Investigating Risk in Our Environment

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FEMA's National Risk Index interactive map provides an intriguing opportunity for exploration of areas of risk in the United States. Its appealing visual interface enables investigation of patterns in variables leading to risk, and in turn leads to examination of the relationships between these variables and how they relate to the investigator personally. This module aims to leverage the quickly-accessed visual representation of information and the readily-available data to engage entry level quantitative reasoning students in pattern recognition and critical thinking, analysis of interaction of variables related to natural hazard risk, while considering how the information impacts them personally. Ultimately we hope to spark student curiosity and encourage further self-driven investigation.

Subject: Quantitative literacy and problem solving

Target Student Audience: First year Math Literacy or Quantitative Reasoning course

Prerequisites: Basic algebra, proportional reasoning and percent, some familiarity with spreadsheet use is also helpful. Percentiles are explained within the module at an introductory level.

Topics: Pattern recognition, interdependence of variable quantities in data and equations, informal expectation, rates and proportional reasoning, dimensional analysis, quantiles (percentiles).

Technology Needed: Excel or other spreadsheet software, Internet access for using the National Risk Index and Desmos websites.

Learning Outcomes:

- Recognize variable and constant quantities described in verbal form.
- Express in symbolic form relationships between variable quantities described in verbal form.
- Identify variables in context as being independent or dependent.
- Describe the effect a change in one contextual variable has on other variable(s) in a given formula and interpret the effects on a single composite score.
- Interpret contextual variables specifically applied to their own community (citizen scientists).
- Discern the interaction of units of measure within calculations.
- Work fluently and fluidly with equations using different notations.

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Introduction

Our lives and the world we live in are complex and varied. In striving to understand this world, from the individual and local community level to the greater national and global level, we create methods to summarize the complex variables with which we interact. Summarizing the information and data we have enables us to distinguish the unexpected or odd patterns and trends from what is normal or usual as well as identify areas of excellence or concern.

There are a variety of things in the world we summarize with single numbers: the stock market performance using measures such as the Dow Jones Industrial Average or S&P 500, the value of a company and its prospects using stock prices, the performance of a country's economy using gross domestic product (GDP), the impact of an earthquake using the Richter scale, and the change in the earth's climate using the Land-Ocean Temperature Index.

Consider aspects of your life that are summarized in a single number. When you go to the doctor, they take your blood pressure. Your doctor uses these numbers as a summary measurement of your cardiovascular health. A patient with diabetes has an A1C measurement taken, which informs them of how well they are managing their disease. In education, a quiz score is used to inform the student and instructor about the student's mastery of objectives.

A. What are some additional examples of ways people, events, or things are often summarized by a single number?

B. One number we use to summarize a student's education is a grade point average (GPA). Reflect on the concept of a GPA.

1. How do we use GPAs to inform us about academic performance?

2. What information does a GPA summarize?

3. What information is not included in a GPA?

4. How might a GPA be misleading or incomplete information?

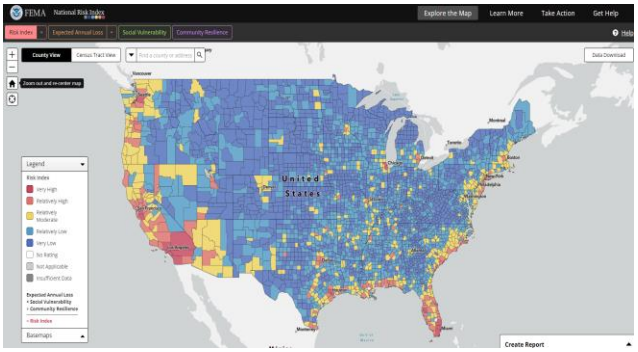
5. What are the advantages of using GPA as a summary value?

The National Risk Index

The National Risk Index as a dataset and online tool to help illustrate the U.S communities most at risk for natural hazards. The Index leverages available data sources for 18 natural hazards, social vulnerability, and community resilience to develop a baseline relative risk measurement for each U.S county and Census tract. (https://hazards.fema.gov/nri/learn-more) (FEMA, 2023)

In the National Risk Index, risk is defined as the potential for negative impacts as a result of a natural hazard. Natural hazards are defined as environmental phenomena that have the potential to impact societies and the human environment. These should not be confused with other types of hazards, such as manmade hazards. For example, a flood resulting from changes in river flows is a natural hazard, whereas flooding due to a dam failure is considered a manmade hazard, and therefore excluded from the National Risk Index. (FEMA, 2023)

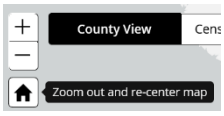
The National Risk Index Map is an interactive map with several features for visualizing natural hazard risk. You can explore the map and search for specific datasets, control the layers of data displayed, change the background and data groupings, and even create reports. The National Risk Index map is accessible at https://hazards.fema.gov/nri/map. (FEMA, 2023)



Open the National Risk Index map and answer the following questions.

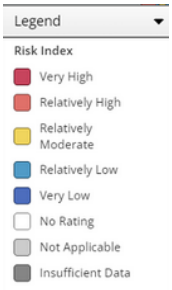
PART I: The Big Picture

The first view you see is the entire country, divided into sections by county (county view), and Risk Index shown by color. Hawaii and Alaska are included—scroll or drag the map left and down or left and up respectively to see them.



Throughout the following explorations, you may choose to zoom in (+) or out (-) on particular regions of the map. To reset the map to its initial view, use the home view icon to zoom out and re-center the map.

The legend indicating the risk index for each color is located on the lower left of the page.



1. How do these colors act as a single value summary of risk?

2. Describe any patterns you notice in the location of counties throughout the country and their corresponding risk level. Discuss why you think these patterns exist.

There are 18 natural hazards you can investigate with the Risk Index tool. Consider focusing on a particular hazard when selecting a county to investigate. A particular risk can be selected by using the drop-down menu on the upper left of the webpage. Explore areas you would expect to have a high risk of natural hazards.

3. Which natural hazards pose the highest levels of risk for these counties? Discuss whether these hazards are what we would expect for the area and if any were unexpected, and why.

    a. Miami-Dade County, FL

    b. Alameda County, CA

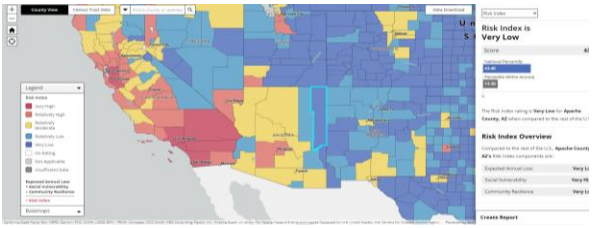
    c. Ocean County, NJ

    d. Hawaii County, HI

    e. County of your choice you feel is at risk

    f. County of your choice you feel is at risk

When you click on a county, a panel will open on the right which identifies the ratings of each Hazard Type Risk for the county. Explore the Hazard Type Risk Ratings for counties which appear to be a Risk Index anomaly within their region. For example, a county with a lower Risk Index compared to the counties surrounding it, or vice versa.



4. How do the Hazard Type Risk Ratings for these anomalous counties differ from their neighboring counties?

    a. La Paz County, AZ

    b. Washoe County, NV

    c. Hennepin County, MN

    d. County of your choice (Indicate why this county is anomalous)

    e. County of your choice (Indicate why this county is anomalous)

Next to the Risk Index dropdown menu box are similar dropdowns for *Expected Annual Loss*, *Social Vulnerability*, and *Community Resilience*. These also have qualitative ratings that describe the community in comparison to all other communities at the same level. Colors are once again used to show these ratings.

5. How do these colors summarize each of these ratings in a single value, and how does this use of color differ from the Risk Index?

6. Recall the counties you explored in #3 which appeared to be risk level anomalies within their region. Revisit these counties and look at each of these other values: *Expected Annual Loss, Social Vulnerability,* and *Community Resilience*. Are these counties anomalies for these other areas?

    a. La Paz County, AZ

    b. Washoe County, NV

    c. Hennepin County, MN

    d. County of your choice from #3

    e. County of your choice from #3

7. Based on your explorations in Part I, what do you think has the greatest impact on a county's Risk Index value, and why?

8. We can also explore the Risk Index value by Census Tract View (adjacent to the County View option). Change the view to Census Tract View. Describe any patterns you notice in the location of these census tracts throughout the country and their corresponding risk level. Are these patterns different from those you saw in the counties in #2? Why or why not? Explain.

9. The largest county in the US by area is San Bernardino County, CA. What is the county risk level, and how does it compare to the census tract risk levels? What do you think accounts for the difference?

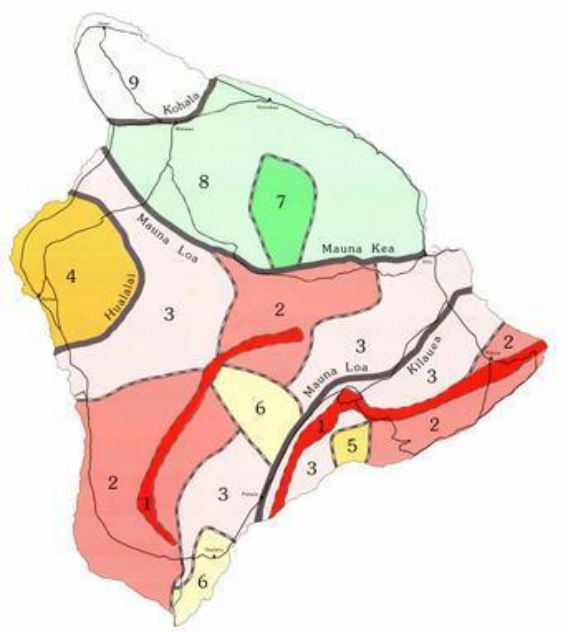
10. The largest county in the US by population is Los Angeles County, CA. What is the county risk level, and how does it compare to the census tract risk levels? How does it differ from San Bernardino County?

11. Revisit one of the counties you found interesting in #3 and discuss how the risk levels in census tract view compare to the risk levels in county view, and what appears to account for these differences.

12. Based on your exploration of patterns in the maps in both county view and census tract view, what are the strengths and weaknesses of visualizing risk using a single value?

PART II: Digging Deeper with Risk and the Risk Index Equation

The National Risk Index Technical Documentation describes risk as: “Natural hazard risk, in the most general terms, is often defined as the likelihood (or probability) of a natural hazard event happening multiplied by the expected consequence if a natural hazard event occurs.” (FEMA, 2023)



Consider buying a house in Hawaii County, HI. The available houses are in lava-flow hazard Zone 2, where 15% to 25% of the land has been covered by lava since 1800, or lava-flow hazard Zone 3, where 1% to 5% of the land has been covered by lava since 1800. (USGS)

1. How do the zone classifications inform your decision about purchasing a house in that zone?

2. Suppose the average house value in Zone 2 is $250,000, while in Zone 3, the average house value is $750,000. How does this information influence your decision about purchasing a house in each zone?

3. Assume the historical percentages of lava-flow coverage are probabilities, and the loss of the average house price is the expected consequence. Using the definition as “Natural hazard risk…[is] the likelihood (or probability) of a natural hazard event happening multiplied by the expected consequence,” create a range of risk values for Zone 2 and Zone 3 based on the information given in #2. What do these ranges suggest about the risk in purchasing a house in Zone 2 vs. Zone 3?

4. What does this “Natural hazard risk” definition look like as an equation? What variable(s) express the expected consequence? What variable(s) express the likelihood of a hazard event? Why?

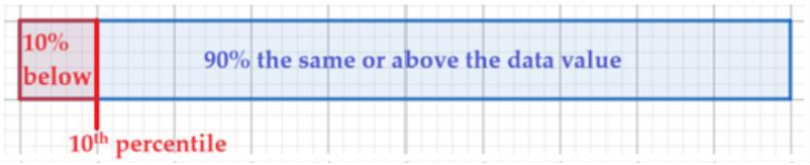
5. What are the flaws in using the historical lava-flow coverage percentages as probabilities?

6. How else could we quantify the likelihood of a natural hazard event?

7. We used average house values as the expected consequence. Why would this make sense? What are the flaws in using house value?

8. How else could we quantify the expected consequence of a hazard event, and what other information would you need?

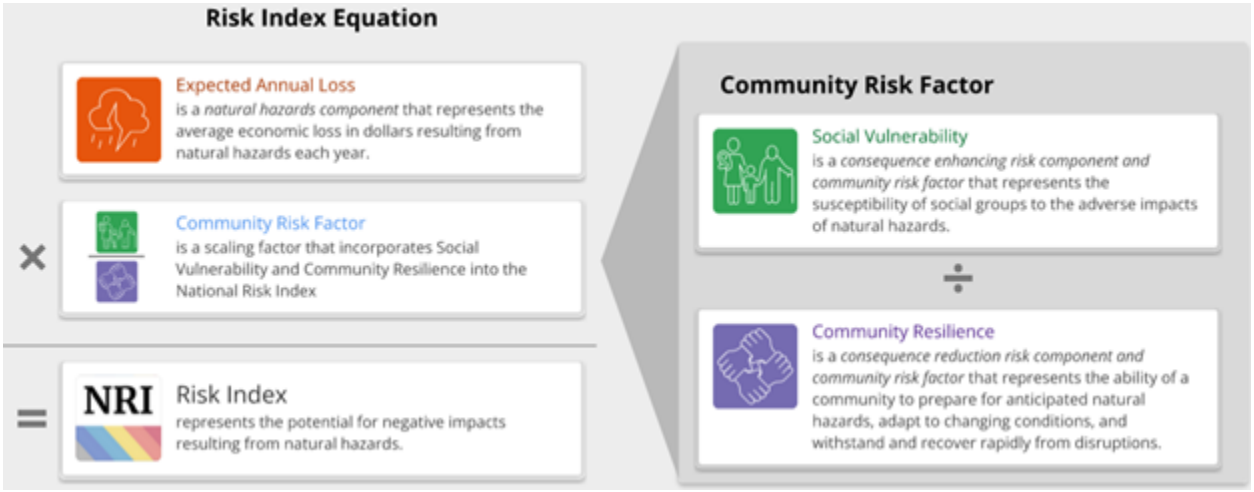
Many of the summary values given in the National Risk Index information are expressed as percentiles. In order to compare and understand values within a set of ordered data we often use percentiles. To determine percentiles for a data set, we divide it into 100 equal parts where each part represents one percent. If a data value lies at the 10th percentile, it means 10% of the other data values are at or below this data value while 90% of the data values are at or above this data value.



If a particular data point is at the 80th percentile, this means that the piece of data is higher than 80% of the data in the set.

Thus, percentiles are useful because they allow us to have an idea how one data value compares to the rest of the data in the set.

“In the National Risk Index, risk is defined as the potential for negative impacts as a result of a natural hazard.” (FEMA, 2023) The National Risk Index provides relative Risk Index percentiles and ratings based on data for Expected Annual Loss due to natural hazards, Social Vulnerability, and Community Resilience. A community's score is represented by its percentile ranking among all other communities at the same level for *Risk, Expected Annual Loss, Social Vulnerability* and *Community Resilience*. For example, if a given Census tract's Risk Index percentile for a hazard type is 84.32 then its Risk Index value is greater than 84.32% of all US Census tracts (FEMA, 2023).



9. Looking at the Risk Index Equation, we see that this equation describes a relationship between three quantities or variables. What are those variables? Assign a symbol to each of these variables and write an equation that represents the Risk Index.

10. On which variables is the Risk Index variable dependent? How does this equation relate to the general definition of "Natural hazard risk…[is] the likelihood (or probability) of a natural hazard event happening multiplied by the expected consequence if a natural hazard event occurs." we worked with previously in #3?

11. Community Risk Factor is one of the variables in the Risk Index equation. What variables does the Community Risk Factor depend on? Assign symbols to these variables and write an equation that represents the Community Risk Factor.

12. If a community has high Social Vulnerability and low Community Resilience, what will we see for the Community Risk Factor?

13. If a community has a low Social Vulnerability and high Community Resilience, what will we see for the Community Risk Factor?

14. If a community has a high Social Vulnerability and high Community Resilience, what will we see for the Community Risk Factor? What if both Social Vulnerability and Community Resilience are low?

15. In the equation for Risk Index, replace the variable for Community Risk factor with its corresponding expression. This new equation should represent the Risk Index in terms of Expected Annual Loss, Social Vulnerability, and Community Resilience.

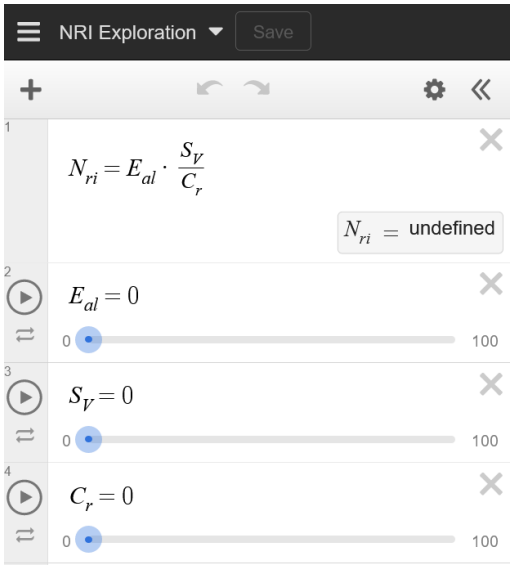
16. What happens to a community's Risk Index value if the Expected Annual Loss increases, assuming the Community Risk Factor remains the same? What could cause an increase to a community's Expected Annual Loss?

17. If we want to end up with the highest Risk Index value, which of the variables (Expected Annual Loss, Social Vulnerability, Community Resilience) would we increase? Decrease?

18. If we want to end up with the lowest Risk Index value, which of the variables (Expected Annual Loss, Social Vulnerability, Community Resilience) would we increase? Decrease?

19. Look back at the legend for the colors used for Expected Annual Loss, Social Vulnerability, Community Resilience. How do the shading gradients reflect the impact of each variable on the Risk Index value?

Optional: Verify your thinking from #12-#18 using the Desmos activity NRI Exploration (https://www.desmos.com/calculator/2u6q6ke6xf)



a. This exploration relates the variables in the National Risk Index equation in a simplified manner, allowing each of the three variables the Risk Index depends on to vary from values 0 to 100. Note how the variables are represented symbolically—how do they compare to how you defined them in #9 and #15?

b. The exploration begins with Community Resilience equal to 0. Why is this problematic both practically and mathematically?

c. Assume Community Resilience is greater than 0. If Expected Annual Loss is 0, what is true about the Risk Index value, no matter what the non-zero values of the other two variables are? What does this mean in context?

d. If Social Vulnerability is 0, what is true about the Risk Index value, no matter what the non-zero values of the other two variables are? What does this mean in context?

e. Use the sliders to change the values and verify your thinking in #16-#18.

f. If you set E_{al} = 1, you can verify your thinking in #12-#14. Why does this work?

Apply your understanding of the interdependence of the variables involved in creating the National Risk Index.

20. The National Risk Index Technical Documentation states: “The risk equation behind the National Risk Index includes three components: a natural hazards risk component, a consequence enhancing component, and a consequence reduction component.” (FEMA, 2023). Which of the variables (Expected Annual Loss, Social Vulnerability, Community Resilience, Community Risk Factor) match each component’s description? How can you tell?

21. If we want to lower or raise the Risk Index single score, which variable should we change to have the most impact, and why? How does this relate to "boots on the ground" community change?

22. If we want to lower or raise the Community Risk Factor single score, which variable should we change to have the most impact, and why? How does this relate to "boots on the ground" community change?

PART III: Applying What We've Learned to Specific Communities

Equation 2: Generalized National Risk Index Risk Equation

$$Risk = Expected\ Annual\ Loss \times Community\ Risk\ Factor$$

$$where\ Community\ Risk\ Factor = f\left(\frac{Social\ Vulnerability}{Community\ Resilience}\right)$$

In Part II, we looked at the generalized National Risk Index Equation in broad, simplified terms. While the mathematical transformation applied to the Community Risk Factor calculation is beyond the scope of our course, the NRI data provided by FEMA (https://hazards.fema.gov/nri/data-resources#csvDownload) includes the results from this transformation, reported in the CSV file as the CRF_VALUE. The county data includes a county-wide Community Risk Factor, but the Risk value calculation is based on the census tract Community Risk Factor. The NRI supporting data includes the Community Risk Factor (CRF_VALUE) for all the census tracts in each county, along with the Expected Annual Loss (EAL_VALT).

The CSV files also contain a myriad of other related data, we will focus on a few of the relevant fields of data. The census tract data for La Paz County, AZ is shown here, where EAL_VALT represents the *Expected Annual Loss* (in dollars) and the CRF_VALUE is the *Community Risk Factor*. This view is available on the first tab in the Sample Counties for Risk Calculation spreadsheet [attach Sample Counties for Risk Calculation spreadsheet].

	A	B	C	D	E	F	G	H
1	COUNTY	COUNTYTYPE	TRACT	POPULATION	EAL_VALT	CRF_VALUE	Risk Value	
2	La Paz	County	20101	934	762561.8	1.863603		
3	La Paz	County	20102	1002	156021	0.714023		
4	La Paz	County	20201	1760	240400.1	1.360185		
5	La Paz	County	20202	581	130533.9	0.981395		
6	La Paz	County	20501	1416	279409.3	1.187392		
7	La Paz	County	20503	1037	477275.1	1.843107		
8	La Paz	County	20504	820	1110536	1.001452		
9	La Paz	County	20505	904	250696.2	1.039855		
10	La Paz	County	20602	977	1088098	1.924567		
11	La Paz	County	940200	3409	116417.7	1.844765		
12	La Paz	County	940300	3611	2344623	1.991553		
13	La Paz	County	980000	0	0	1.508703		
14						Total Risk:		
15								

1. The generalized Risk equation is Risk = Expected Annual Loss * Community Risk Factor.

   a. If the EAL_VALT for the first census tract is in cell E2, and the CRF_VALUE is in cell F2, what would the equation look like, using these cell references as variables?

   b. How is spreadsheet formula related to formula created in Part I #9?

c. Expected Annual Loss is measured in dollars. The Community Risk Factor is a scale factor. Based on these units and the calculation used for Risk, what is the Risk value measured in? How does this relate back to the general definition of Natural Hazard Risk discussed in part I #4?

2. Use the formula you created to calculate the Risk for the first census tract in cell G2 (remember to begin the formula with =) and then copy and fill this formula to calculate the Risk for each of the census tracts in La Paz County, AZ.

   a. Which census tract has the highest Risk value? How does this relate to the tract's Expected Annual Loss (EAL_VALT) and Community Risk Factor (CRF_VALT), relative to the other census tracts in La Paz County?

   b. Which census tract has the lowest Risk value? How does this relate to the tract's Expected Annual Loss (EAL_VALT) and Community Risk Factor (CRF_VALT), relative to the other census tracts in La Paz County?

   c. Find the census tract for part (b) on the NRI map. What do you notice about this tract, and why do you think this is the case? What should we expect for the risk, based on the Social Vulnerability and Community Resilience levels given?

   d. Which census tract has the second lowest Risk value? How does this relate to the tract's Expected Annual Loss (EAL_VALT) and Community Risk Factor (CRF_VALT), relative to the other census tracts in La Paz County?

3. A county's total risk is the sum of the Risk for each census track. Use the spreadsheet command =sum(*range of values*) in cell G14 to find Total Risk for La Paz County, AZ.

4. Complete the census tract Risk and Total Risk calculations for the other counties on the remaining tabs of the Sample Counties for Risk Calculation, Piscataquis County, ME, Washoe County, NV, Hawaii County, HI, and Hennepin County, MN.

5. On the Risk Index map, the Risk scores are given as percentiles. List the Risk percentile from the Risk Index map and the Total Risk value you calculated for each county in the table below. *Be sure to include the units in the Total Risk Value.*

County	La Paz, AZ	Piscataquis, ME	Washoe, NV	Hawaii, HI	Hennepin, MN
Risk Percentile					
Total Risk					

Do the Risk Percentiles make sense in comparison to the Total Risk value? Why or why not?

6. The Bureau of Economic Analysis (US Department of Commerce) provides information on per capita (per person) **personal income** by county, listed in the table on #7 below. (https://www.bea.gov/data/income-saving/personal-income-county-metro-and-other-areas). Our spreadsheet has the population for each census tract. How can we use this information to estimate the total **personal income** for the entire county?

7. Use the spreadsheet to find the total population for each county, then estimate the total personal income for each county. Record this information in the table below, along with the results from #5.

County	La Paz, AZ	Piscataquis, ME	Washoe, NV	Hawaii, HI	Hennepin, MN
Risk Percentile					
Total Risk					
Total Population					
Personal Income per Capita	$53997	$49863	$78078	$49476	$89851
Total Personal Income					

8. Is there a relationship between a county's Risk and its population? A county's Risk and its Total Personal Income? Is it appropriate to expect a relationship between these variables? Why or why not?

9. Use the information to calculate the Total Risk divided by Total Population for each county (record it in the table below). What units does this rate have and what does it mean?

10. Use the information to calculate the Total Risk divided by Total Personal Income (record it in the table below). What units does this rate have and what does it mean? Would it be appropriate to convert it to a percent? Why or why not?

County	La Paz, AZ	Piscataquis, ME	Washoe, NV	Hawaii, HI	Hennepin, MN
Total Risk ÷ Total Population					
Total Risk ÷ Total Personal Income					

11. If we order the sample counties by Total Risk ÷ Total Population, does this order differ from the order by Risk alone? What information does Total Risk ÷ Total Population provide which may account for this?

12. If we order the sample counties by Total Risk ÷ Total Personal Income, does this order differ from the order by Risk alone? What information does Total Risk ÷ Total Personal Income provide which may account for this?

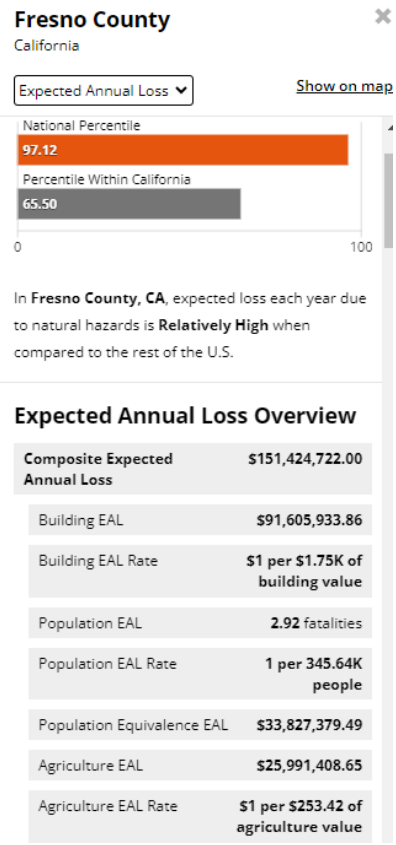
13. If you could compare Risk to other data variables not already included, what would these be and why?

Extension: Repeat the analysis with two counties of your choice and compare all seven counties. Data at the census tract level is available to download in CSV format at https://hazards.fema.gov/nri/data-resources#csvDownload.

PART IV: Focusing on Community

Let's explore percentiles within the National Risk Index and apply

1. Exploring Fresno County, California, we can see that this county is in the 97.12 percentile of the *Expected Annual Loss* nationally and in the 65.50 percentile within California. What does this mean with respect to all U.S. Counties and counties within California? Draw a diagram to illustrate these differing percentiles.



Expected Annual Loss combines values for exposure, annual frequency, and historic loss ratios across the 18 hazard types. The *Expected Annual Loss* rates are intended to estimate the **average expected annual loss** for building values, population, and agriculture values within a community. They provide insight into the relative natural hazard intensities regardless of the community's exposure value allowing for the comparison of expected losses regardless of community size.

2. The Fresno City Hall was built at a cost of $28 million. Fresno County has a *Building Expected Annual Loss Rate* of $1 per $1.75k of building value. Use this rate to find how much Fresno City Hall contributes to the overall *Building Expected Annual Loss*.

3. The 2020 US Census indicates that the population of Fresno City was 542,107 while the population of Fresno County was 1,008,650. The *Population Expected Annual Loss Rate* is 1 person per 345.64k people.

a. Use this rate to find the average expected annual loss of life in Fresno City.

b. Use this rate to find the average expected annual loss of life in Fresno County.

c. What percentage of average expected annual loss of life is attributable to Fresno City?

4. According to the 2017 Census of Agriculture County profile (published by the US Department of Agriculture) the market value of the products sold was $5,742,769k. The *Agricultural Expected Annual Loss Rate* is $1 per $253.42 of value. Use this rate to find the average expected annual loss with respect to agriculture in Fresno County.

5. Identify a US county that interests you; you may choose a county you previously explored.

   a. What is the national percentile for *Expected Annual Loss* for the county? Interpret what this percentile means for the county, and how it relates to Fresno County. Locate the county on the diagram you drew in #1.

   b. Compare the three rates for *Expected Annual Loss* for Fresno County and the county you selected. Which county's rate is higher/lower? How does this relate to their corresponding national percentile for each *Expected Annual Loss* rate?

      i. *Building Expected Annual Loss*

      ii. *Population Expected Annual Loss*

      iii. *Agriculture Expected Annual Loss*

   c. Scroll through the panel on the right to explore the various hazards. Form a hypothesis for why each of the annual loss rates is higher in one county compared to the other.

      i. *Building Expected Annual Loss*

      ii. *Population Expected Annual Loss*

      iii. *Agriculture Expected Annual Loss*

Further Exploration:

The following spreadsheet contains three worksheets: County, Census Tract, and Side-by-Side. You will be entering data into the first two sheets and analyzing the third.

1. Select a county within the United States. [https://hazards.fema.gov/nri/map]. Perhaps it is where you live, where you visit, or someplace you often go. Click the dropdown on

the right and select “Expected Annual Loss”. Enter the values for Expected Annual Loss, Exposure, and Frequency for each risk type into [insert Hazard Exploration Spreadsheet]. This spreadsheet will calculate the Loss Per Event and Percentage of Damaged capital. What does the data tell you about this county with respect to various disasters?

2. Now click on “Census Tract View” and select a census tract within the county you selected. Enter the data for Expected Annual Loss, Exposure, and Frequency into [insert Hazard Exploration Spreadsheet]. What differences do you notice between the selected county from (1) and the selected census tract? What do you believe contributes to these differences?

PART V: Reflection

Recall the explanation of the National Risk Index: “a dataset and online tool to help illustrate the United States communities most at risk… intended to help users better understand the natural hazard risk of their communities” (FEMA, 2023).

1. What are the index values for your community?

2. What do these values say about your community?

3. How accurately does this apply to your community?

4. What unique aspects of your community does this value seem to exclude?

5. What further information do you think would be useful for exploring Risk in your community?

6. What suggestions to you have for your community to decrease its Risk?

We began our exploration with the discussion of how we seek to understand complex situations with many variables by summarizing these situations with a single value, like the National Risk Index. After exploring counties and communities across the United States, how well do you think the National Risk Index does what it intends to do?

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