Technical Documentation

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Climate Hazards Data Integration and Visualization for the Climate Adaptation Solutions Accelerator (CASA) through School-Community Hubs

A Capstone Project submitted in partial satisfaction of the requirements for the degree of
Master of Environmental Data Science
for the
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by

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Technical Documentation Signature Page

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The Capstone Project is required of all students in the Master of Environmental Data Science (MEDS) Program. The project is a six-month-long activity in which small groups of students contribute to data science practices, products, or analyses that address a challenge or need related to a specific environmental issue.

The authors of this Capstone Project will archive this technical documentation on the Bren School's website such that the results of our research are available for all to read. Our signatures on the document signify our joint responsibility to fulfill the archiving standards set by the Bren School of Environmental Science & Management.

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1.0 Abstract

The Climate Hazards Dashboard for California Schools is a platform that maps the current and future risks associated with five climate hazards, including wildfire, extreme heat, extreme precipitation, flooding, and sea level rise for over 10,000 public schools serving Kindergarten through Grade 12 students in California. Each hazard is mapped and visualized at the school-community level, providing an accessible way for students, teachers, school administrators, and neighborhoods to explore data about the climate hazards they face at a scale relevant to their communities. The dashboard also provides an aggregate summary hazard metric for each school and general information about climate adaptation measures for schools and communities. The dashboard contributes to a National Science Foundation research project on accelerating climate adaptation solutions through school-community hubs. The larger research project identifies public schools as promising sites for overcoming barriers to community engagement and climate adaptation planning in historically underserved neighborhoods. By providing schools with information about the intersecting climate hazards faced by the communities they serve, the Climate Hazards Dashboard for California Schools lays the groundwork for working with schools to build community capacity to adapt to climate change.

2.0 Executive Summary

Climate adaptation protects people and places by making them more resilient to the impacts of climate change. Effective climate adaptation must be rapid, broad-based, and centered on the needs of vulnerable and historically underserved communities. However, at-risk communities face socio-structural barriers to adaptation and report experiences of limited self-efficacy, resulting in communities that can be wary, uninterested, or unaware of adaptation support (Abdel-Monem et al. 2010; Whitmarsh et al. 2013; Wibeck 2014; Meerow et al. 2019; Areia et al. 2022; IPCC 2022). Research on community engagement shows that building trust in communities between policymakers and community stakeholders can take years (Few et al. 2007; Klenk et al. 2017).

The dual nature of schools—as places for youth to learn and as places where communities convene—means that they offer unique opportunities for capacity building and community engagement, especially in communities that can traditionally be hard to reach. The over 10,000 public schools serving Kindergarten through Grade 12 (K-12) students in California are promising sites for building community engagement and capacity for climate adaptation. School-community hubs, i.e., programs that intentionally link schools and communities through integrated support services and community engagement (Teo et al. 2022), are a novel organizational form that can be leveraged to support the rapid and broad-based dissemination of innovative climate adaptation solutions.

As a first step to supporting school-community hubs for climate adaptation, administrators, teachers, and students need access to information about the intersecting threats posed by climate change to schools themselves and the communities they serve. Data about climate hazards, including wildfire, extreme heat, flooding, and sea level rise, are available, but they exist in multiple formats across a range of platforms. They are often overly complex and do not provide an integrated overview of the climate hazards faced by a particular school or the neighborhood it serves.

This project **created an interactive dashboard that allows schools throughout California to easily access climate hazard data relevant to their communities.** The project generated one final and two intermediate deliverables:

Final Deliverable:

1. An interactive dashboard summarizing five climate hazards, including extreme heat, wildfire, extreme precipitation, flooding, and sea level rise at the school-community level. The dashboard provides locally specific historical data and future projections for each hazard. In addition, the dashboard provides a hazard summary score for each school. A user guide and information on adaptation measures are also provided.

Intermediate Deliverables:

1. A catalog of the technical specifications of relevant California climate hazard data, all California school locations, and a school district boundary layer.
2. Development of an aggregate climate hazard risk metric and visual representation.

The interactive dashboard provides an accessible way for schools to explore climate hazard data reflecting the intersecting hazards faced by the communities they serve. Results of the project contribute to the National Science Foundation (NSF) research project on Climate Adaptation Solutions Accelerator (CASA) through School-Community Hubs, under the Centers for Research and Innovation in Science, the Environment and Society (CRISES) program.

3.0 Problem Statement

To build toward more inclusive, equitable, and just policies for climate adaptation (Fedele et al. 2019), the historically underserved communities that are also the most vulnerable to climate change must be at the center of planning efforts (Pelling and Garschagen 2019; Owen 2020; Shi and Moser 2021). However, the barriers to inclusive, equitable, and just adaptation are numerous and planners struggle with meaningful community engagement. The more traditional forms of public engagement, such as public noticing and hearings (Freij 2022) and community or technical advisory boards and workshops (Nabatchi and Amsler 2014), often do not generate productive collaboration (Gonzales 2020; Migchelbrink and Van de Walle 2022). There are also barriers specific to the engagement of marginalized and historically underserved communities in planning processes. Their participation may be limited by socio-structural factors, information deficits, and lack of agency (Whitmarsh et al. 2013; Wibeck 2014; Meerow et al. 2019).

Schools can play a pivotal role in overcoming barriers to inclusive, equitable, and just climate adaptation. Schools are uniquely positioned to address barriers to community engagement in climate adaptation planning. First, schools are already on the front lines of climate adaptation. Second, schools offer obvious curricular opportunities for climate change education. Third, schools already function as community hubs, where diverse populations in a neighborhood gather for performances, sports events, and graduations, and already feel like they belong (Teo et al. 2022).

However, to serve as community hubs for climate adaptation planning and activities, schools need information about the intersecting hazards that climate change poses to the communities they serve. Effective climate education and adaptation must be grounded in an understanding of local climate hazards (Monroe 2019). While data about climate hazards are available, they are not presented in a way that serves students and schools. Climate hazard data exist in multiple formats across a range of platforms. The platforms are not designed for a student or school audience, nor do they provide an integrated overview of the climate hazards faced by a particular school or the neighborhood it serves. For example, the National Oceanic and Atmospheric Administration's Climate Mapping for Resilience and Adaptation tool provides great information but is too complex to use with younger students. Cal-Adapt's dashboard, which shows useful wildfire information and other data on pressing climate hazards, is presented on a state-wide scale that is too broad for localized climate lesson plans. California Healthy Places Index features an easy-to-read scoring system but focuses on a single climate hazard.

4.0 Products and Deliverables

The primary deliverable of this project is an interactive dashboard to visualize past, present, and future climate data on five climate hazards at the school-community level for students, teachers, school administrators, and community members to know their climate risks. This dashboard is the first of its kind where climate hazard information is presented at the school-community level.

The interactive dashboard opens to a welcome page with information about the climate hazards that can be viewed, brief instructions on how to get started, drop-down menus to select the school to be explored, a map preview of the selected school, a hazard summary, school closures due to climate hazards, and student demographic data.

The left menu includes the following tabs: *Welcome* page (described above), *Hazards Summary*, *Explore Your Hazards*, *Information*, *Glossary*, *About*, and *User Guid*e. The *Hazards Summary* page provides the aggregated climate hazard summary along with more description. The E*xplore Your Hazards* tab includes five subtabs, one for each of the climate hazards explored, with data specific to the school selected on the *Welcome* page. The *Information* tab provides more detailed information on the dashboard, including background and answers to frequently asked questions. The *Glossary* is a convenient location with technical terms defined. The *About* provides background information on the dashboard creation and the capstone team who created it. Finally, the *User Guide* includes a video demonstrating how to use the dashboard along with a text walkthrough. Further information on dashboard design details can be found in Section 6.7, Dashboard Design.

The intermediate deliverables of this project are a catalog of the California climate hazards data, all California public school locations, the California school district boundary layers, and student and school demographic data in a CSV file format. The interval values for each climate variable in the hazard summary score are also within this catalog. The aggregated climate hazard risk metric and visual representation are further described in Section 6.6, Hazard Summary Score

5.0 Specific Objectives

The project objective is to create an interactive dashboard that provides an accessible and easy-to-use overview of localized climate hazards faced by the communities served by California public schools. The dashboard includes past climate data and future climate projections for five climate hazards: wildfire, extreme heat, extreme precipitation, flooding, and sea level rise. Data are summarized at the school level and characterize the hazard experienced by the community within a three-mile radius of each school. The dashboard provides locally specific data for the over 10,000 public schools in California. In addition, the dashboard provides background information for each school and a climate hazard summary score. The goal of this interactive dashboard is to provide a resource for schools and the communities they serve to learn about the climate hazards they face and to build capacity for school and community engagement related to hazard preparedness.

6.0 Summary of Solution Design

This section describes the end-to-end workflow of preparing the original data for the five climate hazards: wildfire, extreme heat, extreme precipitation, flooding, and sea level rise. Data was used for two primary purposes: (1) plotting or mapping in the interactive dashboard and (2) calculating a hazard summary score for each school. See **Appendix A** for a compilation of the public datasets used throughout the project.

6.1 Climate Hazards

Datasets for each climate hazard were carefully selected to provide intuitive measures and simple visualizations for communities to explore the hazards they face. An important goal of this project is to communicate how risk evolves over time, as a key component of adaptation is being prepared for what may happen in the future. Data for extreme heat and extreme precipitation include present-day conditions, as well as future conditions projected out to 2064. Data for sea level rise compares 2000 sea levels with projected 2050 sea levels. Data for wildfire takes data from 2023 to describe present conditions and historical data from 2015 to show how conditions have changed over time. Data for flooding includes 2024 conditions only. Ideally, all of the datasets would show present conditions and future projections, but data availability, completeness, and ease of communication were constraining factors.

6.2 Extreme Heat and Extreme Precipitation

Description

Historic and projected daily maximum temperature and daily precipitation totals come from Cal-Adapt's Localized Constructed Analogues (LOCA) Derived Products dataset and are accessed through the Cal-Adapt R package. Historic data represents observed values from 1961-2005, while data is projected from 2006-2099. Projections are estimates derived from four general circulation models (GCMs), which model the planet's global climate system, and two representative concentration pathways (RCPs), which address possible future greenhouse gas emissions scenarios. The four GCMs are HadGEM2-ES, CNRM-CM5, CanESM2, MIROC5, and the two RCPs are RCP 4.5 (a middle of the road emissions scenario) and RCP 8.5 (a high emissions scenario). To use the data at a spatial scale meaningful to California, Cal-Adapt downscales the data using LOCA, a statistical process that produces values for daily maximum temperature and daily precipitation totals for 3.7-mile by 3.7-mile grid cells.

Cleaning, Wrangling, and Calculations

The dataset was used to determine how many extreme heat and extreme precipitation days per year each school would experience from 2006 to 2064 under RCP 4.5 and RCP 8.5. The first step in calculating the number of extreme heat and extreme precipitation days is to determine the baseline threshold, or what classifies an extreme event. Threshold values are determined using the historical data from 1961 to 1990. To retrieve historical data, the LOCA downscale grid cells were spatially joined to the school points using ca_locagrid_geom() from the Cal-Adapt R package. California's public schools fall into a total of 1,619 unique LOCA grid cells within California state boundaries. The centroids of the grid cells were used to create an API request. Historic daily maximum temperature and precipitation totals was requested from the Livneh dataset using ca_livneh(TRUE). Threshold values are the 98th percentile of historical data. The mean value of daily maximum temperature and precipitation totals was calculated across all 1,619 LOCA grid cells. For extreme heat, the threshold value is 98°F. For extreme precipitation, the threshold value is a one-day rainfall total of 0.73 inches.

A new API request was created to determine the number of extreme heat and precipitation days, i.e., days exceeding the above thresholds, across all schools from 2000 to 2064. Following the same approach as the threshold, school points were spatially joined with LOCA grid cells to identify the unique cells. Modeled data from 2006 to 2064 was accessed through ca_gcm(gems[1:4]), requesting the four GCM's of interest and the two scenarios of interest ca_scenario(c('rcp45')) and ca_scenario(c('rcp85')). Given the scale of the API request, the modeled data were obtained in 30-year intervals and for separate scenarios. The request returns four dataframes, daily maximum temperature for each grid cell under RCP 4.5 and 8.5 and daily precipitation totals for each grid cell under RCPs 4.5 and 8.5. Next, the data frames were manipulated to count the number of days for each grid cell that exceeded the thresholds for extreme heat and extreme precipitation. Any value above the threshold was assigned a 1, and any value below the threshold was assigned a 0. The sum of extreme days for each year for each grid cell was then found. These values were then joined with the school points based on the grid cell they are located in. Associated with each school is a count of extreme heat and extreme precipitation days under RCP 4.5 and 8.5.

Visualization

Extreme precipitation and extreme heat are displayed in the dashboard as bar graphs showing the total counts of extreme days in each year from 2006-2064. The graphs show yearly totals for RCP 4.5 and RCP 8.5 as side-by-side bars represented as different shades of the same color. The bars for RCP 4.5 are labeled as a "Reduced Greenhouse Gas Emissions Scenario" and the bars for RCP 8.5 are labeled as a "High Greenhouse Gas Emissions Scenario."

Limitations

The threshold values were calculated as absolute values based on the 98th percentile of historical data for the entire state, which doesn't account for regional differences in climate. If the thresholds were instead based on regional 98th percentile values, they would be different for each region. The underlying assumption here is that an extreme heat day and an extreme precipitation day are extreme, no matter where in the state they occur.

A limitation of GCMs is that there is no way to be certain of their accuracy, as they are approximations of future climate conditions. Actual emissions pathways may differ from the scenarios used to generate these projections. To obtain a more accurate approximation, all 32 GCM simulations should ideally be used to develop a comprehensive assessment. However, this is computationally cumbersome and would require more time and computational capacity than is currently available.

To streamline the computational process, an assumption of high spatial autocorrelation of temperature across LOCA grid cells was made. Under this assumption, neighboring grid cells were expected to exhibit similar temperature data. This reduced the number of locations requiring queries from the API from 10,008 to 1,619, significantly decreasing computation. Although this decreases computational extent, it can limit accuracy by not accounting for the potential that a school may be located near the corner of a cell, where the 3-mile buffer would cover 4 different LOCA grid cells that could potentially contain different daily temperature values.

6.3 Flooding

Description

Flood data come from maps created by the Federal Emergency Management Agency (FEMA). FEMA maps combine historical data, scientific analysis, and modeling to assess flood risks in different areas. They incorporate information about past flooding events, topography, hydrology, rainfall patterns, and other relevant factors to identify flood-prone areas and establish flood zones. These maps serve as a crucial tool for assessing and managing flood risk, guiding land use planning, setting insurance rates, and informing disaster response and mitigation efforts.

Specifically, the National Flood Hazard Layer (NFHL) dated April 01, 2024 was used. The NFHL is a geospatial database that represents the current effective flood data for the country, where the digital data covers over 90% of the U.S. population. It is a compilation of effective Flood Insurance Rate Map (FIRM) databases and Letters of Map Change (LOMCs) delivered to communities. The NFHL shows flood risks ranging from low to moderate to high, where all areas in the United States are considered to have some level of risk. Moderate- to Low-risk flood areas are designated with the letters B, C, and X on the NFHL. The risk of flooding in these areas is reduced, but not completely removed. One in three insurance claims comes from moderate- to low-risk flood areas. High-risk flood areas, or Special Flood Hazard Areas (SFHAs) begin with the letters A or V on FEMA flood maps. These areas face the highest risk of flooding. Property owners in a high-risk zone with a mortgage from federally regulated or insured lenders are required to purchase flood insurance as a condition of that loan (FEMA 2024).

FEMA maps focus on current and historical flood risks rather than projecting into the future. They combine historical records of flooding and other natural disasters and ongoing data collection efforts to monitor current conditions. FEMA is required to update flood maps every five years. However, the maps may include recent updates since the NFHL is updated as new studies or LOMC data becomes effective.

The flood data were downloaded using the Search All Products option at FEMA Flood Map Service Center | Search All Products. Using the Jurisdiction search option, a county and jurisdiction are chosen to display a list of product types available from FEMA. By selecting the NFHL Data option under the Effective Products folder and selecting any community within a state, the statewide NFHL dataset can be downloaded directly.

Cleaning, Wrangling, and Calculations

Cleaning and wrangling of the FEMA data is necessary to visualize flooding risk. In California, High-Risk zones include the following subcategories: A, AE, A99, AH, A0, VE, and V. These subcategories were consolidated to form the High-Risk zone in the wrangled data. Moderate to Low zones in California include the X category. Undetermined zoning categories include “Area Not Included,” “D”, and “Open Water,” which refer to areas where there are possible but undetermined, flood hazards or unstudied areas.

Calculations used to assign flood risk to each school buffer area involve intersecting the shapefile of the flood risk zones over the cropped area for the selected school. For each school, the percentage of intersected areas within the High-Risk category is calculated.

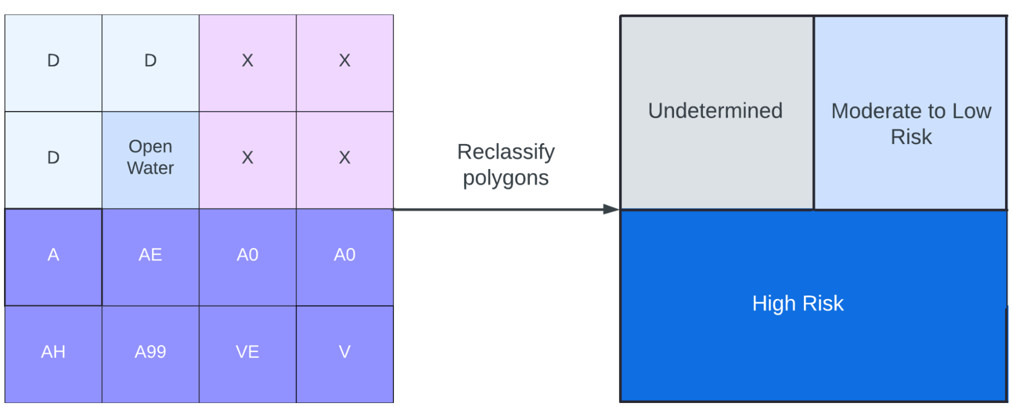

Figure 1: Conceptual diagram of the reclassification of the flooding risk layer (NFHL)

Visualization

Flooding is visualized using geospatial information. As described above, the FEMA flood hazard categories are aggregated into High-Risk, Moderate to Low, and Undetermined zoning categories. To visualize the data, the FEMA flood hazard zones were mapped on top of school buffer areas, with results showing the High Risk and Moderate to Low Risk flood hazard areas within each school buffer.

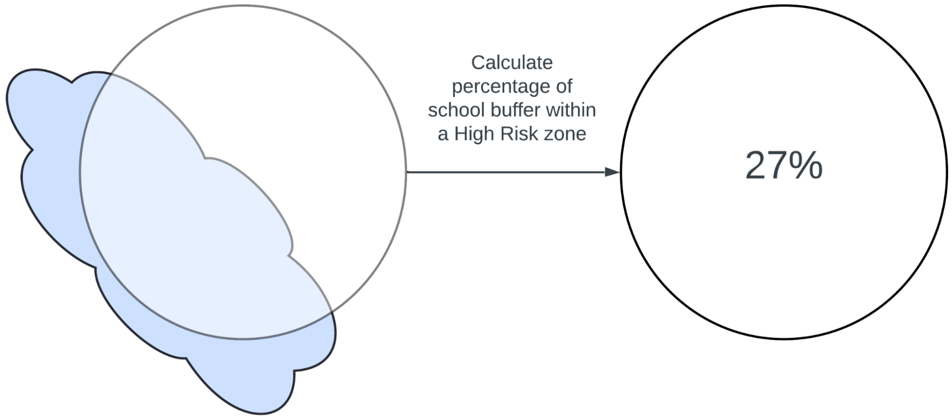

Figure 2: Conceptual diagram of the calculation of percentage of area of a school buffer within a High Risk flood zone

Limitations

Limitations to the project approach include gaps where flooding data was not collected by FEMA, which accounts for roughly 10% of the United States. These include areas excluded from flood mapping within a city or town where NFHL flood data has been published.

There are also limitations with respect to the risk determinations. While FEMA flood maps provide accurate information for communities related to flood risk, there are additional safety measures beyond base flood elevation assumptions that should be considered. The SFHA is defined as the land area covered by the floodwaters of a base flood, which is the computed elevation to which floodwater is anticipated to rise during the base (1-percent-annual-chance) flood event. Buildings that are higher than the base flood elevation experience less damage. The California Building Standards Code requires all buildings to be elevated to at least base flood elevation plus 1 foot. This additional height is used as a factor of safety usually expressed in feet above a flood level for purposes of floodplain management and is called “Freeboard." Freeboard tends to compensate for the many unknown factors that could contribute to flood heights greater than the height calculated for a selected size flood and floodway conditions, such as wave action, bridge openings, and the hydrological effect of urbanization of the watershed. Freeboard is not required by NFIP standards, but communities are encouraged to adopt at least a one-foot freeboard to account for the one-foot rise built into the concept of designating a floodway and the encroachment requirements where floodways have not been designated. Freeboard results in significantly lower flood insurance rates due to lower flood risk (FEMA 2022).

6.4 Wildfire

Description

The US Department of Agriculture’s Forest Service (USFS) developed the wildfire hazard potential dataset for the conterminous United States to inform wildland fire managers on the expected burn probability and intensity of wildfire for 270-meter cells. The dataset is landscape-scale, meaning the cells have values over the entire study area. To build the raster product, the USFS used inputs describing past fire occurrence locations from 1992-2020, vegetation and wildland fuels data from 2020, and fire intensity simulations generated from the large fire simulation system (FSim). The end result is an index of continuous values from 1-10,000, with higher values representing higher wildfire hazard potential. The continuous raster was then used to produce a classified raster with hazard potential classes from 1-7, representing, in ascending order, very low, low, moderate, high, very high, non-burnable lands, and water. Classes 1-5 were produced by assigning values based on percentile class breaks, with ⅔ of the land area falling into the very low and low categories, and the remaining ⅓ falling into the moderate, high, and very high categories. The justification for these breaks is that land managers have limited resources for wildfire prevention and suppression, so only the areas of greatest concern should fall into the high and very high categories. This analysis uses the classified raster for the conterminous United States developed by the USFS. The dataset used is the 4th version of Wildfire Hazard Potential, released in 2023. To provide a comparison of how risk and conditions have changed over time, the 1st version of the dataset, released in 2015, is also reclassified and mapped in the dashboard.

Cleaning, Wrangling, and Calculations

The goal for using these datasets is to assign each school buffer area a wildfire hazard potential score from 0-5, in 2015 and 2023. This analysis primarily uses the sf and terra R packages to conduct spatial operations. Wildfire hazard potential is mapped for the conterminous United States, but this analysis only requires the area covering California. The first step in the process is to reproject the raster to be on the same coordinate reference system as the California school points using terra::project(). Then, the raster is cropped to the boundaries of California. To prepare the boundary layer, the internal boundaries of the California School Districts data were dissolved using sf::st_union(), returning a polygon with only the boundary of California. Using terra::crop() with the argument mask = TRUE crops the raster to the exact boundary, rather than just the square bounding box of the California boundary.

The process for assigning wildfire hazard potentials to school buffer areas involves taking the mean value of all cells that overlap with each school buffer area. With the data cropped, the next step in the analysis is to reclassify the raster. To perform calculations on the raster, all cells with values of 6 or 7, representing non-burnable lands and water, respectively, are converted to a value of 0. The reclassified raster now only has values from 0-5. The raster is then cropped to the school buffer areas to perform the calculation more quickly.

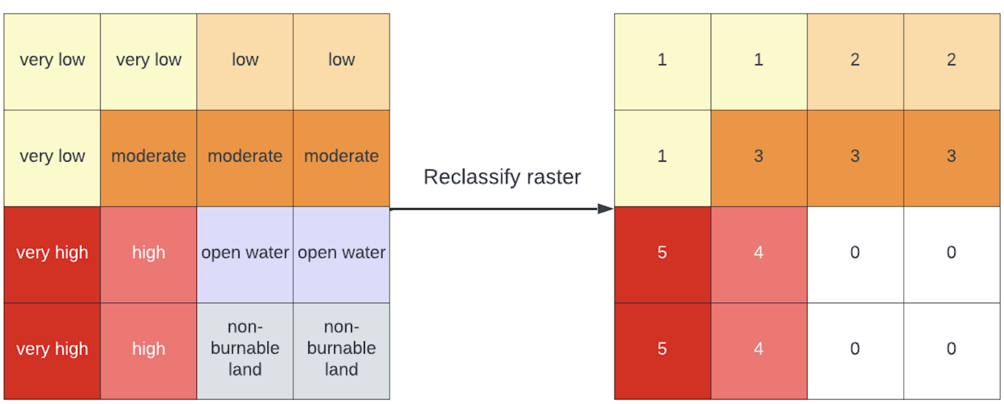

Figure 3: Conceptual diagram of the reclassification of the wildfire hazard potential raster

Using terra::extract() with the raster and the school buffers and specifying the argument fun = "mean", the mean wildfire hazard potential score is calculated for each buffer. The function selects any cell that overlaps with each school buffer, not just those fully contained within buffers. It then calculates the mean of overlapping cells, outputting a layer of polygons identical to the school buffers with an included column of the means. Buffers with a mean of 0 retain their value. All values greater than 0 but less than 1 are rounded up to 1. All other values are then rounded to the nearest whole number. The final means take a value of either 0, 1, 2, 3, 4, or 5, representing the wildfire hazard potential categories of no risk, very low, low, moderate, high, and very high.

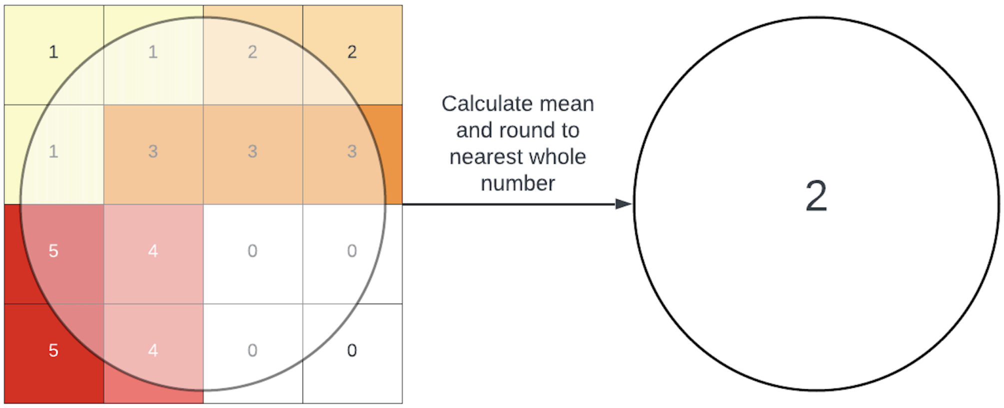

Figure 4: Conceptual diagram of the mean wildfire hazard potential score calculated for a school buffer

Visualization

Similar to flooding, wildfire is a spatially-explicit phenomenon. Simply because a school buffer is categorized as high wildfire hazard potential doesn't mean that the entire area is prone to burning. Certain cells factored into that calculation may have originally been non-burnable lands or very low risk. What's more meaningful is the risk of specific locations within each school buffer. As such, the reclassified wildfire hazard potential pixel data is overlaid with school buffers in a map on the dashboard, showing communities the areas of highest concern.

Limitations

Whenever the raster is cropped using masking, the raster is resampled, resulting in fractional values. To reclassify the values in the raster, the cropped raster cells must first be rounded to the nearest whole numbers. Of the total 12,905,914 cells in the California cropped raster, 9,273 cells were rounded either up or down to a value different from their original. This means that our estimate of the mean for each school buffer area will be skewed for buffers that overlap with these cells.

During the reclassification, values 6 and 7, representing non-burnable lands and water, are classified as 0. This implies that when calculating the mean, these areas pull the mean of a school buffer lower. The original intention of the dataset was to classify these separately and not factor them into risk. However, this analysis does factor these categories into wildfire hazard potential.

6.5 Sea Level Rise

Description

The U.S. Geological Survey (USGS) created the Coastal Storm Modeling System (CoSMoS) to estimate future flood-hazard exposure for California by modeling the combined effects of static sea level rise and storm surges during coastal storms. CoSMos outputs multiple data products. This project used the CoSMoS flood hazard dataset. The flood hazard dataset are polygons describing the extent of flooding under 10 sea level rise scenarios ranging from 0-5 meters relative to sea levels in the year 2000 and annual, 20-year, and 100-year coastal storms. This project uses data generated under a 25 centimeter (0.8 feet) sea level rise scenario and a 100-year coastal storm. This amount of sea level rise, 25 centimeters, aligns with the California Ocean Protection Council's most likely projection for 2050 sea levels under an intermediate emissions scenario (California Sea Level Rise Guidance 2024). CoSMoS categorizes a 100-year storm as a storm with total water levels averaging 4 meters and 1.8 meters above mean sea levels on the open coast and estuaries, respectively.

Cleaning and Wrangling

The goal for using this dataset is to map the extent of flooding under the 0.8 feet sea level rise and 100-year coastal storm scenario and derive the percentage of area of each school buffer affected. This analysis primarily uses the sf package for spatial operations. The CoSMoS flood hazard shapefiles are available by coastal county and for the San Francisco Bay, so the first step in the analysis is to combine the 14 downloaded shapefiles into one. The polygons also extend into the open ocean, so the combined dataset is clipped to the boundary of California using sf::st_intersection() and the same boundary layer used in the wildfire data preparation.

To calculate the percentage of area of each school buffer affected by sea level rise and a coastal storm, the area of intersection between sea level rise polygons and each school buffer needs to first be calculated. Instead of using entire school buffers, the buffers are first clipped to the coastline, as only land area should be considered. Using sf::st_intersection() with the clipped buffers and the sea level rise polygons returns new polygons that are the overlap between each school buffer and sea level rise polygons. Each intersection polygon is associated with a specific school identifier, called a CDSCode, so additional polygons are created where sea level rise polygons intersect with multiple school buffer areas. Additionally, multiple original sea level rise polygons can fall within one school buffer. To conduct a join on these intersection polygons and the school buffers, the area of each intersection polygon is calculated by finding the sum of the area for each CDSCode, accounting for the multiple polygons. Then, the table of sea level rise areas and the school buffers are joined by CDSCode, and the percentage of area of each school buffer affected by sea level rise and a coastal storm is calculated.

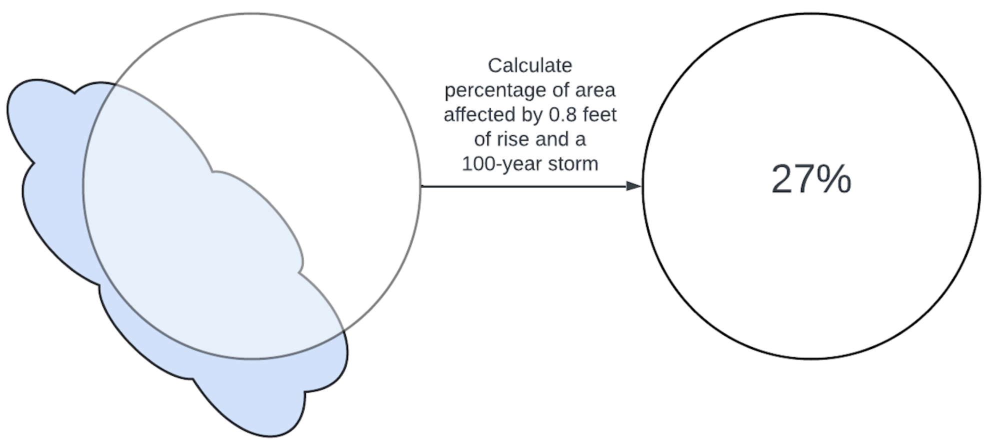

Figure 5: Conceptual diagram of the calculation of percentage of area of a school buffer affected by sea level rise and a coastal storm

The 2050 sea levels are relative to 2000 sea levels, so the 2000 data are simply the flood hazard polygons from CoSMoS with no sea level rise and a 100-year coastal storm. These polygons are combined for each county and the San Francisco Bay and simplified in the same manner as the 2050 sea level rise data.

Visualization

Sea level rise extent is mapped in the dashboard for every school buffer area by clipping the original sea level rise polygons to the specified school buffer based on user input. To improve map load times, the shapefile is reduced in size and simplified using sf::st_simplify() with a specified distance tolerance of 10 meters. The simplify function draws simplified polygon borders, smoothing vertices within the specified distance tolerance. This process reduces the size and resolution of the original sea level rise polygons. To provide a comparison to the projected 2050 sea levels, 2000 and 2050 levels are mapped side-by-side in the dashboard.

Limitations

CoSMoS data is still being generated, and the current version only has shapefiles from the southern border of California up to Point Arena in Mendocino County. The USGS has stated plans to continue mapping for the north coast of California, with no definite date of release. School buffer areas north of the CoSMoS extent are calculated and mapped as expected to experience no sea level rise, which is most likely not the case. Clear text in the dashboard beneath the maps notes the limitations in availability of data. Lastly, simplifying the sea level rise polygons greatly improves map load times but loses some fine detail of the extent of flooding. The specified distance tolerance was chosen to strike a balance between data simplification and retaining detail.

6.6 Hazard Summary Score

The following section describes the methodology used to calculate the hazard summary score. See **Appendix C** for a summary table describing the intervals for each hazard and the number of schools within each interval.

Description

To provide schools with a summary of their risk for each hazard and their total hazard risk in relation to all other schools in California, a simple scoring system was developed. The hazard summary score takes a single value for each hazard for each school and normalizes them on a scale from 0-5, with 0 representing no risk, and 1-5 representing lower to higher risk. The single values for each school that were normalized are the total number of projected extreme heat days and extreme precipitation days between 2030-2035 under RCP 8.5, the percentage of school buffer area within High Risk flood zones, the percentage of school buffer land area affected by 0.8 feet of sea level rise and a 100-year coastal storm, and the mean wildfire hazard potential score for each buffer area. The total score for each school is the sum of each normalized value, with possible values from 0-25.

Cleaning, Wrangling, and Calculations

Values were normalized using five defined equal intervals based on the range of values for each hazard. The interval sizes were defined by taking the range of data across the entire set of schools and dividing by five.

Schools were then assigned a value from 1-5 for each hazard based on the interval they fell in. Schools with a value of 0 for any of the hazard metrics were excluded from the interval calculations and assigned a 0 hazard score. Since wildfire hazard potential is already on a scale from 0-5, no transformation is needed. The total score is the sum of the individual normalized hazard scores.

Visualization

Based on the user selecting a specific school in the dashboard, the hazard summary is plotted as a lollipop chart, with line segments and labels for each hazard. The total score is also plotted on a bar from 0-25, with a line placed at the position of the total score. To avoid raising alarm from using a green-red color scale, a yellow-purple color scale was chosen simply to show a difference between hazard score values. A yellow-to-purple gradient is also more user-friendly for color-blind users.

Limitations

Normalizing data involves transforming and obscuring true values for data. The hazard summary is simply intended to provide direction for users to navigate to individual hazard tabs. If a school receives a 5 for extreme heat and low scores for other hazards, the hope is that they pay closer attention to the information in the extreme heat tab. Additionally, the labels in the plot that display “lower risk” and “higher risk” versus “low risk” and “high risk” indicate that the normalization of the data makes values of 1-5 relative to other schools. While a value of 0 means no risk given the scope of this analysis, a value of 1 does not mean low risk.

6.7 Dashboard Design

The California Schools Interactive Dashboard consists of six main pages: *Welcome, Hazards Summary, Explore Your Hazards, Information, Glossary, About,* and *User Guide*. As well as five additional sub-pages under the *Explore Your Hazards* page which display information and visualizations for each climate hazard: *Extreme Heat, Wildfire, Extreme Precipitation, Flooding, Sea Level Rise.* Each of these sub-pages has interactive graphs and maps, as well as two discussion questions: “What does this diagram tell us?” and “How is this hazard measured?” All maps have a topographic and satellite basemap that can be toggled on and off.

The *Welcome* page allows users to find school-specific information by allowing them to select their school based on their city and school district. Based on the user selection, the information on the *Welcome, Hazards Summary,* and *Explore Your Hazards* pages will update automatically with the relevant information. This page also displays a map of the selected school point location with a 3-mile buffer, days of school closures due to natural disasters, and student demographic information.

The *Hazards Summary* page provides more detailed information on the Hazards Summary graph that is displayed on the *Welcome* page. This includes a total hazard score for each school from 0-25 with the school's total score highlighted. The primary “Hazards Summary” graph is otherwise similar on both pages.

The *Information* page includes general information on climate adaptation in schools at a local level in addition to kid and teenager-friendly resources on climate change.

The *Glossary* defines key terms used throughout the dashboard with sources from where the definition was obtained. The *User Guide* hosts a video walkthrough of the dashboard with step-by-step instructions on how to use the dashboard. It also includes a brief text walkthrough to accompany the video.

The *About* page includes background information on the project and Capstone team with short biographies for the four dashboard creators.

When the user clicks on *Explore Your Hazards*, it reveals a drop-down menu of the five climate hazards.

Extreme Heat and *Extreme Precipitation* contain a bar graph displaying extreme heat days per year from 2006-2064 for the selected school under RCP 8.5 (high emissions scenario) and RCP 4.5 (reduced emissions scenario). The emissions scenarios can be toggled on and off by the user. By hovering over each bar, the year, total number of days above the threshold, and the emissions scenario are shown in a popup.

Wildfire contains two maps of a school's wildfire hazard in 2015 and 2023. Each map shows the school's wildfire hazard per pixel within the buffer and includes a scale bar and legend with information on the scoring of each pixel. *Sea Level Rise* also has two maps displaying past sea level rise in 2000 and projected sea level rise in 2050 within the buffer. Each map also includes a scale bar and a legend showing the flooding extent.

Flooding contains a single map of a school buffer filled in by the areas flood risk zone. This map also includes a scale bar as well as a legend with information on the flood risk zone range.

7.0 Summary of Testing

7.1 Code Testing

Code testing will consist mainly of manual checks and unit tests to ensure that individual components are in the right format to proceed with use in functions. For climate hazards data, this will involve making sure that the correct variable was extracted from the raw data using the Cal-Adapt API with information for all of California's school districts. For calculating the climate hazards, manual checks and unit tests will make sure that values have been standardized correctly and that outputs are within the prescribed range of values. The team will seek technical help from the faculty advisor to support the statistical methods employed in aggregated climate hazard risk development. Any intermediate and final outputs will also be vetted through team code review.

7.2 UX Testing

The dashboard underwent two phases of User Experience testing with graduate teaching students in the UCSB Gevirtz School of Education to test the basic functionality of the dashboard and the usability of the dashboard in a classroom setting.

The first phase of testing was conducted with graduate teaching students working in Elementary Schools (Grades K - 6) in the Santa Barbara Area. The students were provided with handouts of preliminary graphs and figures prior to testing the dashboard. The students were then split into small groups of 3-5 teachers per group, and each group worked with two members of the team to walk through the dashboard. The students were given 6 minutes to interact with the dashboard with no guidance before moving into a 4-minute open-floor discussion where they provided their feedback and asked any clarifying questions.

The second phase of testing was conducted with graduate teaching students working in High

Schools (Grades 9-12) in the Santa Barbara Area. The students were provided with updated handouts of the graphs, figures, and dashboard pages to record their feedback while going through the live interactive testing session. The students were not split into groups for live testing and were given 15 minutes as a whole class to walk through the dashboard individually. This was followed by an open-floor discussion where they provided their feedback and asked any clarifying questions. Their handouts with notes were collected at the end of the session.

Feedback from the two User Experience testing sessions was recorded and used to refine the dashboard. Changes incorporated from the sessions included the following:

- simplifying text descriptions throughout the dashboard,
- changing the colors on the hazard summary plot,
- adding icons to each hazard subtab,
- providing a button to highlight interactive elements on each hazard page, and
- providing opportunities for discussion under the hazard plots.

8.0 User Documentation

In addition to this document, documentation for this project can be found in the CASAschools Github repository and on the data archival in Dryad. Documentation can be found in the form of README.txt files. The README on the landing page of the repository describes the purpose of the project and directs users to subdirectories for each component of the project. Each subdirectory contains a README with an overview of the analysis conducted and data used. Commented code in the Quarto documents provide line-by-line descriptions of processes. Each subdirectory also contains a “session_info.txt” file that provides R and R Studio version information and the R packages used. See **Appendix B** for a full list of R packages used and version information. The Dryad archival contains a README detailing the submitted datasets, the original datasets used, and the contents of the Github repository.

8.1 Github Repository

The CASAschools organization contains two repositories: *climate_hazards* and *shiny_dashboard*. The *climate_hazards* repository contains data wrangling and preparation of the five climate hazards to be included in the interactive dashboard. The *shiny_dashboard* repository is the code for building the dashboard and how the interactive element was built in. The following tables provide folder structure and file connections across both repositories.

Table 1. ***Climate Hazards Repository***

Directory/Folder	**Files**	**Description**
calmatters	1. calmatter_cleaning.qmd	(1): Cleaning and prepping of Calmatters Disaster Days of school closures due to natural disasters
extreme_heat	1. caladapt-r.qmd 2. schools_extreme_heat_days_rcp45.qmd 3. schools_extreme_heat_days_rcp85.qmd	(1) Determining 98th percentile threshold of extreme heat days

	4. dashboard_prep.qmd	(2) Calculate number of extreme heat days for RCP 4.5 (3) Calculate number of extreme heat days for RCP 8.5 (4) Joining RCP data and calculating yearly values for 2030 - 2035 for hazard summary metric
precipitation	1. caladapt_precip_r.qmd 2. schools_extreme_precip_days_rcp45.qmd 3. schools_extreme_precip_days_rcp85.qmd 4. joining_data.qmd	(1) Determining 98th percentile threshold of extreme precipitation days (2) Calculate number of extreme precipitation days for RCP 4.5 (3) Calculate number of extreme precipitation days for RCP 8.5 (4) Joining RCP data and calculating yearly values for 2030 - 2035 for hazard summary metric
flooding-FEMA	1. FEMA_schools.qmd 2. Flooding_mapping.qmd	(1) Joins high risk with schools to find percentage of area (2) Categorizes risk categories into high, moderate to low, and undetermined and creates leaflet map
wildfire	1. wildfire_prep.qmd 2. wildfire_mapping.qmd	(1) Cleans wildfire data and prepare it for use in the hazard summary score (2) Prepares current and past wildfire data for mapping in the dashboard
sea_level_rise	1. sea_level_rise.qmd	(1) Cleans sea level rise data and prepares it for use in the hazard summary score and mapping in the dashboard
climate_hazard_summary	1. hazard_summary.qmd	(1) Calculations of hazard summary metric
License	N/A	Creative Commons CCO Public Domain license
README.md	N/A	Repository information and description
session_info.txt	N/A	Version and years of packages used in this repository

Table 2. ***Shiny Dashboard Repository***

Directory/Folder names	Files	Description
R	1. heat_plot.R 2. precip_plot.R 3. wildfire_map2012.R 4. wildfire_map2023.R 5. flood_map.R 6. slr_map_2000.R 7. slr_map.R 8. summary_home.R 9. summary_tab.R 10. summary_score_tab.R 11. summary_title_home.R 12. update_school_name.R 13. school_filtered.R	(1-7): Functions for plotting the five climate hazard visualizations in an interactive dashboard. (8): Function for plotting hazard summary lollipop plot on home page (9): Hazard summary plot and bar output (10): Hazard summary tab lollipop and gradient bar (11):Function of hazard score lollipop chart on home page (12): Updates the hazard summary tab text “Total Score” is updated for each school selection (13): School name updates for home page graph to school selected
text	1. about_text.md 2. information.md 3. glossary.md 4. heat.md 5. precipitation.md 6. flooding.md 7. wildfire.md 8. slr.md 9. about_text.html 10. information.html 11. glossary.html 12. heat.html 13. precipitation.html 14. flooding.html 15. wildfire.html 16. slr.html	(1-8): Markdown files containing text for each tab on the dashboard about, information, glossary, extreme heat, extreme precipitation, flooding, wildfire, sea level rise. (9-16): HTML files for running the markdown files on a website
www	1. heat_tutorial.jpg 2. precip_turorial.jpg 3. flooding_tutorial.jpg 4. wildfire_tutorial.jpg 5. slr_tutorial.jpg 6. CASAschools2.JPG 7. climate_ed.jpeg 8. Schoolyard.jpg	(1-5): Climate hazard plots interactive elements highlighted features (6-8): Additional images added in the Information tab
global.R	N/A	Datasets, packages, and global options

		needed to run the dashboard
ui.R	N/A	Dashboard structure and elements such as dropdown boxes and sidebar
server.R	N/A	Function of dashboard outputting plots in relation with the user inputs in dropdown values
session_info.txt	N/A	Version and years of packages used in this repository

9.0 Archive Access

All the raw data is publicly available and does not require any proprietary software to access or process the files. The metadata will document how anyone can access the data from the Cal-Adapt API, FEMA, USGS, and USFS. Code used to prepare the data for mapping, plotting, and use in the hazard summary calculations is available in *CASAschools* GitHub organization.

All datasets used are publicly available and have no restrictions on redistribution and reuse. The code and data generated are licensed under a Creative Commons Zero v1.0 Universal which grants permission to the public to use the generated code.

The raw datasets obtained from Cal-Adapt, the Department of Education, and additional datasets are too large to be stored on the *CASAschools* Github organization. Instead, the reproducible code will be stored to explain how to access the data from the Cal-Adapt API, the calculations for the hazard summary score, the preparation of other climate hazards, and the deployment of the interactive dashboard. All of this will be publicly accessible for reproducibility. Dryad will be used to archive and preserve the final data generated throughout the project. These are any tables and geospatial layers used for plotting, mapping, and displaying the hazard summary in the interactive dashboard. See the data archival on Dryad.

Additionally, all raw data, intermediate outputs, and final outputs will be transferred to the client. Intermediate outputs include any geospatial or tabular data wrangled necessary for analysis, such as layers clipped to the boundary of California. The client will also be directed to the *CASAschools* GitHub organization to access the code written to generate these outputs and the interactive dashboard.

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Appendices

Appendix A: Public Datasets Used

The following table compiles the public datasets used throughout the project:

Dataset	Year(s) Covered	Source	Data Type	Spatial References	Variable Names
California public schools locations	2022-2023	CA Department of Education	Geospatial layer (.shp) with latitude and longitude of the 10,009 California public schools location.	EPSG 3857	school_points
School closures	2002-2019	CalMatters Disaster Days	Tabular data (CSV) of school closures by day due to disasters across 15,077 California public, private, and charter schools	N/A	calmatters
Maximum daily temperature	1961 - 2064	CalAdapt	LOCA grid cells as a vector (polygon) layer containing daily maximum temperatures	EPSG:4326	extreme_heat
Maximum daily precipitation	1961 - 2064	CalAdapt	LOCA grid cells as a vector (polygon) layer containing daily maximum temperatures	EPSG:4326	extreme_precip
National Flood Hazard Layer	04/11/2024	Federal Emergency Management Agency (FEMA)	Geospatial database(GDB) representing current effective flood data, where maps have been modernized. Compiles effective Flood Insurance Rate Map (FIRM) databases and Letters of Map Change (LOMCs)	EPSG:4269	FEMA_reclass_simple
Wildfire Hazard Potential for the United States (4th edition)	2023	USDA Forest Service	Raster layer of 270 meter pixels (GeoTIFF) classifying wildfire hazard potential from very low to very high	EPSG:5070	whp_reclass
Wildland Fire Potential for the conterminous	2015	USDA Forest Service	Raster layer of 270 meter pixels (ESRI Grid) classifying wildfire hazard potential	EPSG:5070	whp_reclass2012

United States			from very low to very high		
Coastal Storm Modeling System (CoSMoS)	2000	US Geological Survey (USGS)	Geospatial layers (.shp) describing flooding extent with a variety of sea level rise and coastal storm scenarios	EPSG:26910	ca_slr_2000
Coastal Storm Modeling System (CoSMoS)	2050	US Geological Survey (USGS)	Geospatial layers (.shp) describing flooding extent with a variety of sea level rise and coastal storm scenarios	EPSG:26910	ca_slr

Appendix B: Software and R Packages Used

Software and versions used:

- R Studio version 2022.12.0.353.20
- R version 4.2.2 (2022-10-31)

R packages installed and used, the version numbers, and source:

- abind 1.4-5 2016-07-21 [2] CRAN (R 4.2.2)
- backports 1.4.1 2021-12-13 [2] CRAN (R 4.2.2)
- base64enc 0.1-3 2015-07-28 [2] CRAN (R 4.2.2)
- broom 1.0.5 2023-06-09 [2] CRAN (R 4.2.2)
- bslib 0.7.0 2024-03-29 [1] CRAN (R 4.2.2)
- cachem 1.0.8 2023-05-01 [2] CRAN (R 4.2.2)
- caladaptr * 0.6.8 2024-04-02 [1] Github (ucanr-igis/caladaptr@0b8608f)
- class 7.3-20 2022-01-16 [2] CRAN (R 4.2.2)
- classInt 0.4-10 2023-09-05 [2] CRAN (R 4.2.2)
- cli 3.6.2 2023-12-11 [1] CRAN (R 4.2.2)
- cluster 2.1.4 2022-08-22 [2] CRAN (R 4.2.2)
- codetools 0.2-18 2020-11-04 [2] CRAN (R 4.2.2)
- colorspace * 2.1-0 2023-01-23 [2] CRAN (R 4.2.2)
- countrycode * 1.6.0 2024-03-22 [1] CRAN (R 4.2.2)
- crosstalk 1.2.1 2023-11-23 [1] CRAN (R 4.2.2)
- data.table 1.14.8 2023-02-17 [2] CRAN (R 4.2.2)
- DBI 1.2.2 2024-02-16 [1] CRAN (R 4.2.2)
- DEoptimR 1.0-11 2022-04-03 [2] CRAN (R 4.2.2)
- devtools * 2.4.5 2022-10-11 [2] CRAN (R 4.2.2)
- dichromat * 2.0-0.1 2022-05-02 [2] CRAN (R 4.2.2)
- digest 0.6.35 2024-03-11 [1] CRAN (R 4.2.2)
- diptest 0.77-1 2024-04-10 [1] CRAN (R 4.2.2)
- dplyr * 1.1.3 2023-09-03 [2] CRAN (R 4.2.2)
- e1071 1.7-14 2023-12-06 [1] CRAN (R 4.2.2)
- ellipsis 0.3.2 2021-04-29 [2] CRAN (R 4.2.2)
- fansi 1.0.6 2023-12-08 [1] CRAN (R 4.2.2)
- fastmap 1.1.1 2023-02-24 [2] CRAN (R 4.2.2)
- flexmix 2.3-19 2023-03-16 [1] CRAN (R 4.2.2)
- fontawesome * 0.5.2 2023-08-19 [2] CRAN (R 4.2.2)
- forcats * 1.0.0 2023-01-29 [2] CRAN (R 4.2.2)
- fpc 2.2-12 2024-04-30 [1] CRAN (R 4.2.2)
- fs 1.6.4 2024-04-25 [1] CRAN (R 4.2.2)
- generics 0.1.3 2022-07-05 [2] CRAN (R 4.2.2)
- ggplot2 * 3.5.0 2024-02-23 [1] CRAN (R 4.2.2)
- glue 1.7.0 2024-01-09 [1] CRAN (R 4.2.2)
- gridExtra * 2.3 2017-09-09 [2] CRAN (R 4.2.2)
- gtable 0.3.4 2023-08-21 [2] CRAN (R 4.2.2)
- hms 1.1.3 2023-03-21 [2] CRAN (R 4.2.2)
- htmltools 0.5.8.1 2024-04-04 [1] CRAN (R 4.2.2)
- htmlwidgets 1.6.4 2023-12-06 [1] CRAN (R 4.2.2)

- httpuv 1.6.9 2023-02-14 [2] CRAN (R 4.2.2)
- httr 1.4.5 2023-02-24 [2] CRAN (R 4.2.2)
- insight 0.19.11 2024-05-12 [1] CRAN (R 4.2.2)
- janitor * 2.2.0 2023-02-02 [2] CRAN (R 4.2.2)
- jquerylib 0.1.4 2021-04-26 [2] CRAN (R 4.2.2)
- jsonlite 1.8.8 2023-12-04 [1] CRAN (R 4.2.2)
- kernlab 0.9-32 2023-01-31 [2] CRAN (R 4.2.2)
- KernSmooth 2.23-20 2021-05-03 [2] CRAN (R 4.2.2)
- knitr 1.46 2024-04-06 [1] CRAN (R 4.2.2)
- later 1.3.0 2021-08-18 [2] CRAN (R 4.2.2)
- lattice 0.20-45 2021-09-22 [2] CRAN (R 4.2.2)
- lazyeval 0.2.2 2019-03-15 [2] CRAN (R 4.2.2)
- leafem 0.2.3 2023-09-17 [2] CRAN (R 4.2.2)
- leaflet * 2.2.2 2024-03-26 [1] CRAN (R 4.2.2)
- leaflet.extras * 1.0.0 2018-04-21 [1] CRAN (R 4.2.2)
- leaflet.minicharts * 0.6.2 2021-05-11 [1] CRAN (R 4.2.2)
- leaflet.providers 2.0.0 2023-10-17 [2] CRAN (R 4.2.2)
- leafsync 0.1.0 2019-03-05 [2] CRAN (R 4.2.2)
- lifecycle 1.0.4 2023-11-07 [1] CRAN (R 4.2.2)
- lubridate * 1.9.2 2023-02-10 [2] CRAN (R 4.2.2)
- lwgeom 0.2-13 2023-05-22 [2] CRAN (R 4.2.2)
- magrittr 2.0.3 2022-03-30 [2] CRAN (R 4.2.2)
- MASS 7.3-58.1 2022-08-03 [2] CRAN (R 4.2.2)
- mclust 6.0.0 2022-10-31 [2] CRAN (R 4.2.2)
- memoise 2.0.1 2021-11-26 [2] CRAN (R 4.2.2)
- mime 0.12 2021-09-28 [2] CRAN (R 4.2.2)
- miniUI 0.1.1.1 2018-05-18 [2] CRAN (R 4.2.2)
- modeltools 0.2-23 2020-03-05 [2] CRAN (R 4.2.2)
- moments 0.14.1 2022-05-02 [1] CRAN (R 4.2.2)
- munsell 0.5.1 2024-04-01 [1] CRAN (R 4.2.2)
- nnet 7.3-18 2022-09-28 [2] CRAN (R 4.2.2)
- nullabor 0.3.9 2020-02-25 [1] CRAN (R 4.2.2)
- pillar 1.9.0 2023-03-22 [2] CRAN (R 4.2.2)
- pkgbuild 1.4.4 2024-03-17 [1] CRAN (R 4.2.2)
- pkgconfig 2.0.3 2019-09-22 [2] CRAN (R 4.2.2)
- pkgload 1.3.4 2024-01-16 [1] CRAN (R 4.2.2)
- plotly * 4.10.4 2024-01-13 [1] CRAN (R 4.2.2)
- png 0.1-8 2022-11-29 [2] CRAN (R 4.2.2)
- prabclus 2.3-3 2023-10-24 [1] CRAN (R 4.2.2)
- profvis 0.3.7 2020-11-02 [2] CRAN (R 4.2.2)
- promises 1.2.0.1 2021-02-11 [2] CRAN (R 4.2.2)
- proxy 0.4-27 2022-06-09 [2] CRAN (R 4.2.2)
- purrr * 1.0.2 2023-08-10 [2] CRAN (R 4.2.2)
- R6 2.5.1 2021-08-19 [2] CRAN (R 4.2.2)
- raster 3.6-26 2023-10-14 [2] CRAN (R 4.2.2)
- RColorBrewer * 1.1-3 2022-04-03 [2] CRAN (R 4.2.2)
- Rcpp 1.0.12 2024-01-09 [1] CRAN (R 4.2.2)
- readr * 2.1.4 2023-02-10 [2] CRAN (R 4.2.2)

- regressinator * 0.1.3 2024-01-11 [1] CRAN (R 4.2.2)
- remotes 2.4.2.1 2023-07-18 [2] CRAN (R 4.2.2)
- rlang 1.1.3 2024-01-10 [1] CRAN (R 4.2.2)
- rlist * 0.4.6.2 2021-09-03 [1] CRAN (R 4.2.2)
- robustbase 0.95-0 2022-04-02 [2] CRAN (R 4.2.2)
- rstudioapi 0.15.0 2023-07-07 [2] CRAN (R 4.2.2)
- sass 0.4.9 2024-03-15 [1] CRAN (R 4.2.2)
- scales 1.3.0 2023-11-28 [1] CRAN (R 4.2.2)
- sessioninfo 1.2.2 2021-12-06 [2] CRAN (R 4.2.2)
- sf * 1.0-14 2023-07-11 [2] CRAN (R 4.2.2)
- shiny * 1.7.4 2022-12-15 [2] CRAN (R 4.2.2)
- shinycssloaders * 1.0.0 2020-07-28 [1] CRAN (R 4.2.2)
- shinydashboard * 0.7.2 2021-09-30 [1] CRAN (R 4.2.2)
- shinyWidgets * 0.8.6 2024-04-24 [1] CRAN (R 4.2.2)
- snakecase 0.11.1 2023-08-27 [2] CRAN (R 4.2.2)
- sp 2.1-4 2024-04-30 [1] CRAN (R 4.2.2)
- stars 0.6-4 2023-09-11 [2] CRAN (R 4.2.2)
- stringi 1.7.12 2023-01-11 [2] CRAN (R 4.2.2)
- stringr * 1.5.0 2022-12-02 [2] CRAN (R 4.2.2)
- terra * 1.7-55 2023-10-13 [2] CRAN (R 4.2.2)
- tibble * 3.2.1 2023-03-20 [2] CRAN (R 4.2.2)
- tidyr * 1.3.0 2023-01-24 [2] CRAN (R 4.2.2)
- tidyselect 1.2.1 2024-03-11 [1] CRAN (R 4.2.2)
- tidyverse * 2.0.0 2023-02-22 [2] CRAN (R 4.2.2)
- timechange 0.2.0 2023-01-11 [2] CRAN (R 4.2.2)
- tmap * 3.3-3 2024-05-06 [1] Github (mtennekes/tmap@a4e9fc9)
- tmaptools 3.1-1 2023-10-19 [2] Github (r-tmap/tmaptools@0c8b0b1)
- tzdb 0.3.0 2022-03-28 [2] CRAN (R 4.2.2)
- units * 0.8-5 2023-11-28 [1] CRAN (R 4.2.2)
- urlchecker 1.0.1 2021-11-30 [2] CRAN (R 4.2.2)
- usethis * 2.1.6 2022-05-25 [2] CRAN (R 4.2.2)
- utf8 1.2.4 2023-10-22 [1] CRAN (R 4.2.2)
- vctrs 0.6.5 2023-12-01 [1] CRAN (R 4.2.2)
- viridisLite 0.4.2 2023-05-02 [2] CRAN (R 4.2.2)
- withr 3.0.0 2024-01-16 [1] CRAN (R 4.2.2)
- xfun 0.43 2024-03-25 [1] CRAN (R 4.2.2)
- XML 3.99-0.16.1 2024-01-22 [1] CRAN (R 4.2.2)
- xtable 1.8-4 2019-04-21 [2] CRAN (R 4.2.2)
- zoo * 1.8-12 2023-04-13 [2] CRAN (R 4.2.2)

Appendix C: Hazard Summary

Hazard and Metric	**Intervals**	**Number of Schools in each Interval**	**Summary Statistics**
Extreme Heat Days: Total number of extreme heat days for each school between 2030-2035 under an RCP 8.5 scenario	**0**: 0 **1**: 1 - 181.8 **2**: 181.8 - 363.6 **3**: 363.6 - 545.4 **4**: 545.4 - 727.2 **5**: 727.2 - 909	**0:** 443 **1:** 5821 **2:** 2273 **3:** 1255 **4:** 49 **5:** 167	**min:** 0 **min (excluding 0):** 1 **max:** 908 **mean:** 161
Extreme Precipitation Days: Total number of extreme precipitation days for each school between 2030-2035 under an RCP 8.5 scenario	**0:** 0 **1:** 1 - 270 **2:** 270 - 540 **3:** 540 - 810 **4:** 810 - 1080 **5:** 1080 - 1350	**0:** 3 **1:** 8701 **2:** 1060 **3:** 206 **4:** 33 **5:** 5	**min:** 0 **min (excluding 0):** 1 **max:** 1349 **mean:** 172
Flooding: Percentage of each school buffer area within a high risk flood zone	**0:** 0 **1:** >0 - 19.52 **2:** 19.52 - 39.04 **3:** 39.04 - 58.56 **4:** 58.56 - 78.08 **5:** 78.08 - 97.60	**0:** 712 **1:** 9210 **2:** 55 **3:** 20 **4:** 9 **5:** 2	**min:** 0 **max:** 97.60 **mean:** 0.85
Wildfire: Mean wildfire hazard potential score of all pixels that intersect with each school buffer	Wildfire hazard potential is already on a scale from 0-5	**0:** 0 **1:** 3992 **2:** 2913 **3:** 2391 **4:** 634 **5:** 78	**min:** 1 **max:** 5 **mean:** 1.99
Sea Level Rise: Percentage of each school buffer area affected under projected 2050 sea levels and a 100-year coastal storm	**0:** 0 **1:** >0 - 18.9 **2:** 18.9 - 37.8 **3:** 37.8 - 56.7 **4:** 56.7 - 75.6 **5:** 75.6 - 94.5	**0:** 8272 **1:** 1636 **2:** 78 **3:** 13 **4:** 3 **5:** 6	**min:** 0 **max:** 94.45 **mean:** 0.80