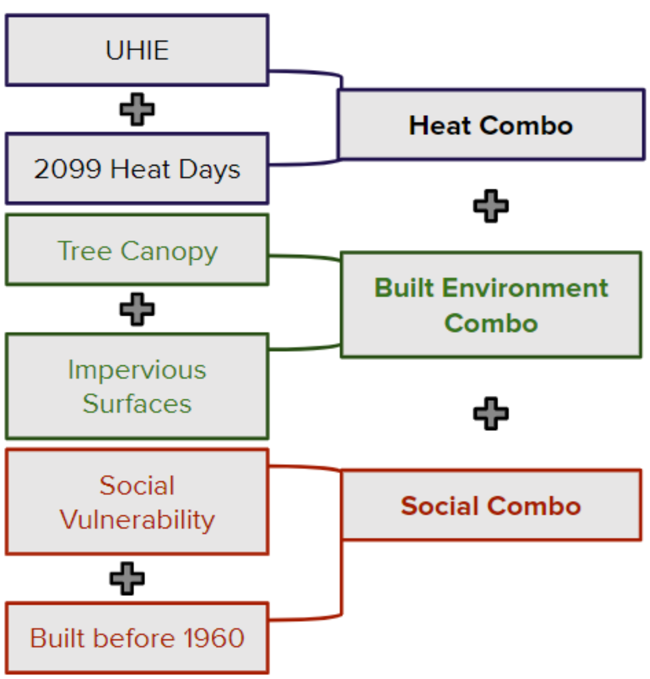
Data was selected based on regional availability, trusted data sources, and granularity. The intention of this project is not to create yet another data source or mapping tool, but instead, to combine existing data resources in a way that is meaningful and action-oriented.

In order to account for extreme heat risk, we used Cal Adapt's four models (CanESM2, MICROC5, HadGEM2-ES, and CNRM-CM5) using the scenario for RCP 85 in combination with data on Urban Heat Island Effect as a way to account for broadscale landscape-scale changes in temperature as well as the factors that exacerbate heat due to the urban environment. To account for factors of the built environment, we used data reflection share of impervious surfaces and tree canopy.

In acknowledging that indoor air temperature is a major factor in heat risk and mortality, we wanted to capture access to air conditioning and indoor air quality conditions. Due to inadequate data on air conditioning, we used housing unit age as a proxy since most housing units built before 1960 lack air conditioning.

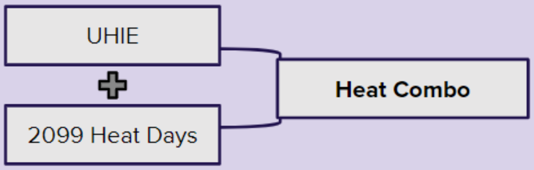
BCDC's Community Vulnerability layer was selected after careful consideration of the available data on social vulnerability for the region. We considered MTC's Equity Priority Communities, California's Low-Income and Disadvantaged Communities, and the CDC's Social Vulnerability Index data. Ultimately we chose to use BCDC's layer because of its regional specificity and focus on climate vulnerabilities.

Extreme Heat Hotspots Data Logic



This data was combined using the following logic, further detailed in the descriptions and indices below.

Combining the Data

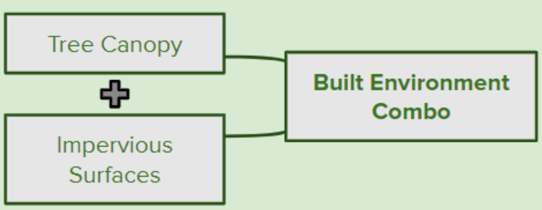


Description	Index

Data on the number of extreme heat days came from Cal Adapt's four models. Models were combined in accordance with CalAdapt guidance[1], then output average number of extreme heat days (census tract level) were overlaid with tessellations, then averaged within the tessellation. All the tessellations were then ranked 1 – 5 based on the distribution of the means (as seen in table right). Data from the Urban Heat Island data layer was overlaid with the tesselation then averaged within the tessellation. All the tessellations were then ranked 1 – 5 based on the mean. Since data was already ranked 1 – 5, we converted to whole numbers through binning (i.e. if <1 then rank = 1, if under 2 then rank = 2, etc). We then combined the UHIE and 2099 Heat Days data together as seen in the Index.

Mean Avg 2099 Heat Days	Rank
Under 3	1
Over 3, Under 10	2
Over 10, Under 17	3
Over 17	4

		Average # Heat Days (2099)				
Urban Heat Island Effect Rank		Rank 1	Rank 2	Rank 3	Rank 4	Rank 5
	Rank 1	1	1	2	3	4
	Rank 2	1	2	2	3	4
	Rank 3	2	2	3	4	5
	Rank 4	3	3	4	5	5
	Rank 5	4	4	5	5	5

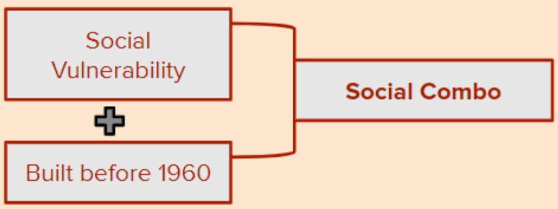


Description	Index

[1] https://www.energy.ca.gov/sites/default/files/2019-11/Projections_CCCA4-CEC-2018-015_ADA.pdf

Tree cover data was binned so that the highest tree cover areas were given the lowest rank and vice versa. The data was binned based on the mean when overlaid with the tessellation as follows: Rank 1 = over 0.35, Rank 2 = 0.15-0.35, Rank 3 = under 0.15. Impervious surface data was overlaid with tessellation and summarized (mean), then ranked 1 – 3 based on distribution: Rank 1 = 0-16, Rank 2 = 16 – 40. Rank 3 = over 40.

Impervious Surfaces \ Tree Canopy	Rank 1	Rank 2	Rank 3
Rank 1	1	1	2
Rank 2	1	2	3
Rank 3	2	3	4



Description

Housing unit age was ranked 1 – 4 based on the average age after being summarized into hexagons. Social vulnerability was averaged while being summarized into hexagons. The two data layers were then combined to result in the ranked score for "Social."

Index

Built Before 1960 \ Social Vulnerability	Rank 1	Rank 2	Rank 3	Rank 4	Rank 5
Rank 1	1	1	2	3	4
Rank 2	1	2	3	4	4
Rank 3	2	2	3	4	5
Rank 4	2	3	4	5	5

Putting It All Together

To combine these three final components, Social, Built Environment, and Heat, we added the final scores together with slight weighting for social and heat factors. We used the following equation:

Heat Combo Score *(1.25)* + Built Environment Score + Social Combo Score *(1.25)* = Final HEAT Score