**A set of Activities for Teaching Core Content core content from the UCGIS GIS&T Body of Knowledge**

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This document presents a set of activities to teach core concepts in the UCGIS GIS&T Body of Knowledge as a proof of concept, advocating for a comprehensive e-Book.

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**Introduction: The UCGIS Body of Knowledge as an Instructional Resource.**

What are the best resources to teach GIScience? The array of textbooks, lessons, blog essays, software tools, and other resources continues to expand in volume and in the diversity of applications and in domain areas. One of the best content resources in my judgement is the Body of Knowledge from the University Consortium for Geographic Information Science (UCGIS).

The UCGIS is a non-profit organization that creates and supports communities of practice for GIScience research, education, and policy endeavors in higher education and with allied institutions. It is the professional hub and organization for the academic GIS community in the United States, with partnerships extending this capacity abroad.

University Consortium for
GEOGRAPHIC INFORMATION SCIENCE
GIS&T Body of Knowledge

As a part of its mission to expand and strengthen Geographic Information Science education, the UCGIS documents the domain of GIScience and associated technologies (GIS&T) through a *Body of Knowledge.* This living, digital assemblage of chapters was first launched in 2016, and new and revised content is continually added as new chapters from a wide variety of individual and group authors.

Why is the UCGIS Body of Knowledge among the best to use for GIS instruction? In my view, there are six main reasons, though I could argue that more reasons exist:

(1) The project has roots in the original National Center for Geographic Information and Analysis (NCGIA) Core Curriculum project, a rigorous set of content that I and other instructors used from the 1990s into the early 2000s.
(2) Some content has been curated from the first GIS&T Body of Knowledge, published in 2006, which was vetted from some of the most expert GIScience instructors and researchers.

(3) The Body of Knowledge is online, so it can be used in its entirely, in blocks (for example, by knowledge area), or as individual chapters. Its content is updated as GIS tools, data, education, and society evolve. This is essential given the rapid pace of change in the theory, applications, and technology behind GIS, as well as the dynamic nature of societal institutions (before and during COVID times) and expectations.

(4) The content is rigorous: As of the end of 2021, the Body of Knowledge contained 211 chapters, covering 10 knowledge areas. These 10 knowledge areas include the following:

1. Foundational concepts (such as set theory, time, and networks),
2. Knowledge economy (such as competence in GIS work, and project planning and management),
3. Computing platforms (such as mobile devices and cyberinfrastructure),
4. Programming and development (such as Python and GIS APIs),
5. Data capture (such as ground verification and accuracy assessment, and multispectral imagery),
6. Data management (such as data models and map projections),
7. Analytics and modeling (such as spatial queries and agent-based modeling),
8. Cartography and visualization (such as terrain representations, data types, and representing uncertainty),
9. Domain applications (such as agriculture, real estate, and digital humanities), and
10. GIS&T and Society (law and policy, governance, and critical perspectives).

(5) The structure of the Body of Knowledge is perfect for instruction: Free, open to all, modular chapters, that can be used in a sequential manner or used as-needed to meet instructional, course, and program needs. Each chapter is clear, short, and practical while also providing theoretical foundational content. Graphics are helpful and relevant. The structure of the body of content library makes it easy to search, find, and use its content. The interface and the content is not over-engineered nor is it burdened with needless items that do not contribute to teaching and learning.

(6) The authors not only are experts at the topics that they contributed to the Body of Knowledge, but they are also good instructors. I know many of them personally and I can attest that they are dedicated to advancing GIS knowledge to enable people to make smarter decisions no matter what domain area in which they are working. For several years, I served as content editor for the project, and I have authored two chapters in the Body of Knowledge. I have great respect for this library of work and the editors who have labored to gather and maintain the content, including Dr John Wilson from the University of Southern California who leads this entire effort and Dr Diana Stuart Sinton who supported and nurtured this effort for many years from her leadership position at UCGIS.

In sum, the project has roots in some major curricular resources of the past but is relevant for today: It is *current, authoritative, and rigorous.*

### Linking the UCGIS Body of Knowledge to Hands-on Activities

Because the focus of the GIS&T Body of Knowledge is education, and because much of that education is aimed at practical ways of teaching, each chapter includes learning objectives and instructional assessment questions that instructors can use to teach the specific concepts. However, one thing that is missing in my view is a set of practical activities that instructors could use to teach each concept.

Because my career focus is on GIS in education, and because I have spent many years writing GIS-based curricular items for lesson libraries, journals, and books, I thought it would be instructive and helpful to the community to illustrate how selected content from the Body of Knowledge could be taught using today's modern web GIS tools, maps and apps, and data.

Why are such a set of activities needed? First, GIS is a visual language, and hands-on activities with maps and visualizations is a natural fit and a logical aid in the learning of GIS. Second, GIS is an applied methodology; an approach to solving problems. The best way to learn GIS is to use it to analyze patterns, relationships, and trends, and to solve problems in our 21st Century world. Third, instructors are busy people, and they often lack the time to develop their own activities to teach fundamental concepts, particularly activities that are based on a rapidly evolving platform such as GIS. By providing these activities, my aim is to provide students with thoughtful and useful activities to cement their readings of concepts in the UCGIS GIS&T Body of Knowledge, and to provide instructors with ways of teaching those concepts.

➔ Furthermore, I propose that an expanded version of this concept of linking foundational chapters in the Body of Knowledge to activities be published as an e-Book and library to accompany the Body of Knowledge. Such a book could be useful to instructors in GIS&T, and also in other disciplines looking for ways to incorporate hands-on activities to foster critical thinking, spatial thinking, and problem solving in their curriculum, courses, and programs.

  I look forward to hearing the community's reaction to such a proposal. Who has time, interest, and expertise to take this concept and the examples I have written here, and expand this to a full e-Book?

For this proof of concept, I have chosen 5 selected Body of Knowledge chapters to teach from using hands-on activities. These include two that I authored or co-authored and three additional chapters:

(1) Location Privacy.
(2) GIS&T Education and Training.
(3) Error-based Uncertainty.
(4) Scale and Generalization.
(5) Common Thematic Map Types.

For each chapter, I have created 3 activities. These activities are meant as a proof of concept. Many more activities are possible given the ready availability of GIS tools and data sets. These activities can be used as is, but I also encourage you be creative—mix and match, and modify activities as you see fit to meet your course and program objectives.

**The Activities: Overview:**

(1) Location Privacy.
   A) Teaching location privacy and resolution with a big pixel image.
   B) Considering location privacy when sharing photos.

C) Investigating ethics and location privacy through case studies.

(2) GIS&T Education and Training.
   A) Teaching spatial thinking and geotechnology skills through mapping business locations.
   B) Investigating international migration through a web mapping application.
   C) Examining the world's water balance through a web mapping application.

(3) Error-based Uncertainty.
   A) Analyzing earthquakes in ArcGIS Online.
   B) Cartographic vs. Geographic Basemaps: USGS Topographic Maps Example.
   C) Considering sampling frequency in mapping: Real-time weather investigation.

(4) Scale and Generalization.
   A) Investigating coordinate precision.
   B) Investigating building footprints in ArcGIS Online.
   C) Walking on Water? Investigating resolution and scale.

(5) Common Thematic Map Types.
   A) Examining color on maps using the Color Brewer.
   B) Investigating dot density maps with ArcGIS Online.
   C) Mapping isolines with Axis Maps contour tools.

**The Activities: Details:**

**1. Location Privacy.**

The location privacy chapter in the Body of Knowledge begins by defining privacy and location privacy, describing reasons for privacy concerns surrounding GIS&T, and then makes the case that these issues are more important now than ever before. Technological trailblazing tends to precede legal safeguards. The development of GIS tools and the work of the GIS&T research and user community have typically occurred at a much faster rate than the establishment of legislative frameworks governing the use of spatial data, including privacy concerns. Yet even in a collaborative environment that characterizes the GIS&T community, and despite progress made, the issue of location privacy is a particularly thorny one, occurring as it does at the intersection of geotechnology and society.

**Location Privacy Activity 1: Teaching location privacy and resolution with a big pixel image.**

This activity invites you to use a high resolution image to foster considerations about resolution and location privacy. Ever since those ultra-high-resolution "gigapan" or "gigapixel" images began appearing from Microsoft and other sources a decade ago, the public has been fascinated by them. They can also serve as useful instructional tools to teach about location privacy and resolution. For example, use the following image taken off of the Oriental Pearl Tower in China (at 468m this was the tallest tower in China, from 1994 to 2007). Note that the working URL for this image is here: http://en.bigpixel.cn/t/5834170785f26b37002af46d but that the URL is not secure and that its URL changes often. If when reading this essay the link is not working, do a search on "big pixel Shanghai" on the web and locate its new home. And/or, substitute another big pixel image for the above. The Shanghai tower and other similar images are compiled from billions of pixels, and thus, its resolution allows the user to zoom from small to a very large detailed scale. A video on how I teach with it is here.

*Big pixel image from Oriental Pearl Tower in China–initial view.*

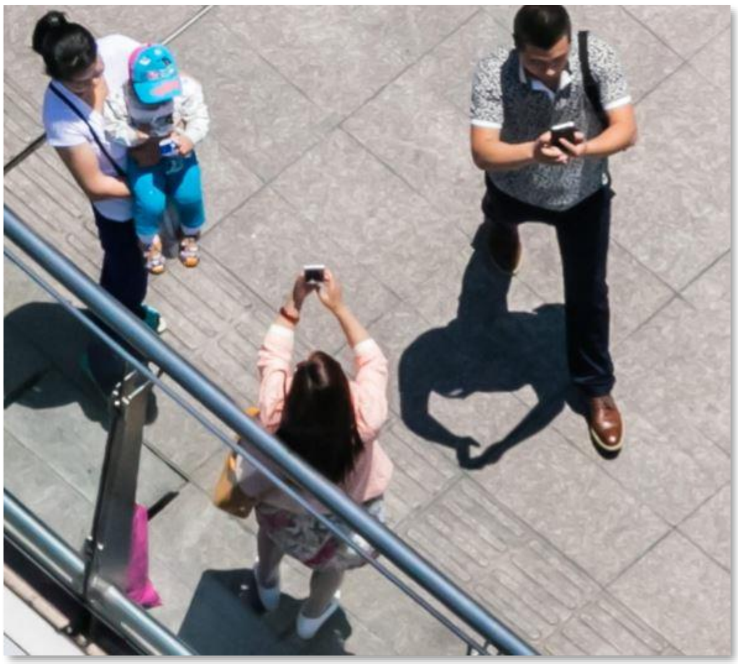

*A larger scale section of the above image. You can even determine what is on the dashboard of people's cars.*

First, examine the cultural geography, assessing the land use, zoning, traffic, and other aspects of the built environment. How much of the local culture, commerce, and other aspects of the city can be determined from the image alone? Second, examine the physical geography–the terrain, the vegetation, the landforms, the river winding through the city, and other aspects of the physical landscape. These questions can be asked in a GIScience, cartography, geodesign, or geo-visualization course, but also in cultural or physical geography courses.

Third, and more specifically for GIS&T courses, consider the resolution and tie their reflections to what you have discussed thus far on this topic in your course. Consider: How much detail can you see in the foreground vs the background? If time permits, compare this image to another gigapan image somewhere else. Can you see inside office buildings? Can you see inside residential windows? Can you read license plates on cars? What are the pros and cons of being able to do so?

Can you determine what pedestrians look like to the degree that you would recognize them on the street if you saw them face to face?

Consider and discuss: Do your answers and the resolution of this image bring up any ethical concerns?



*Big pixel image from the Oriental Pearl Tower in China–one detailed view out of thousands that exist simply by zooming in to a large scale across the image.*

Fourth, consider the related topics of The Internet of Things and our connected world. Where does information come from? Increasingly, information is from webcams, sensors, and also from the largest network of all--humans—a network of 7.5 billion people collecting data.

Discuss: What kinds of information are those humans gathering, both intentionally and unintentionally?

Discuss face recognition software and how none of the faces in this big pixel image (as of this writing) are blurred. What are the implications for blurring faces? What are the implications for not blurring?

Fifth, take a random sample of 10 people that you find across the gigapixel image. How many people are holding a tablet or smartphone? Do the results surprise you?

How many of those on their phones are obviously taking a picture? Take 1 more random sample of 10 and compare to the first sample. What implications do your survey results of 10 people have on information, and for society?

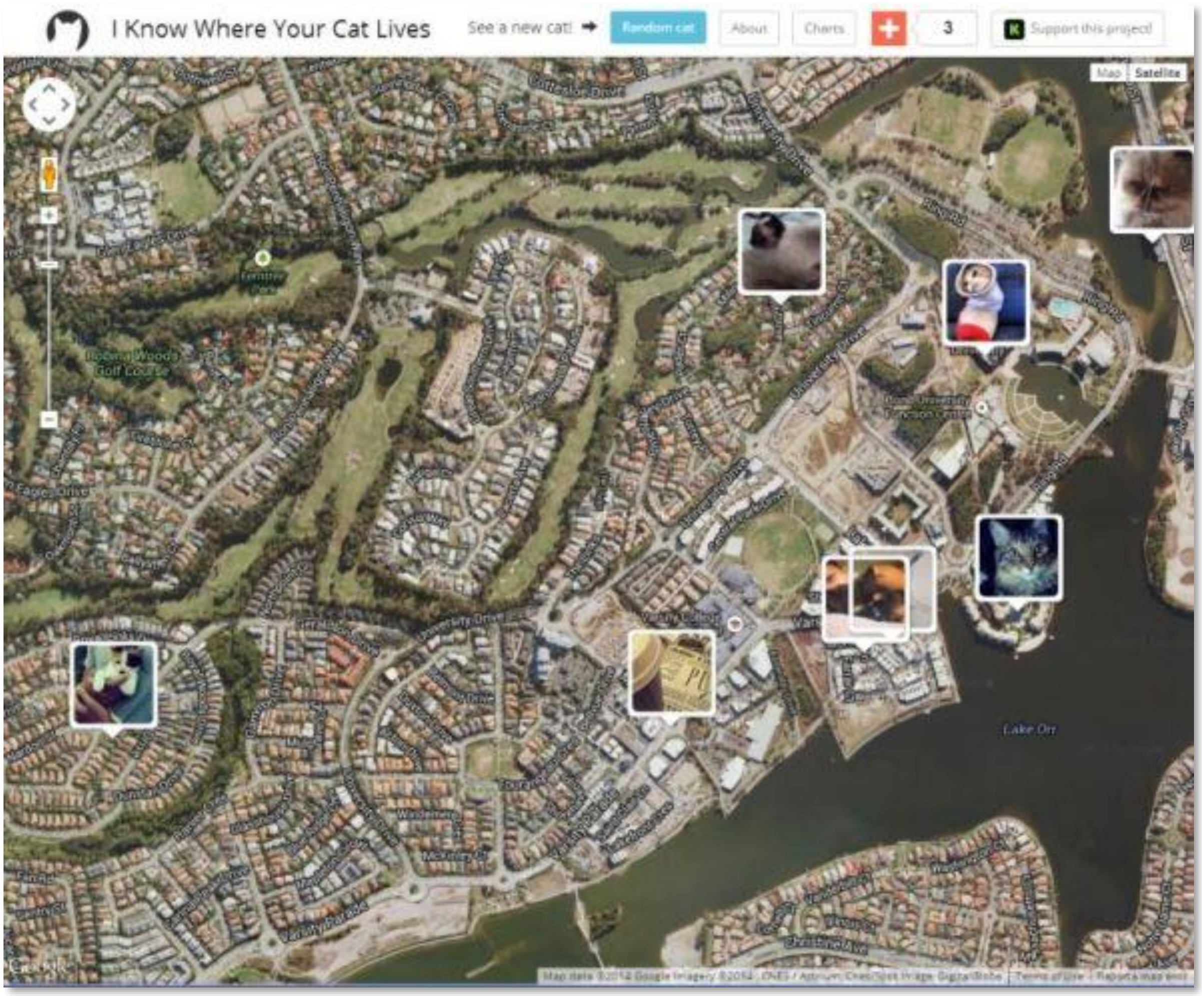
Consider the photos and videos that all of these people are recording, posting, and marking the locations of. Are the movements of the people carrying these devices being tracked on purpose (such as via a fitness app, or because people have location tagging enabled on their camera)? Are the movements being tracked inadvertently? What services and tracking might be blocked or enabled depending on the country the person happens to be standing in, in this or other gigapan photographs? What are the positive and possible negative implications of each?

Consider that probably none of these people realized they were being captured by the gigapan image. What are the implications of this image or being captured on a daily basis by traffic cams, other people's phones and cameras, and other image-gathering devices?

### Location Privacy Activity 2: Does posting pictures compromise privacy? Does posting pictures potentially harm the environment? Considering location privacy when sharing photos.

This activity asks you to read an article and consider the possibility that posting pictures may compromise privacy.

Read the following New York Times article: "What the Internet Can See from Your Cat Pictures". It begins with the statement, "Your cat may never give up your secrets. But your cat photos might." The article went on to describe a site that is named, appropriately, "iknowwhereyourcatlives.com", built by Florida State University professor Owen Mundy. The site's web map shows the locations and photographs of thousands of cats, and, presumably, the location of the cat owners. The site was created to demonstrate "the status quo of personal data usage by startups and international megacorps who are riding the wave of decreased privacy for all," Professor Mundy wrote describing the site.




*Pet pictures mapped in an online mapping tool by location.*

Using this article and other posts about location privacy in the Spatial Reserves data blog, discuss the following: As the world becomes ever more monitored and measured, the 7.5+ billion humans inhabiting it are increasingly affected by these and other monitoring activities. They are also increasingly contributing to vast archives of data, often inadvertently, in part through the "Internet of Things." As an increasing proportion of the data collected can be mapped, so can people's location, movements, and habits. The Spatial Law and Policy site alone contains news and dozens of documents pointing to current issues of location privacy in our everyday lives. Examine and discuss the story about privacy in the Boston Marathon and frequent reflections about laws and expectations of location privacy. Do you think geospatial professionals be trained in the awareness issues? Why or why not? And if so, how much should they be asked to know?

Geospatial technologies have proven to benefit our planet in ways unimaginable even a few years ago. However, those involved with the geospatial industry need to be included in the conversations about the privacy implications of the types of data collected to make improvements on our planet. And even seemingly innocuous activities such as posting pictures of your cat have their share of privacy implications.

Read the following National Geographic article about the potential harm of "over-loving" a place resulting from tourists posting geotagged photographs: https://www.nationalgeographic.com/travel/features/when-why-not-to-use-geotagging-overtourism-security/

Discuss: Do you have any mixed feelings about photographs potentially harming a place? What kinds of places are most precious and interesting to you?

As someone keenly interested in the protection of natural places such as caves (the author of this essay is a lifelong caver and a geographer), riparian zones, beaches, lava fields, prairies, woodlands, and many other special places, part of me wants to see few visitors tramping on those places. Hence, I understand the point that the article makes about overexposure to places, whether from guidebooks, tweets, Instagram posts, Google map posts, or via other means. But as someone who at the same time wants to know about these places so I too can explore them, I can well appreciate the crowdsourcing efforts happening on our planet. These efforts include the sharing of ordinary and extraordinary places on our planet for the sheer joy of them and telling others about these places. Does a solution exist reconciling these two viewpoints?

On the potential downside of geotagging photos, consider the following synopsis of the following story about potential harm to rare species from location-tagged data: https://spatialreserves.wordpress.com/2017/11/20/potential-harm-to-rare-species-from-location-tagged-data/

Discuss the following: (1) Do you think sharing photos of a place does more good or more harm? (2) What is your opinion of the percentage of positive impact vs. negative impact that geospatial technologies are having? (3) Do you post pictures of yourself, your pets, or anything else to social media? Do you include the location with those photos? Does it matter if you do or do not do this?

### Location Privacy Activity 3: Investigating ethics and location privacy through case studies.

This activity invites investigation into selected case studies to understand ethical implications of GIS&T. Thanks to modern cloud-based GIS, everyone is potential data creator, not simply a data consumer. And because maps are powerful means of communications, maps that are shared with millions of potential data users need to be created with thoughtful care. Embedded in the decisions about how, when, and where to create and share maps are ethics. Examine the case studies in this collection from Penn State. How many of them are related to location privacy?

Dig deeper into the following three case studies: (1) Tracking mobile phones in mobility research, (2) low-level radioactive waste siting map, and (3) geo-tagging bear-baiting hunting sites.

For case study (1): Discuss the following: Should the researchers described in this study have been required to acquire informed consent before their phone calls and movements were tracked, even though individuals' names were removed from the records? What is the connection between location privacy and tracking phones in mobility research? What are the implications of using mobile phone usage and movement in light of the COVID era when such data could potentially be used to track the source and spread, and possible mitigation, of outbreaks of pandemics such as COVID?

For case study (2), discuss the following: How do you think the GIS analyst should respond to the contractor in terms of the most suitable scale at which to map the potential waste sites? Why? What are the possible connections between location privacy and the mapping of potential sites for low level radioactive waste?

For case study (3), discuss the following: How do you think Alaska Department of Fish and Game should respond to the citizens group that has petitioned the Alaska Department of Fish and Game to require hunters to specify bait station locations with GPS coordinates? Name 2 possible *benefits* that gathering and publishing the coordinates would bring, and the groups that could benefit. Name 2 possible *harmful effects* that gathering and publishing the coordinates would bring, and the groups that could be harmed. What is the connection between location privacy and the mapping of bear bait stations?

Which of these 3 case studies do you think has the most potential concern for location privacy? Why?

Which of these 3 case studies could possibly affect you in the future? How?

## 2. GIS&T Education and Training

The GIS&T Education and training chapter in the Body of Knowledge begins by analyzing the roots of education and training in formal educational settings and in professional development. It makes the case that methods and approaches for teaching and learning *about* geospatial technologies and *with* geospatial technologies have evolved in tight connection with the advances in the internet and personal computers. The chapter details what those advances were, how they impacted GIS, and what their implications were on the need for and the delivery of GIS education. The evolution of GIS education in schools and universities, professional development in the workplace, and GIS educational research are described, along with a look toward future needs and trends. The chapter describes how the adoption and integration of GIS and related geospatial technologies into dozens of academic disciplines led to a high demand for instruction that is targeted and timely. The chapter recognizes that the combination of "targeted and timely" is challenging to meet consistently given the widening of and diversifying of audiences and settings. The chapter ends by discussing academic degrees, concentrations, minors, certificates, and numerous other programs that have abounded within formal and informal education.

I submit that the goals of GIS&T education and training include fostering spatial thinking, critical thinking, problem solving, holistic thinking, data fluency, consideration of societal issues surrounding GIS, and rigorous use of GIS tools, I have designed the following activities so that students are using accessible web based GIS tools but using the most important tool of all—their brains.

### GIS&T Education and Training Activity 1: Teaching spatial thinking and geotechnology skills through mapping business locations.

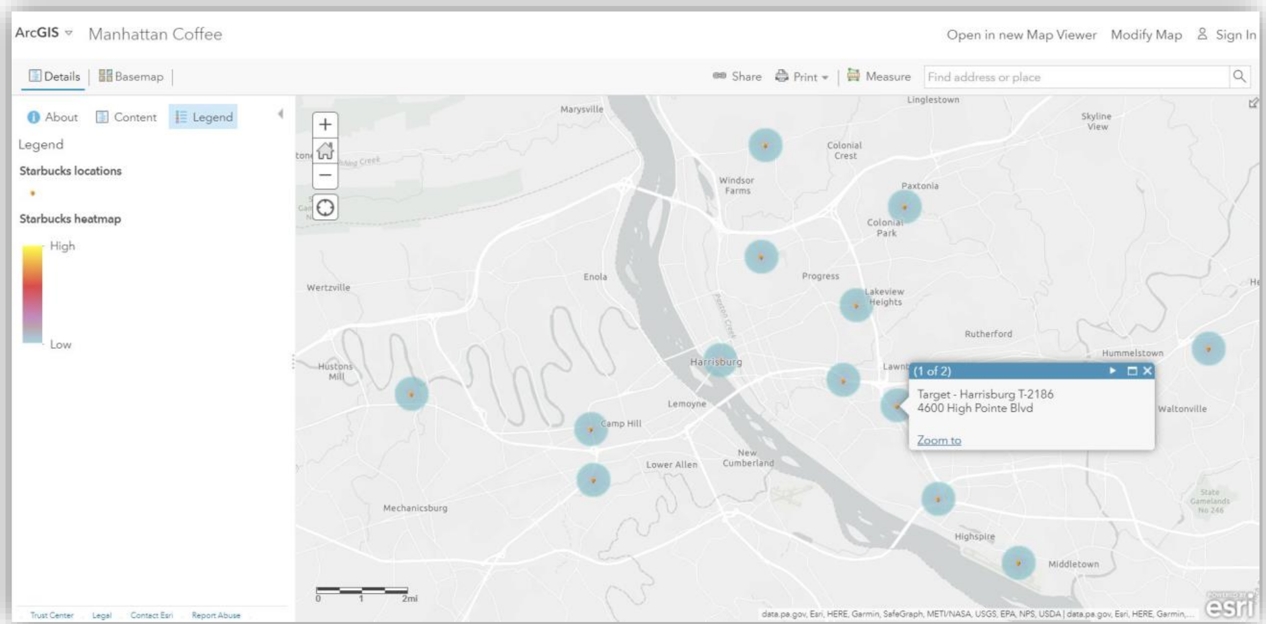
In this activity, you will have the opportunity to hone your spatial thinking skills and GIS&T skills through interacting with a map and a set of data in a web GIS environment (ArcGIS Online). Examine this interactive web map of Starbucks coffee establishments around the world. The Starbucks data has been loaded into ArcGIS Online, a web based GIS from Esri. The map is global in scope but first opens with a view centered on Manhattan, one of New York City's boroughs. After examining the map, read the following text and discuss the questions posed.


*Starbucks heatmap for New York City in ArcGIS Online (showing classic viewer; you can use the new viewer if you would like).*

Consider the cartography used: The data are displayed as points and also as a *heat map*. How do the points and the heat map help you understand the number and distribution of Starbucks? Which is better—the points, or the heat map, at a large scale? Which is better at a small scale? A heat map shows the relative clustering of data, with "hot" or "bright" colors indicating clustering of a certain variable or feature, and "cool" or "green-blue" colors indicating areas containing fewer of a specific variable or feature. A heat map doesn't show "temperature" or "hotness" but is so named because of the bright colors showing "more clustering" of something. Furthermore, a heat map is different from a "hot spot" map; the latter shows areas of statistically significant difference.

Clustering. The objective of GIS is never *just* to make a map; it is to *understand* the issue or phenomenon being mapped. Why are Starbucks clustered in this part of the New York City and not in other parts? To assist you in your answer, use Basemap > change the basemap to Imagery with Labels. Zoom in to Manhattan. You can use the Show Contents of Map button to display the map layers, and then toggle them on and off as shown below (or make them semi-transparent from a menu from the (…) choice when you click on and expand the individual layers). Note how the data changes in its symbology as you change the scale (zoom in and out), which is a powerful feature of modern GIS.

In the search box near the map, enter Harrisburg PA and zoom to Harrisburg. Compare the number of Starbucks in Harrisburg versus New York City. Consider where Starbucks are concentrated in Harrisburg. Does this pattern surprise you? Do some research and find the population of New York City and Harrisburg. Does it surprise you that there are fewer Starbucks in Harrisburg than in New York City?




*Starbucks in the Harrisburg PA area shown in ArcGIS Online.*

Clustering is often performed automatically in a modern GIS. It can be powerful, but it can also hide data that you may wish to explore. In any GIS, know how to turn clustering off if you need to.

In the search box, enter Champaign, IL (home of the University of Illinois), note the number of Starbucks, and then do the same for Macomb, IL (home of Western Illinois University). Which city do you think is larger? Examine Illinois cities by population here: [https://www.illinois-demographics.com/cities_by_population](https://www.illinois-demographics.com/cities_by_population) Which university do you think is larger?

Think bigger picture: Consider different specific types of business—a gas station, convenience store, concert hall, home improvement store, airport—they all have different population thresholds that they must meet. Some are viable in a small town or even in no town at all, while others, such as IKEA or other chains with a large footprint, need a large nearby population base to stay in business.

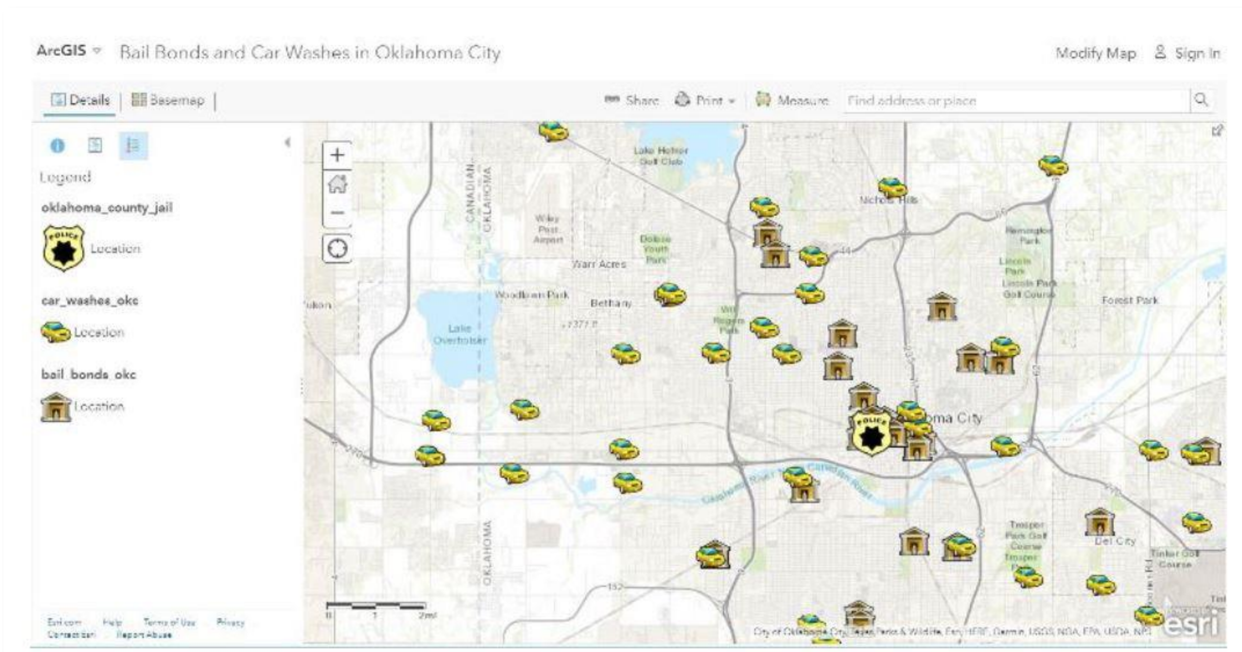
How are Starbucks distributed in other major cities around the world? Shanghai? London? Go to these places on the Starbucks map. Compare the distribution and number there vs. New York City. Think about the types of products sold at a Starbucks. How does the type of product sold or delivered by a business influence where it expands globally?

Next, consider a company's headquarters location: The headquarters of Starbucks is in Seattle Washington, located in the northwest corner of the continental USA. How does the location of the headquarters of a chain influence where, how, and the rate at which it expands? What are 2 other factors that influences if and when a business could expand? Name 1 other business chain that you have visited that has spread regionally, 1 that has spread nationally, and 1 that has spread globally.

Through the use of these web GIS tools (here, ArcGIS Online), and representing data with cartographic elements, you are thinking spatially, considering geography, but also sociology (consumer preferences), and economics (prices, personal income, global trade).

**Mapping other businesses.** You can map the location of *any* business as point data. Consider the following [map of 2 types of businesses in a different city, for example, car washes versus bail bonds (Links to an external site.)](#) Open this map; it will look similar to the image below. Turn on and off the 2 layers, one at a time. Describe the spatial pattern of each type of business. Which is more dispersed? Which is more clustered? Why do the 2 businesses mapped exhibit different spatial patterns? What is the relationship between bail bonds and the location of the county jail? Consider antique malls—would these tend to be clustered in a city, or dispersed? Why? Consider convenience stores—would these tend to be clustered in a city, or dispersed? Why?

Note the symbols that are used for this map. In this case, we are interested in the location of the businesses, rather than how much sales volume occurred at each or the number of employees. The businesses are mapped as *discrete symbols.* Think about whether these symbols are suitable or confusing. Experiment with changing the symbols to something else.




*Two types of businesses in a metropolitan area. Source: Joseph Kerski using ArcGIS Online classic viewer.*

To the left of the map > Contents > open the table for your car washes layer. This table represents the "I" part of GIS. Note how many car washes are in this dataset. Do the same thing for the bail bonds layer. Which business contains more sites in this metropolitan area?

**Be critical of data—including maps.** In each of these maps and in others in these hands-on activities, *always* investigate the source of the map layer. Where did the map data come from, who created it, at what scale was it created? Is it curated? Is it trustworthy? Is it suitable for your use? These are elements of *metadata,* which is especially important in mapping. In this case, the Starbucks metadata does not contain much information, but there is some information available here: http://www.arcgis.com/home/item.html?id=33f0d1a9b4d6453e8f6110c9eb2c36d5 (Links to an external site.)

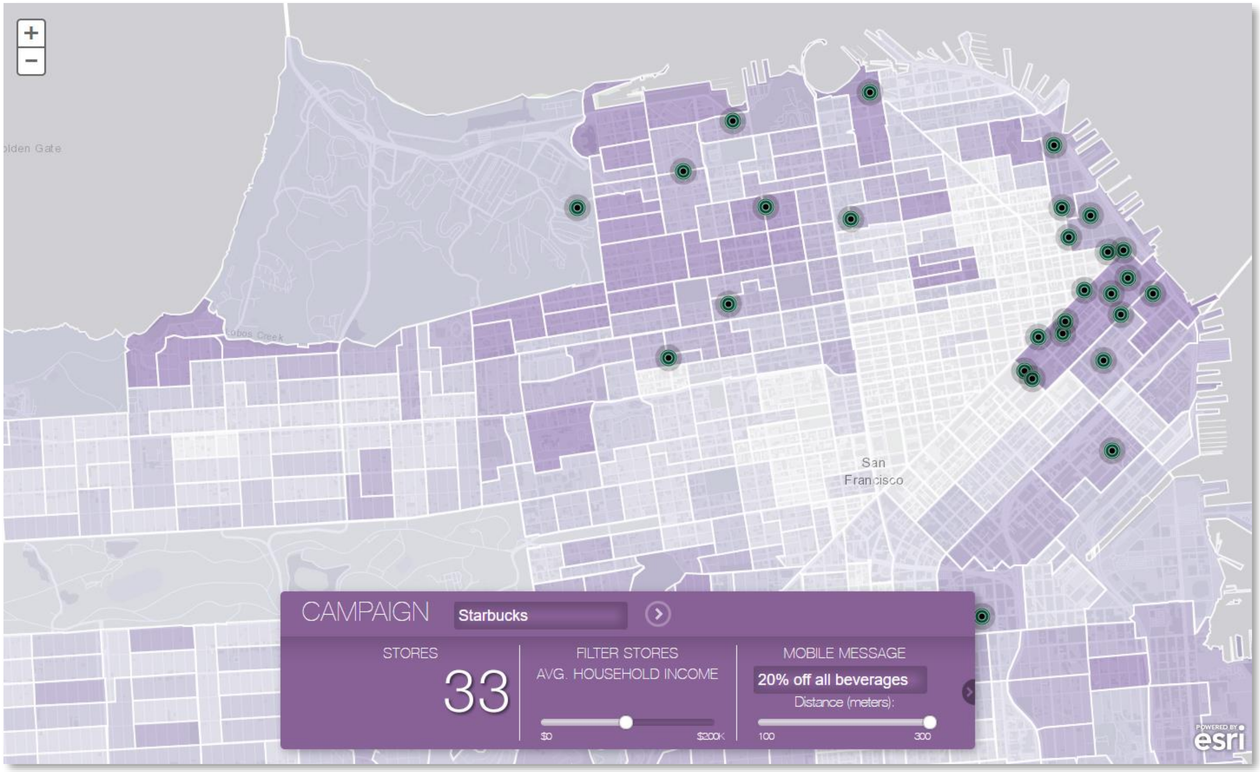
What is the date of the Starbucks data? Think about which data you might want to map where having data 10 years out of date is OK (such as geologic strata of Pennsylvania) and on the opposite end of the spectrum, when even data that is 1 day old may not very useful (such as mapping current wildfires in California).

Thus, be critical of the data. **Make sure you question ALL data on the web, including and** *especially* **maps!** Maps have an aura of authenticity and are often taken as “the truth.” But, nowadays, *anyone* can make a map and post it to the web. All maps are inaccurate, because they are representing the oblate spheroid that is the Earth on a 2D or even projected 3D image on your computer screen. Furthermore, maps, including satellite imagery, are only *representations* **of reality**—and hence, are symbolized and generalized and processed in various ways. There are many maps that show false information, and also, many maps that may be useful but contain no metadata. Despite their limitations, maps are incredibly *useful representations of reality*. But to make effective use of maps, make sure you understand the benefits and limitations of maps and always be critical of them.

**A business web mapping application.** Open the following Starbucks web mapping application for San Francisco.

The map you were examining earlier of Starbucks was a map in ArcGIS Online. Now you will be for San Francisco examining a web mapping *application*. A web mapping application contains one or more web maps, wrapped in a 'shell' with additional information (tools, text, images, functionality, and so on). In this you will be using a web mapping application. A large part of your work in GIS&T in the future will be designing, building, and deploying these web mapping applications. In the past, most of the cartographic output was directed to plotters, with a goal of outputting onto paper or other physical material. Physical materials are still used sometimes, but nowadays, much more output is published to and consumed on the web.

Let's say you want to offer a coupon for Starbucks based on locations of stores, household income, and proximity to stores. Note how the number of stores changes as you change the thresholds for the household income and for the proximity. Note how the streets and areas outside the neighborhoods being examined are muted in gray, a very effective technique to direct your attention on specific areas of the city.




*Web mapping application – filtering stores by income and the distance for a mobile message coupon.*

**GIS&T Education and Training Activity 2: Investigating International Migration through a Web Mapping Application**. In this activity, you will use a web mapping application to teach and learn about GIS&T along with real world data across space and time. One of the maps in the [Esri Coolmaps gallery (Links to an external site.)]() enables you to [visualize migration data over time and space in a 2D and 3D tool (Links to an external site.)]() that is a powerful and effective web mapping application but yet is responsive in a web browser.

Open the map. The [map opens (Links to an external site)]() in 3D mode and also in Play mode, showing a set of data for selected countries. At the time of this writing, the play mode showed the UAE, Mexico, China, and Singapore during the 1990s, 2000s, 2010, and 2013. This selected set of countries provides a good introduction for teaching about the patterns, relationships, and trends in the data. The time periods are shown below the lower part of the map, with the out-migration and in-migration available for each of the four time periods. The thickness of the lines coming out from or going to each country selected indicates the amount of migration, and the end points of each line indicates the countries sending people to or receiving people from each country. For each country, the raw number of out- and in-migrants is indicated, along with the percentage of that country's total population for each time period.

**Consider the cartographic design.** After viewing the introductory data, use the "pause" button to stop the Play mode and to be able to use the drop-down menu to select from the list of the world's countries. The capability of selecting countries and time, the cartography, and the ability to switch between 2D and 3D combine to make this a useful teaching and research tool. Consider the cartography used: How does the dark gray basemap and the orange migration lines help focus your attention on the theme of migration rather than on the physical or cultural geography of the countries?

**Be critical of the migration data.** In keeping with the GIS&T theme about being critical of the data, ask, "Where did the data come from? Can you trust it?" In this case, the data came from the United Nations Trends in International Migrant Stock: The 2013 Revision is provided by the UN Department of Economic and Social Affairs. Use the "i" button to go to the data's source. Whenever possible, investigate the data at its source, and study how and when it was collected. Think about: How long does a migrant have to live in a country before he or she is no longer considered a "migrant", according to this data set? Think about: Not every country has a national census or publishes the results from their census. How does this affect your view of the data?

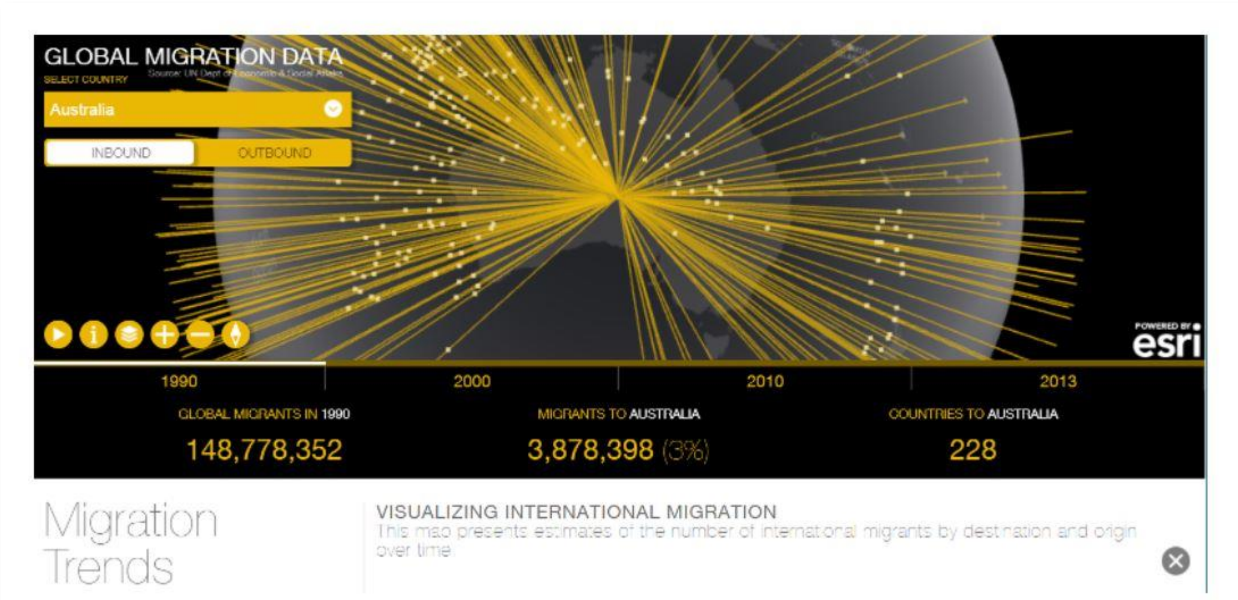
**Focus on 1 country.** Choose a country and ask deeper questions about it while analyzing the map. For example, Australia: How has Australian immigration changed in amount and in the countries sending migrants to Australia over the past 25 years? What are some of the social and political changes that are occurring in the country with the changes in migration? What do you think Australia will be like in 25 years if current trends continue?

Often, analyzing maps confirms certain hypotheses and preconceived notions and yet shatters others. For example, switch the country analyzed to the USA or Reunion Island and observe the high percentage of Reunion Island's population moving to the USA. Is it part of climate-induced sea-level rise migration? Or does it simply reflect that a large percentage of the country's relatively small population moved to the USA? Switch the country analyzed to Somalia: Compare the number of people moving to Somalia to the number moving from Somalia. Now compare the number of countries sending people to Somalia vs. the number where Somali people moved to.

Consider the social, economic, political, and personal reasons for moving from and moving to a country. How many people in your circle of close friends have moved to your local area in the past decade? How many have moved away? Why did they do so? The number of countries that sent people to Somalia is small, while the number of countries receiving Somalians somewhat higher. Dig deeper and consider: Given ongoing political, health, and economic challenges in Somalia, what keeps most of the population in Somalia rather than emigrating? Consider the financial resources required to move, the strong sense of place inherent in humans, and other factors that might be important. What would induce *you* to leave your homeland, particularly if it would entail leaving everyone you loved behind?

If the 3D map interferes with your understanding of migration rather than enhances your understanding, toggle to the 2D map. 2D might be particularly useful for countries like Australia with long distance international migration patterns. Note that Australia has one of the highest percentages of migrants living there of any country over 10 million people, at nearly 50% of the total population. (Links to an external site.) Which countries have high rates of both immigration **and** emigration? Why is this the case for these countries?

Given the changes you observe on the map over time, make 2 predictions of world population movement over the next 25 years and use the map's data to support your predictions.



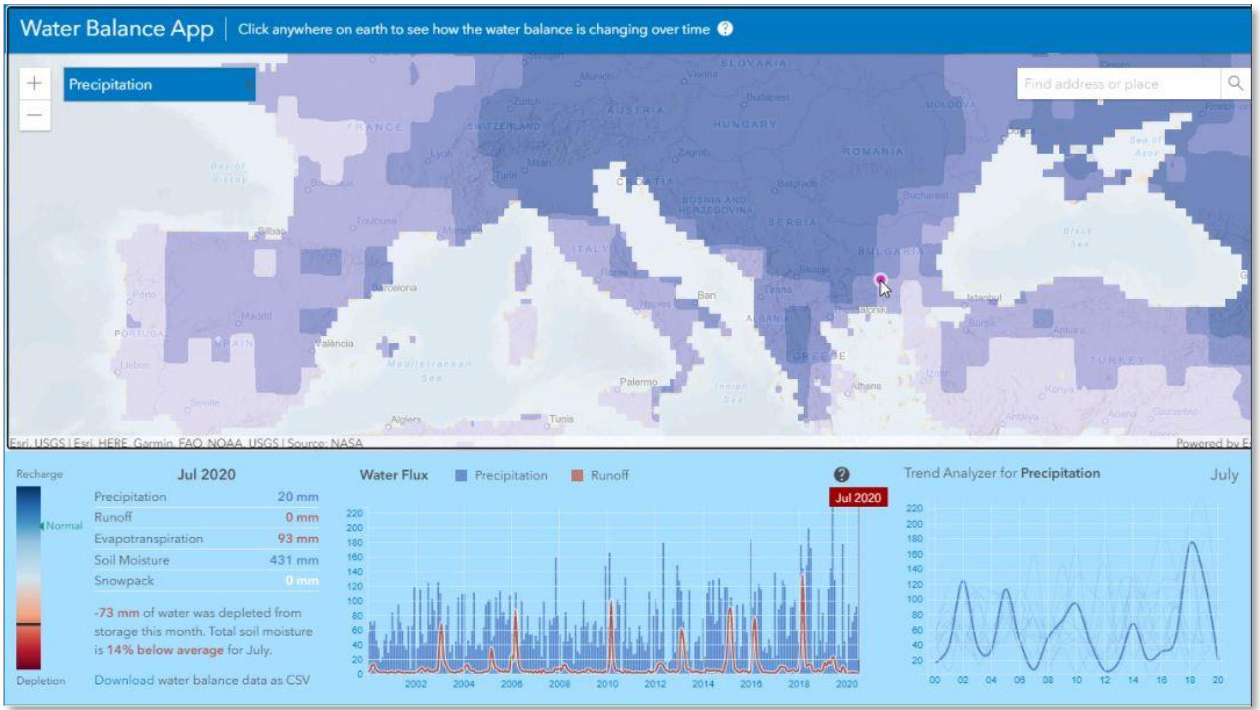

*Migration flows to and from each country 3D visualization.*

### GIS&T Education and Training Activity 3: Examining the world's water balance.

In this activity, you will use a web mapping application to foster spatial thinking and the use of GIS&T with real-world and near-real-time data. Turn your attention to the physical environment and access the Living Atlas of the World water balance, on: https://livingatlas.arcgis.com/waterbalance/. Water is critical to all life on Earth, and water quality and quantity are an important part of the UN's Sustainable Development goals, as integral as they are to survival, the environment, health, and economics. This web mapping application allows the user to examine 6 variables in the critical area of water resources, that you can access on the left side of the map, for any area in the world. Change the variable to precipitation. Click in the Amazon region in South America.

Pan across the graph along the bottom. Note that you can easily detect, rather than a summer and winter, a wet season and a dry season. Note the Y axis that indicates the amount of precipitation. Further note that this is not real-time data, but *near* real time data that is updated monthly with the latest data being a few months old. Note also that this data is aggregated and is of medium (several tens of square kilometers in cell size) resolution; certainly not for 1 or 10 meters in resolution, but very useful for regional studies. Can you find any other place on Planet Earth with a marked change between a wet season and a dry season? If so, name at least 1 other place. Hint: A famous one is in central India, with its monsoons.

Compare India and Brazil to your own location, noting the difference in the pattern of precipitation and the amount of precipitation. In what form does most of the precipitation fall in your area (snow, sleet, rain, hail) versus those areas you have been examining thus far? What difference do these forms make? For example, in some locations of the world, most of the precipitation falls as snow. Snowmelt provides soil moisture and water critically needed throughout dry summers.




*The Water Balance app, part of the ArcGIS Living Atlas of the World.*

Next, click in southeast Texas and determine if you can detect precipitation spikes, taking special note of the dates when these spikes occurred. Hypothesize based on the dates whether these spikes could be from major hurricanes and tropical storms over the past 15 years.

Next, click in southern Libya: Note the very low numbers on the Y axis there. Note further that many months and indeed, many years, experience no precipitation whatsoever. What is the longest period you can detect with no precipitation? Based on the precipitation regime here, what do you suspect the population density and the ecoregion types are in southern Libya? You could confirm your hypothesis by going to [www.arcgis.com](www.arcgis.com) (ArcGIS Online) and creating a map with a population and ecoregions layers, and zooming to southern Libya. Or, simply conduct online research outside of the use of web GIS tools.

From a cartographic standpoint, how effective do you think this web mapping application is? It is an example of increasing number of IoT (Internet of Things) direct feeds to maps and web mapping applications. This IoT trend is important to decision makers, so they can make use of real time and near-real time tools and data at their fingertips.

For further investigation: You can also download the data as a CSV file and sort and obtain means and other statistical measures in Excel. You can also map the CSV data in ArcGIS Online or ArcGIS Pro and run spatial statistical measures on it.

Further consider the ease of use of these web mapping applications (migration map application and the water balance app). You did not have to sign in to anything to use these web mapping applications: All you need is a web browser, and an internet connection. Consider how such tools and capabilities are opening up the world of geospatial data, analysis, and maps to a truly global audience, and what the implications of that will be.

### 3. Error-based uncertainty.

The error-based uncertainty chapter in the Body of Knowledge begins by stating that the largest contributing factor to spatial data uncertainty is error. It then defines error, and states that uncertainty results from a lack of knowledge of the extent and of the expression of errors and uncertainty's propagation through analyses. The chapter makes the case that error and its sources is key to addressing error-based uncertainty in geospatial practice. A sample of issues related to error and error based uncertainty in spatial data are presented, including the types of error in spatial data, the special case of scale and its relationship to error, and ends with describing approaches to quantifying error in spatial data.

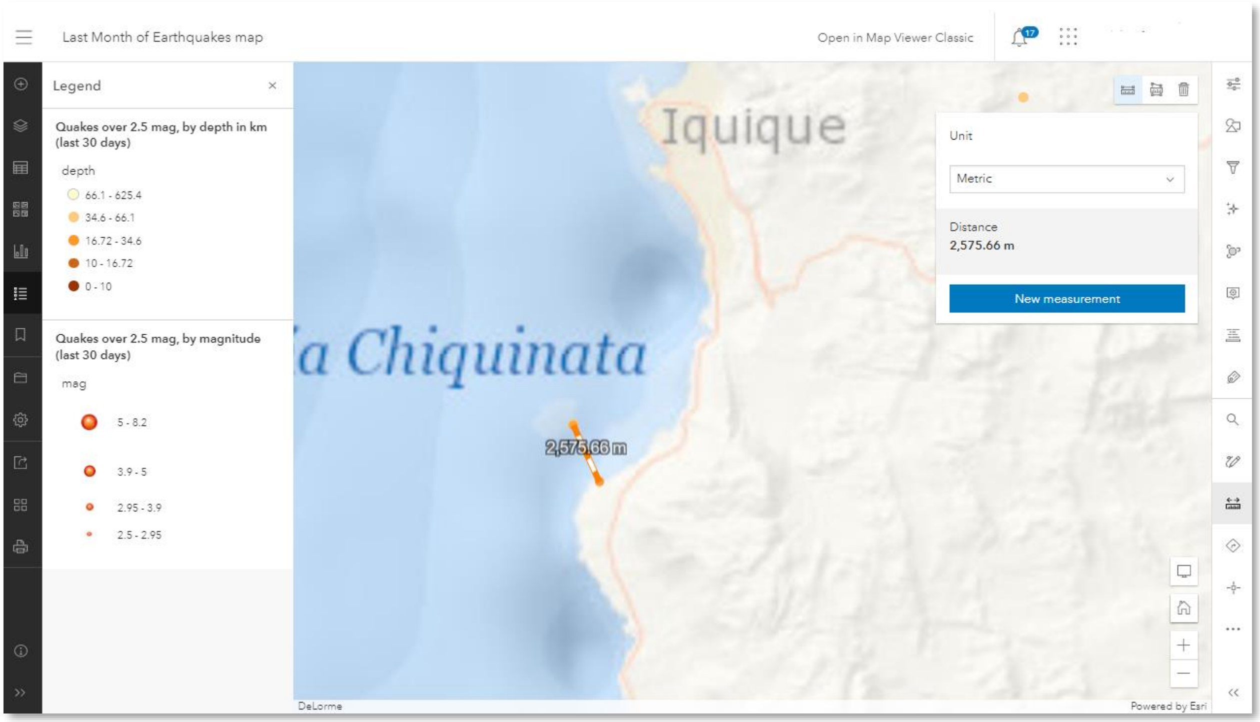
**Error-based uncertainty Activity 1: Analyzing Earthquakes in ArcGIS Online.** In this activity, you will use ArcGIS Online and base map data to more fully understand and appreciate the concepts of error and uncertainty. The chapter's author describes spatial scale the spatial extent of a study area and associated areal coverage of a dataset. Spatial scale determines the representation of data. Errors can be introduced when data for a particular study area may not be available from the same source, or at the same spatial or temporal scale.

The chapter also discusses measurement scale, the precision at which a dataset is generated, and states that cartographic scale describes the level of generalization of map features.

Map readers sometimes consider anything that is digital as accurate and complete, including, and especially, maps. Maps are incredibly useful, but are representations of reality, not reality itself. Reality is complex, especially considering how complex and dynamic the Earth is, given its many themes, layers, and cycles, and the interaction of these cycles and processes at different scales. Maps, including those in a GIS environment, are inherently full of errors and distortions, from the map projection they are drawn from, to missing data, to generalized lines. Nowadays, *anyone* can make a digital map. Everyone is a potential map creator, no longer just a map consumer. Open and examine this map on the last 30 days of earthquake data in ArcGIS Online. Some of these earthquakes are of concern because they occur under the land surface, while others are of concern because they occur under the ocean and thus pose the threat of tsunamis. Zoom in to an earthquake that is just offshore, such as this one (at the time of this writing) off the coast of northern Chile, below. Use the measure tools to measure the distance between the earthquake and the shoreline.

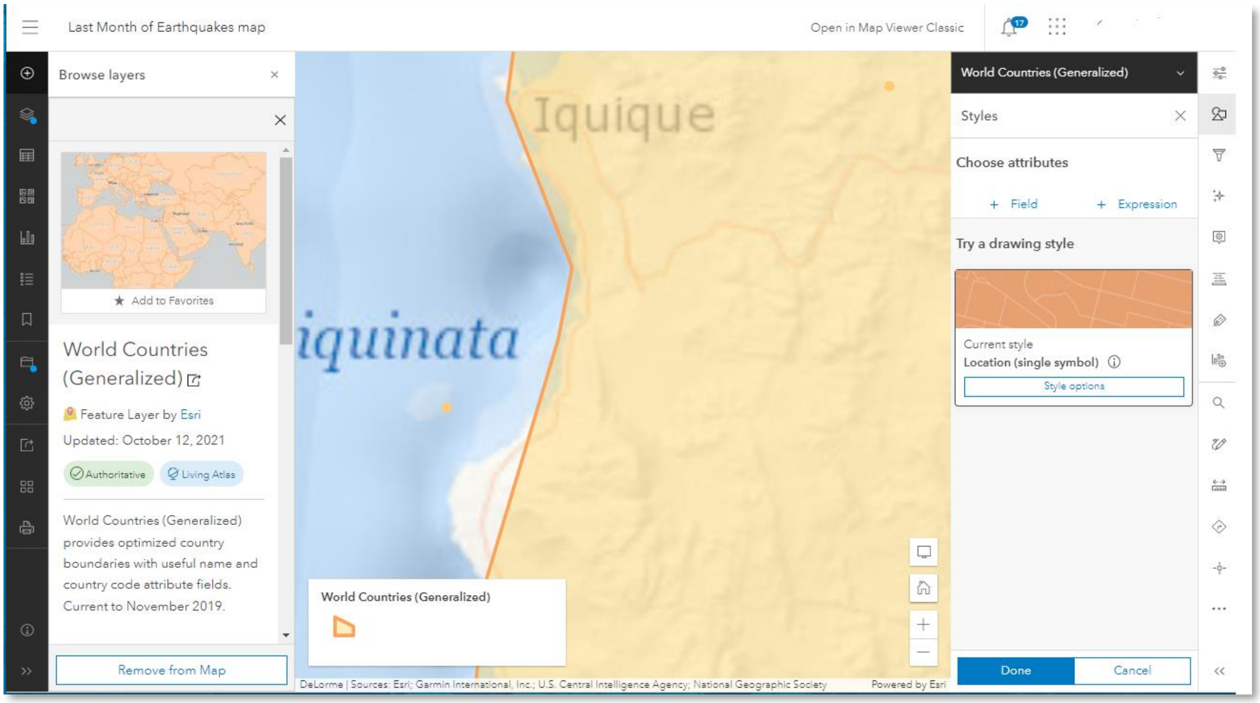
The distance you measure depends on several things, including (1) exactly where you start and end your line where you are measuring, (2) the detail and scale of the shoreline as depicted on the basemap you are using, and (3) the accuracy of the earthquake epicenter itself. The placement of your line and the distance you measure in (1) partly depends on the scale of your map at which you begin and end your line: If you are zoomed in to a large scale, your distance is likely to be measured more accurately because you are able to place its start and end points on the earthquake epicenter and the shore. But complicating even this component is: How can you determine which part of the shore is nearest to the epicenter. On (2), consider the base map you are using: At which scale was it collected? If you, as in the example below, are conducting your analysis at a large detailed scale, and your basemap is really a small scale global map, the map will not include every cape and bay and indentation of the shoreline.

Consider the longstanding geographic conundrum and problem of measuring the total distance of the coastline of, say, the British Isles, or Italy. The answer depends in large part on scale: The larger the scale, the longer the coastline will be. In the example below, using the topographic basemap, the distance from the shoreline to the epicenter was measured at 2.575 km:




*Measuring the distance from an earthquake epicenter to the nearest part of the coast in ArcGIS Online.*

Next, sign in to ArcGIS Online with a free account (from developers.arcgis.com) or your school or university account > Add data > from ArcGIS Online, add the World Countries (Generalized) to your map. As the name implies, world countries generalized is a map most suited for global studies only. It will not include coastal or boundary details. Observe the world countries map layer and the angular coastline at Chile (or wherever you are examining it). Does it confirm the "global" nature of this layer? Re-do your measurement, this time to the world countries generalized layer.




*Measuring the distance from an earthquake epicenter to the nearest part of the coast in ArcGIS Online using the world countries generalized map.*

Finally, consider aspect (3) of your data: The accuracy of the earthquake epicenters themselves. We do not have a seismic station under every square meter of land and under water. Rather, the epicenters are determined by measuring P and S waves from earthquakes that arrive at seismic stations at specific times after an earthquake has occurred, and using triangulation from several stations and other mathematical computations, the epicenter is determined. While these epicenters are located to a high degree of accuracy, according to reports such as this that indicate errors and confidence intervals, care should be used, particularly in mapping, not to overassign confidence to meters, tens of meters, or even a kilometer or two in these epicenter locations.

Thus, given the above discussion, be cautious when you are using mapped data, even those data from real-time feeds from the Internet of Things such as stream gauge height, traffic, earthquakes, weather, wildfire perimeters, and others. As an outrageous case in point, the weather data station for Cleburne Texas was online for nearly a year before it was corrected. Yes, it *does* get hot in Texas, but not this not, or this windy, or this wet! The only normal reading is the pressure:

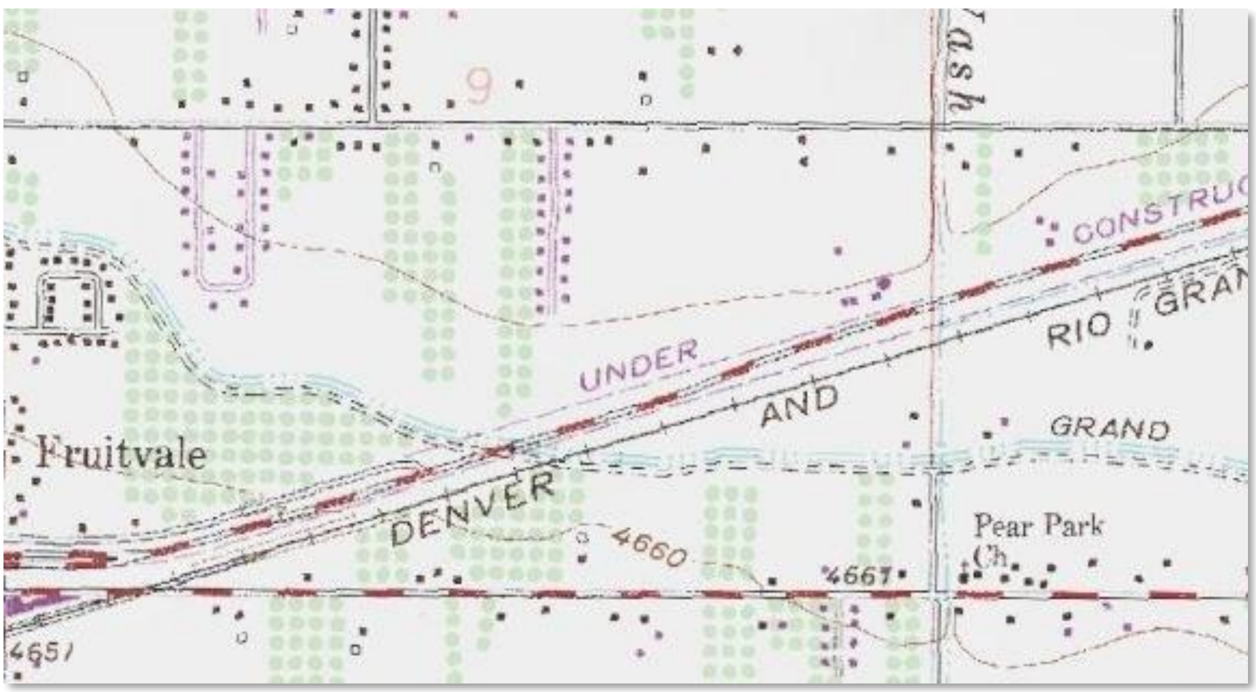

*It does get hot in Texas, but this is ridiculous! An erroneous weather station data point. Note besides the temperature, the humidity, wind speed, and precipitation rate. The only "normal" reading is the pressure.*

If you weren't critical of your data, your resulting analysis, such as an interpolated surface from regional weather data, would have a large spike because of this erroneous point.

Thus, always consider the factors that could lead to error. But also consider your data needs and requirements: In the above study, noting that the earthquake was probably 1 km or so offshore is suitable for your analysis (and for alerting the local population if the magnitude was of sufficient concern). For another study, where you are locating a gas pipeline or specific archaeological finds, you might require sub-meter or even sub-centimeter spatial accuracy. Similarly, you may not need 25-cm imagery for your study; for a regional study, 1 meter imagery might be ideal. This leads to another discussion about data: *More* is not always *better.*

**Error-based uncertainty Activity 2: Cartographic vs Geographic Basemaps: USGS Topographic Maps Example.** In this activity, you will consider USGS topographic maps, error, and uncertainty. Digital datasets are intended for use at the scale of the source data: USGS topographic maps were most often created at 1:24,000, 1:100,000, and 1:250,000-scale, though other scales exist. Most of them were originally created in the analog mapping days and afterwards were scanned and converted to digital format for use in a GIS. *Just because you, the user, can zoom in to a very large scale using GIS tools, your* *data does not become more accurate as you zoom in!* For example, you can zoom in on a 1:24,000-scale USGS topographic map in ArcGIS Online or in ArcGIS Pro quite easily (try it!). But, making a decision at 1:10,000-scale, say, from a 1:24,000-scale map is treading on dangerous ground. Furthermore, these maps, and the Digital Line Graphs (DLG) derived from them, were originally created as cartographic products. These were created according to national map accuracy standards, which was the best that the USA was creating for many decades in terms of accuracy. However, to enhance readability, sometimes, especially if two features ran parallel for any distance, features were offset.

Consider the example below, and elsewhere, where a road and railroad are parallel: Here, running from the southwest to the northeast. In this and elsewhere on this scale of map (and even more so at smaller scales such as 1:100,000), the road was offset from railroads so that the map reader could distinguish between these two features. If the features were not offset, the road would look like it was "on top" of the railroad. Railroads had the priority, so the roads were offset and the railroad's spatial accuracy preserved. As a result, the position of the road is inaccurate on the resulting topographic map, but also the road is offset on the vector DLG data. Again, depending on your project goals, this offset of 10 or so meters may not matter, but you should not use this data to lay fiber optic cable or other very detailed large scale work.



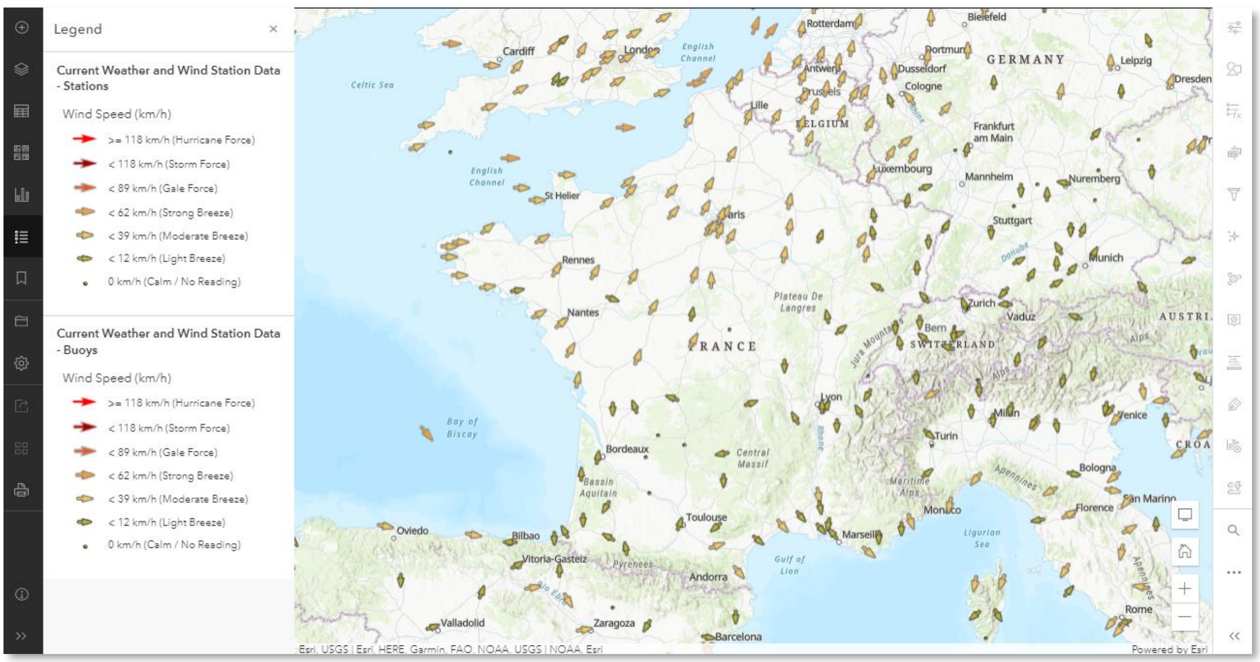

*Section of USGS 1:24,000-scale map showing road running parallel to a railroad.*

Go to [www.arcgis.com](http://www.arcgis.com) – ArcGIS Online, and create a new map. Change the base map to USGS topographic. Note that these maps only cover the USA, so you need to be examining an area within the USA. Search on Grand Junction, Colorado, and zoom to the southeast of the city to find the above location. Or, find another place on a topographic map—there are many!—where a road is close to and parallel to a railroad. Use the measure tools and measure the offset. What is the measurement?

**Error-based uncertainty Activity 3: Considering sampling frequency in Mapping: Real-time weather investigation.** The uncertainty chapter also includes an intriguing discussion about errors—that they may arise when observations are not collected at a sampling frequency representative of the feature or process under consideration. In this activity, you will consider these points as you build practical experience using GIS and real data (weather) while considering uncertainty.

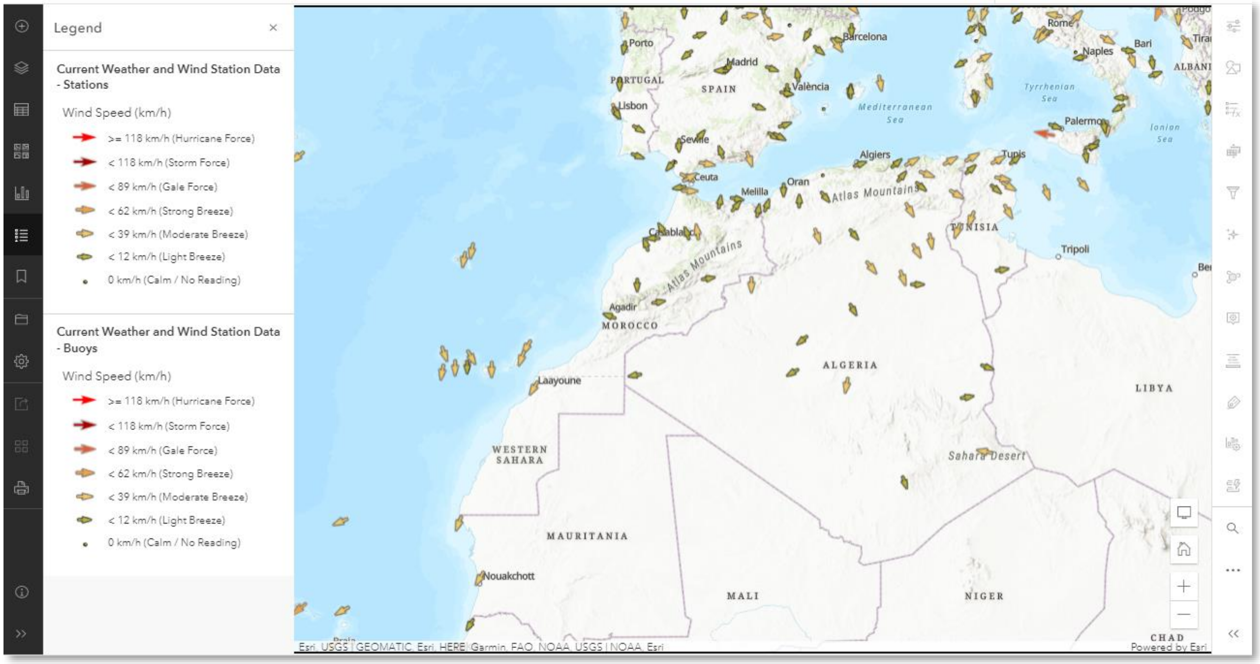
Access the current weather and wind station data from the ArcGIS Living Atlas of the World, here: https://www.arcgis.com/home/item.html?id=cb1886ff0a9d4156ba4d2fadd7e8a139 This data includes a variety of weather variables in very close to real time for the entire planet. Open this data in the classic or new ArcGIS Online map viewer. Click on a few weather stations. How old is the data? 5 minutes? 15 minutes? Would you say it is "real time" or "near real time"?

Let's say you were going to create an interpolated surface of wind speed and direction (or pressure or temperature, which is also contained in this data layer) for France. Zoom to France and note the distribution and number of weather stations, indicated below by the wind vector locations:




*Current weather data as shown in ArcGIS Online map viewer.*

Zoom around the map to different places around the globe. Note that the weather stations cover the entire planet. Note further that some stations are on the water, via weather buoys. However, the distribution of weather stations on the planet varies widely. Zoom to Algeria. Most of the weather stations are in the more populated northern part of the country, understandably, with few stations in the southern region covered by the Sahara Desert:




*Current weather data as shown in ArcGIS Online map viewer focusing on Algeria.*

If you were going to create an interpolated surface in Algeria that indicated wind speed, direction, pressure, or temperature, your GIS software (such as ArcGIS Online or ArcGIS Pro) could do this, and not give you an error message. However, you should have much less confidence in the accuracy of the interpolated surface in the southern part of the country, where the software is interpolating a surface with very few input points. Furthermore, creating a surface entails the GIS software looking for points within search tolerances for nearby points. Near the boundaries of any polygon, such as countries, if you are creating a surface, to have increased confidence in the surface near the borders, you should be including points on the other side of those borders. So, even for the surface you generate for France, don't stop at the French borders! You should include points within at least 100 km extending into Spain, Italy, Switzerland, Germany, Belgium, the Atlantic Ocean, and the UK, for example. The same thing holds for generating a surface for Algeria.

This activity involving mapping, symbolizing, classifying, and generating interpolated surfaces from weather data can be accomplished in its entirety via a lesson in the Learn ArcGIS library that I authored, here: https://learn.arcgis.com/en/projects/predict-weather-with-real-time-data/

http://gistbok.ucgis.org/bok-topics/statistical-mapping-enumeration-normalization-classification

http://gistbok.ucgis.org/bok-topics/common-thematic-map-types

## 4. Scale and Generalization.

The scale and generalization chapter in the UCGIS&T Body of Knowledge discusses the multiple meanings of scale, in GIScience and in other disciplines. Scale refers to relative proportions between objects in the real world and their representation. The author expands on phenomenon scale, analysis scale, and cartographic scale. The chapter then defines generalization—the act of modifying detail, usually reducing it, in geospatial data, and then discusses how computations and graphical medication processes can be used to achieve it. These include simplification, aggregation, smoothing, resampling, and several other techniques.

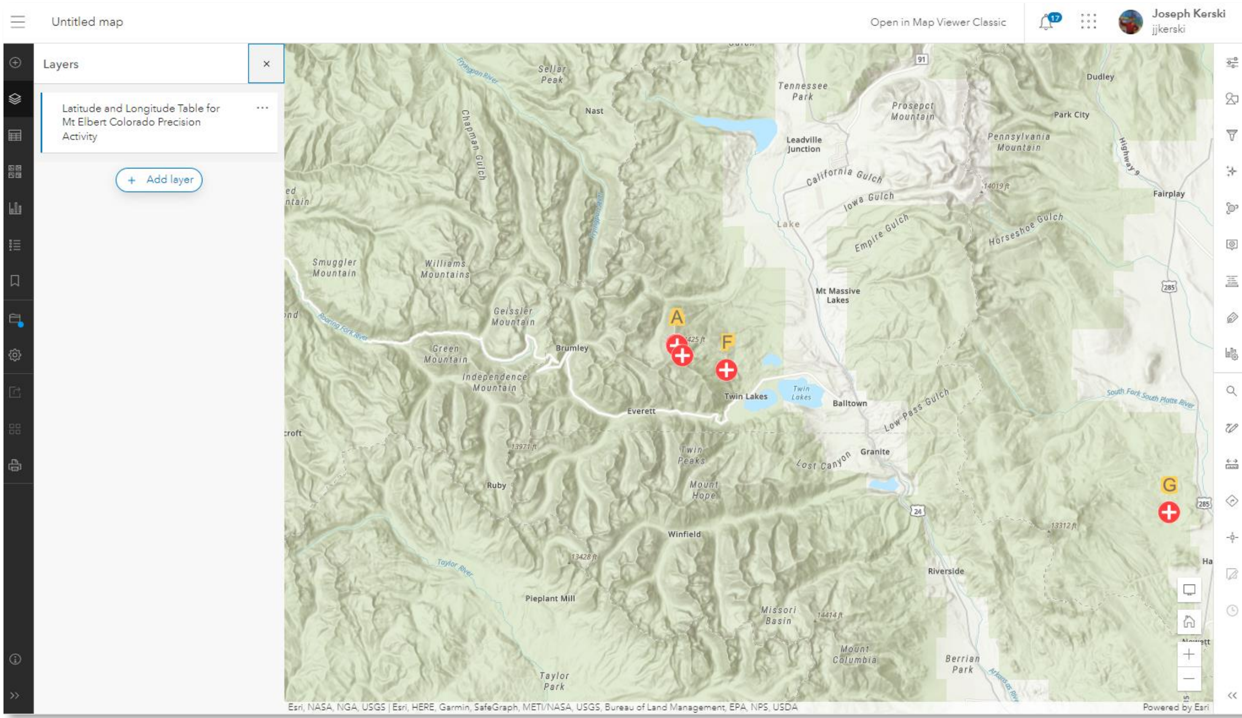
**Scale and generalization Activity 1: Investigating coordinate precision.** An important element in scale, resolution, and generalization in mapping is precision. Precision is how close measure values are to each other; or thought of in another way, how many decimal places exist in areal and length measurements and in coordinates. In this activity, by examining coordinates in decimal degree format, with varying amounts of precision, you will understand how precision and scale fit together in an interactive way with implications for research and instruction.

A table has been created with a set of coordinate pairs, shown below:

| point | decimal_place_figures | latitude | longitude |
|---|---|---|---|
| A | 6 | 39.117742 | -106.445364 |
| B | 5 | 39.11774 | -106.44536 |
| C | 4 | 39.1177 | -106.4453 |
| D | 3 | 39.117 | -106.445 |
| E | 2 | 39.11 | -106.44 |
| F | 1 | 39.1 | -106.4 |
| G | 0 | 39 | -106 |

The first coordinate pair with a latitude, longitude value of 39.117742, -106.445364 is the location for Mt Elbert, Colorado, the highest point in Colorado. Note that this coordinate pair (point A) contains 6 decimal places (or "figures") after the decimal, but point B contains 5 figures, point C contains 4 figures, and so on, to point G, which contains no figures after the decimal. In scanning the table of coordinates, you can hypothesize that by removing successive figures after the decimal place, the resulting coordinate will be in a different location than the point on the line above it.

Now it is your turn to map these coordinates. Go to ArcGIS Online (www.arcgis.com) and sign in with your personal or your organizational ArcGIS Online account. Start a new map with the new map viewer > Add > add a web service > enter this URL that contains a feature service from the above table: https://services.arcgis.com/IZtlGBUe4KTzLOl4/arcgis/rest/services/Latitude_and_Longitude_Table_for_Mt_Elbert_Colorado_Precision_Activity/FeatureServer Once you have added it to your map > edit the layer style > change the point symbols to something larger so that the points are easier to see on the map. Then add labels indicating A through G in the table above: > add labels > use Point as the Label field. Your map will look similar to this, below:

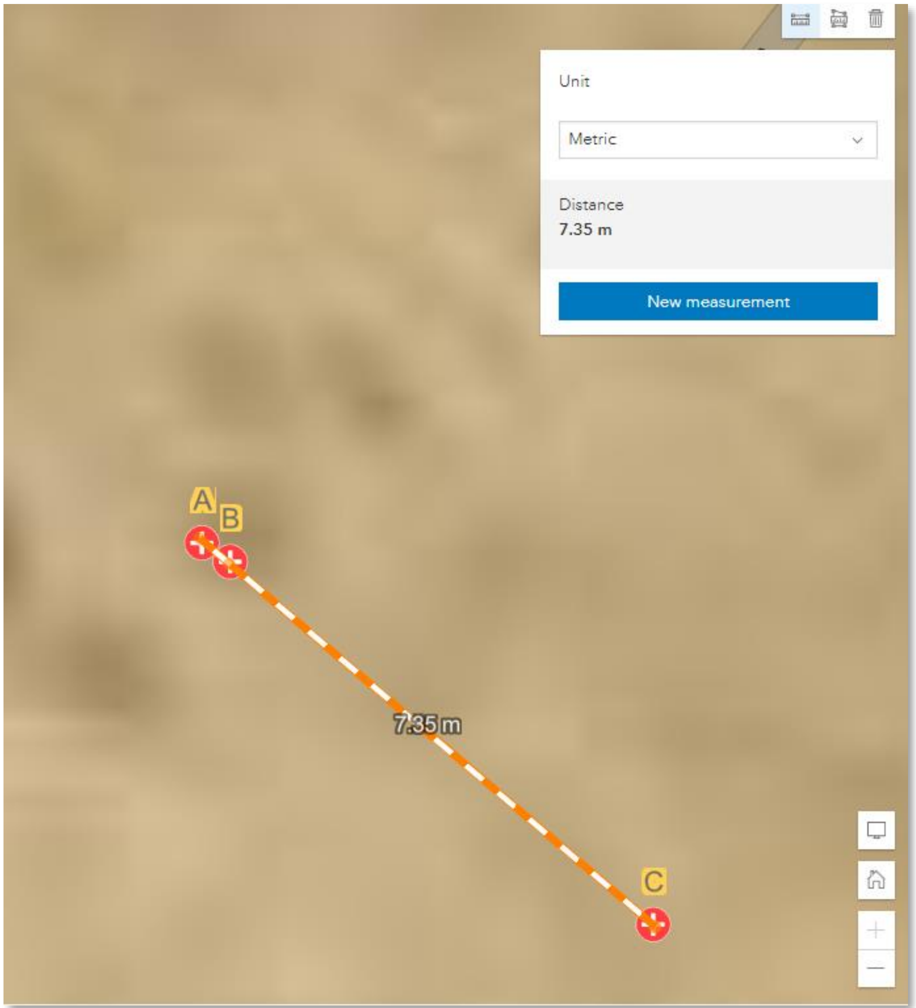


*Points mapped with decreasing precision in ArcGIS Online map viewer.*

Next, change the basemap to imagery and zoom in to the vicinity around Point A. You will see points A through D northwest and south of a snow field that appeared on the satellite imagery at the time this lesson was created, shown below. Save your map if you wish so you can return to it later.


*Selected points near Mt Elbert as shown in ArcGIS Online map viewer.*

Use the measure tool to determine the distance from Mt Elbert as measured with 6 figures after the decimal place and Mt Elbert as measured with only 4 figures after the decimal place, as shown below:




*Measuring distances between points as shown in ArcGIS Online map viewer.*

You can see that while it is less than a meter from Point A to Point B, it is over 7 meters to Point C.

Using the above procedures, measure the distance between each of these points, filling in the following table:

| Between these 2 points: | The distance is (in meters) | The distance is (in km) |
|---|---|---|
| A to B | | |
| B to C | | |
| C to D | | |
| D to E | | |
| E to F | | |
| F to G | | |

If you do not have an ArcGIS Online account, a map has already been saved and shared publicly for you to examine, here:
https://www.arcgis.com/apps/mapviewer/index.html?webmap=f4c31d023e9548e1bd5a0224bda8f87b

How does the distance between points increase as the number of digits to the right of the decimal place decreases? What direction are the points "moving" from A to G, and why?

If you were going to tell a friend to meet you on Mt Elbert, which of the above coordinates would suffice for you to give? Would C be sufficient with 4 digits? Maybe not—the terrain at the mountain top is steep and you might not see your friend who had reached point C beyond the snowfield. Surely Point B would be sufficient, because you would see your friend less than 1 meter away. When would you need to provide coordinates such as Point A containing 6 digits to the right of the decimal place? If you were laying a gas pipeline or fiber optic cable, would you need 6 digits? Why? Name a reason when would you need even more than 6 digits.

Discuss how the need for precision varies depending on your project and mapping needs. Along these lines, examine the table below, modified from bliss.com, noting how the number of decimal places in coordinates affects the distance that can be measured. Note that the distances are those between each degree of latitude anywhere on Earth, but are those between each degree of longitude but *only at the Equator,* because longitude lines converge as you approach the poles.

| **Decimal Places** | **Decimal Degrees** | **Distance** | **Concept** |
|---|---|---|---|
| 0 | 1.0 | 111 km | Can identify a Country or large Region from another |
| 1 | 0.1 | 11.1 km | Can identify a large city from a neighboring large city |
| 2 | 0.01 | 1.11 km | Can identify a small village from the next |
| 3 | 0.001 | 111 m | Can separate one neighborhood or street from another |
| 4 | 0.0001 | 11.1 m | Can identify an individual street or parcel of land. |
| 5 | 0.00001 | 1.11 m | Capacity to distinguish one tree from another. |
| 6 | 0.000001 | 11.1 cm | Measuring approximately 4 inches wide (10.16 cm). Used for structural design and surveying in engineering. |
| 7 | 0.0000001 | 1.11 cm | Used for precision geographic surveying, representing the practical limit of the use of GPS. |
| 8 | 0.00000001 | 1.11 mm | Conceptually the **width of a paper clip**. Can be used for charting volcanic movements and tectonic plate shifts. |

| | | | |
|---|---|---|---|
| 9 | 0.000000001 | 111µm | Representative of the width of a strand of thread, in the range of microscopy. |

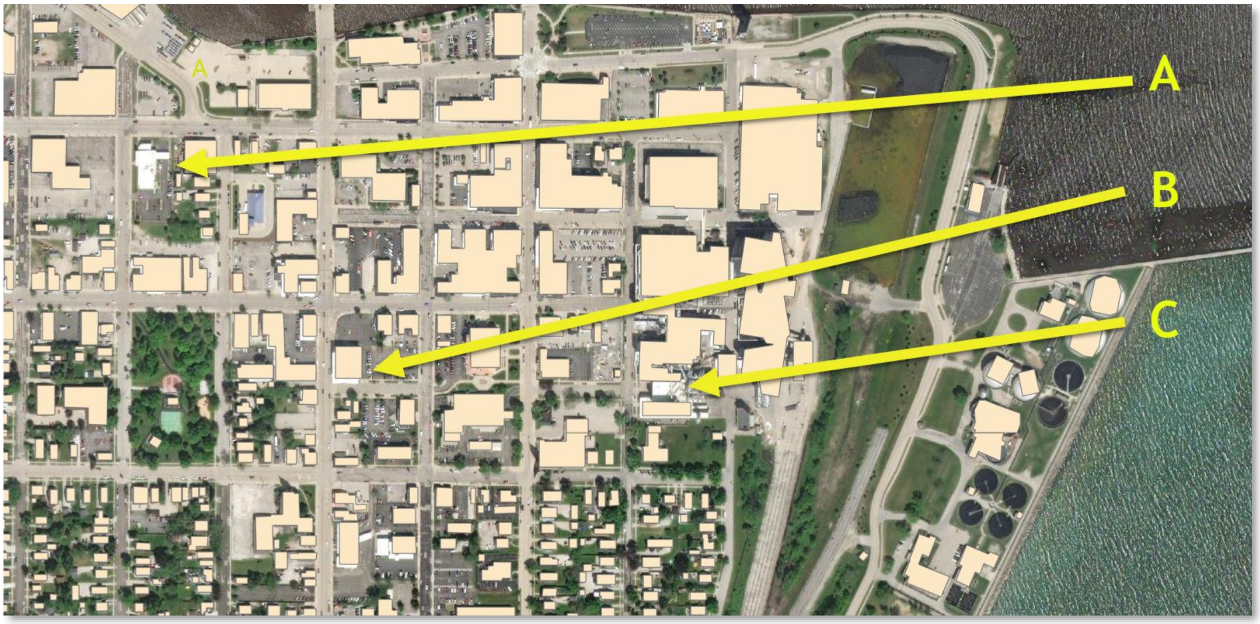
Discuss: If you wanted to find Vienna Austria, how many decimal places would you need in your coordinates? If you wanted to find a concert hall in Vienna, how many would you need? If you wanted to find a specific seat inside the hall, or an electrical box, how many would you need?

Discuss: How is the concept of scale related to precision in coordinate system measurement?

**Scale and generalization Activity 2: Investigating building footprints in ArcGIS Online.** In this activity, you will have an opportunity to do some hands-on work using a truly “big data” set and consider scale and generalization. Microsoft has released a free set of deep learning generated building footprints covering the USA. This dataset contains at the time of this writing, 129,591,852 computer generated building footprints. They were derived using computer vision algorithms on satellite imagery.

In support of this work and to make these building footprints available to the ArcGIS community, Esri consolidated the buildings into a single layer and shared them in ArcGIS Online. The footprints can be used for visualization using vector tile format or as hosted feature layer to do analysis. Access the map using this URL. Note that there is a visibility filter applied to this layer, so you will not see the buildings until you zoom in to a larger scale. Use the search tool and find Manitowoc Wisconsin. Change the basemap to satellite imagery. Zoom in to the area where the Manitowoc River flows into Lake Michigan, so that you are seeing the image similar to that shown below.

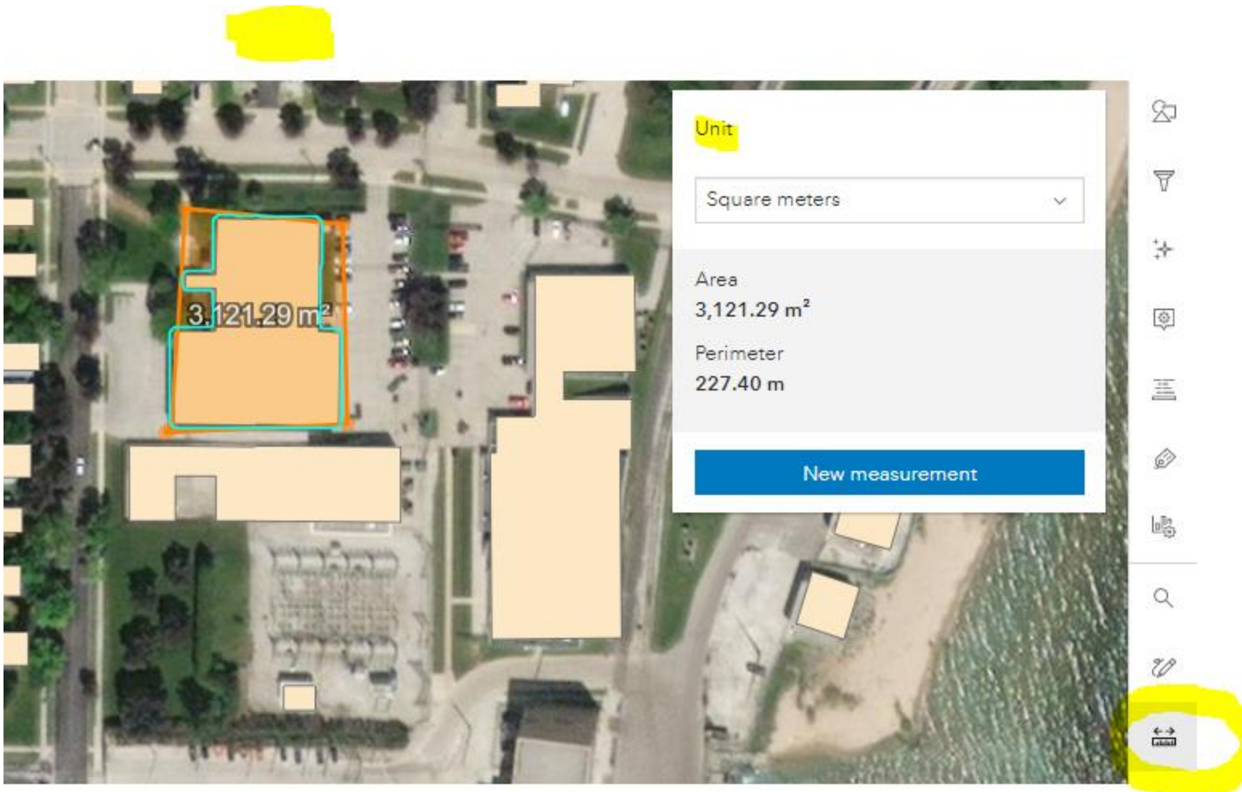
What percentage of the buildings shown in the imagery have been captured in the buildings layer, in your estimate? Note however that not all of the buildings have been captured: Describe the situation at point A below, then point B, and then point C. Which building is missing, which is offset from the imagery, and which building is incomplete? Can you find more in this image, or in the adjacent area, that fall into categories A, B, or C? Are there any buildings in the buildings layer that are not on the satellite image?




*Examining Microsoft building footprints in the ArcGIS Online map viewer.*

Using the measure tool, zoom in and measure the offset on point B's building. Which do you think is in its correct geographic position—the building as shown on the image or the building that is shown on the buildings layer? Remember that even images have been manipulated to "fit" onto the Earth's surface, and they too need to be viewed critically. For more on image data quality, read this essay: https://spatialreserves.wordpress.com/2019/05/12/imagery-it-is-what-it-is-well-not-always/. From the reading, name 2 ways in which imagery may have been altered, and why.

Click on the buildings in your ArcGIS Online map of Manitowoc. What attributes are shown? More attributes exist than that which appear in the default popup. Change the attributes to show all field attributes, including the attribute shape_area. Next, configure the popup so that it shows shape_area. Click on a few large buildings to test your popup to make sure shape_area is displaying. What units do you think these shape areas are in? Test your hypothesis by using the measure tools on a few buildings, such as below:




*Measuring Microsoft building footprints in the ArcGIS Online map viewer.*

Can you sort on shape_area and find the largest buildings in the data set? Can you use filter in ArcGIS Online to filter buildings with an area of at least 300? You may not be able to do this given bandwidth: Remember, there are over 125 million buildings in the table!

**Scale and generalization Activity 3: Walking on Water? Investigating resolution and scale.** In this activity, you will consider resolution and scale using a common activity (walking) and a common use of technology (a fitness app).

After walking on the Lake Michigan pier at the same location you were examining above, Manitowoc Wisconsin, a geographer enjoyed a stroll in the brisk wind to and from the lighthouse at the end of the pier. While doing so, the geographer recorded the trek on a smartphone fitness application called Runkeeper. But upon mapping the track, it appeared as the geographer had been walking on the water! (Geographers *do* possess some superpowers, but not that one!). Examine the map below with the track.


*Examining fitness track on a fitness base map.*

Examine the image below of the pier with the photograph that the geographer captured while en route to the lighthouse.

*Pier that the person gathering the fitness track was traversing. Watch your step!*

It all comes down to paying close attention to your data, and knowing its sources. The global base map used by the fitness app had generalized out the pier (in this case, under the "selection/elimination" type of generalization described in the Body of Knowledge chapter). It is important to note that maps and apps in the web enabled GIS world are continually evolving: The pier was added in for subsequent editions of the Runkeeper basemap. But consider the importance of scale and resolution in any project involving maps or GIS. In the above case, even if the geographer scrolled in to a larger scale on the fitness app's mapping tool, the pier did not appear on the fitness app's base map. It does, however, appear in the base map in ArcGIS Online and in Google Maps.

The above example was a mere inconvenience: The safety of the walking geographer was not jeopardized in any way by not having a larger-scale basemap. However, read the following paragraph from the Esri Press book *The GIS Guide to Public Domain Data*:

> One of the many driving forces behind the emergence of digital spatial record keeping came from pipeline incidents. In 1970, seventy-nine people were killed, 380 injured, and 101 houses were destroyed by fire when a construction worker in Osaka, Japan, inadvertently punctured a gas pipeline. Rapid urban development had resulted in the chaotic arrangement of pipelines and, as the positions of the pipes were largely undocumented, neither the worker nor the construction company had access to detailed plans of the new network. Utility companies were subsequently compelled to make plans of their networks and make those data available to others (Kubo, Sachio. 1987. "The

Development of Geographical Information Systems in Japan." International Journal of Geographical Information Science, 1362–3087, 1(3):243–252.)

Thus, neglecting these important concepts of resolution, scale, and spatial data quality have led not only to bad decisions, but have cost people their property and even their lives. Today, while GIS tools allow us to instantly zoom to a large scale, the data being examined might have been collected at a much smaller scale. Much caution therefore needs to be used when making decisions when the analysis scale is larger than the collection scale. For example, if you are making decisions at 1:10,000 scale and your base data was collected at 1:50,000 scale, you are treading on dangerous ground. Or, one could say, you are "walking on water"!

## 5. Common Thematic Map Types.

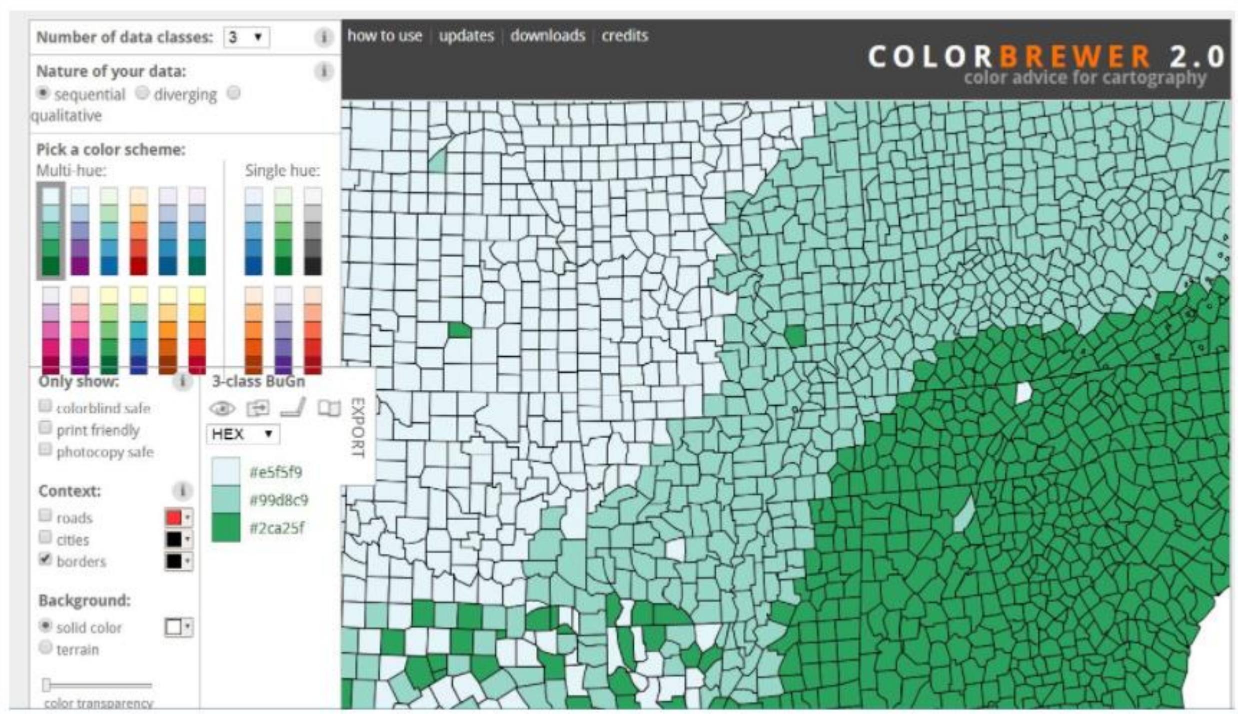
The UCGIS&T Body of Knowledge [common thematic map types chapter] begins by reviewing common types of thematic maps, including choropleth, proportional symbol, isoline, dot density, dasymetric, flow maps, cartograms, and some others. The chapter states that each thematic map type requires a different data processing method and employs different visual variables, resulting in representations that are either continuous or discrete and smooth or abrupt. As a result, each solution highlights different aspects of the mapped phenomena and shapes the message for the map readers differently. Thematic maps are tools for understanding spatial patterns, and the choice of thematic map type should support this understanding. Therefore, the main consideration when selecting a thematic map type is the purpose of the map and the nature of the underlying spatial patterns. The chapter describes the visual variables that are applied in each type of thematic map and provides design considerations for each thematic map type. It also provides an overview of the relative strengths and limitations of each thematic map type.

### Common Thematic Map Types: Activity 1: Examining color on maps using the Color Brewer.

One way to represent the world is through choropleth maps. In a choropleth map, a variable such as population, or crime rate, or % of land in agriculture, is represented with a single tone or color for a specific geographic unit (county, block group, watershed, and so on). In this activity, you will use the ColorBrewer tool designed by Cartography Dr Cindy Brewer to learn about color and the number of classes on maps.

Go to: http://colorbrewer2.org/#type=sequential&scheme=BuGn&n=3 (Links to an external site.)

The color brewer opens with a green-blue 3 class map, as shown below.




*Color Brewer tool.*

Note that this county map does not depict real data, but rather is a diagnostic tool for evaluating the robustness of individual color schemes. This tool can help you design better maps because colors (even very similar colors) are easy to differentiate when they appear in a nicely ordered sequence (such as a legend or in most of the area on the map). The task of differentiating the colors becomes much harder when the patterns on the map are complex, such as the "random" area in the southwest corner of the map.

First, test the following using Color Brewer: Change the number of classes from 3 to 5 to 9. With each change, can you easily distinguish every color in the random southwest section of the map? If you have a 9-class map, you should be able to clearly see 10 unique colors. If you cannot, change the color to another scheme. You should see that more classes doesn't mean for a better, more understandable map. Maps are powerful means of communication, but the limits of human cognition is something you will need to pay close attention to when designing your maps.

Second, test the following: Within each large band of color on the map, there are several polygons filled with each map color, representing the "outliers" in your data--those that do not fit the overall pattern. For example, if you have a seven-class map, there will be six outlier colors per band, demonstrating the appearance of all map colors with each as a surrounding color. Can you see each outlier clearly? Do all pairs of outliers in the band look different? If not, try choosing a different scheme or fewer classes.

Think about: When working in GIS, you will be using real world data, unlike here in ColorBrewer. These data will not always fit in a nice, neat box. You may be mapping the amount of exercise that people do in a relatively exercise-prone area, and in a certain census tract, for example, the amount if far less. Why?

Further investigation is needed, but how will you map it so that this tract is evident but does not detract from the overall message of your map?

Next, experiment with sequential, diverging, and qualitative color schemes. Sequential schemes (see map example here (Links to an external site.) ) contain data classes that are logically arranged from high to low, and this stepped sequence of categories should be represented by sequential steps in colors being lighter or darker. Low data values are usually represented by light colors and high values represented by dark colors. Slope (steepness of terrain) or population densities are well represented by sequential color schemes. Diverging schemes (see map example here (Links to an external site.)) allow the emphasis of a quantitative data display to be progressions outward from a critical midpoint of the data range.

A typical diverging scheme pairs sequential schemes based on two different hues so that they diverge from a shared light color, for the critical midpoint, toward dark colors of different hues at each extreme. Qualitative color schemes (see map example here (Links to an external site.)) use differences in hue to represent nominal differences, or differences in kind. The lightness of the hues used for qualitative categories should be similar but not equal. Assign the lightest, darkest, and most saturated hues in the scheme to categories that warrant emphasis on the map. Data about land use (such as pasture land vs. urban) for example, or soil type, are well represented by a qualitative color scheme.

Note that the HEX, RGB (Red Green Blue), and CMYK (Cyan Magenta Yellow Key/Black) codes are also provided inside ColorBrewer. These codes will come in handy in your future work with GIS just as they probably do already when you work with photo editing and design software.

Another key influence on map readers' perception is the way that the classes are divided on your map. Consider how, as you work with ColorBrewer, the classification method and color work together to communicate the information that you are conveying on your maps.

### Common Thematic Map Types: Activity 2: Investigating Dot Density maps with ArcGIS Online.

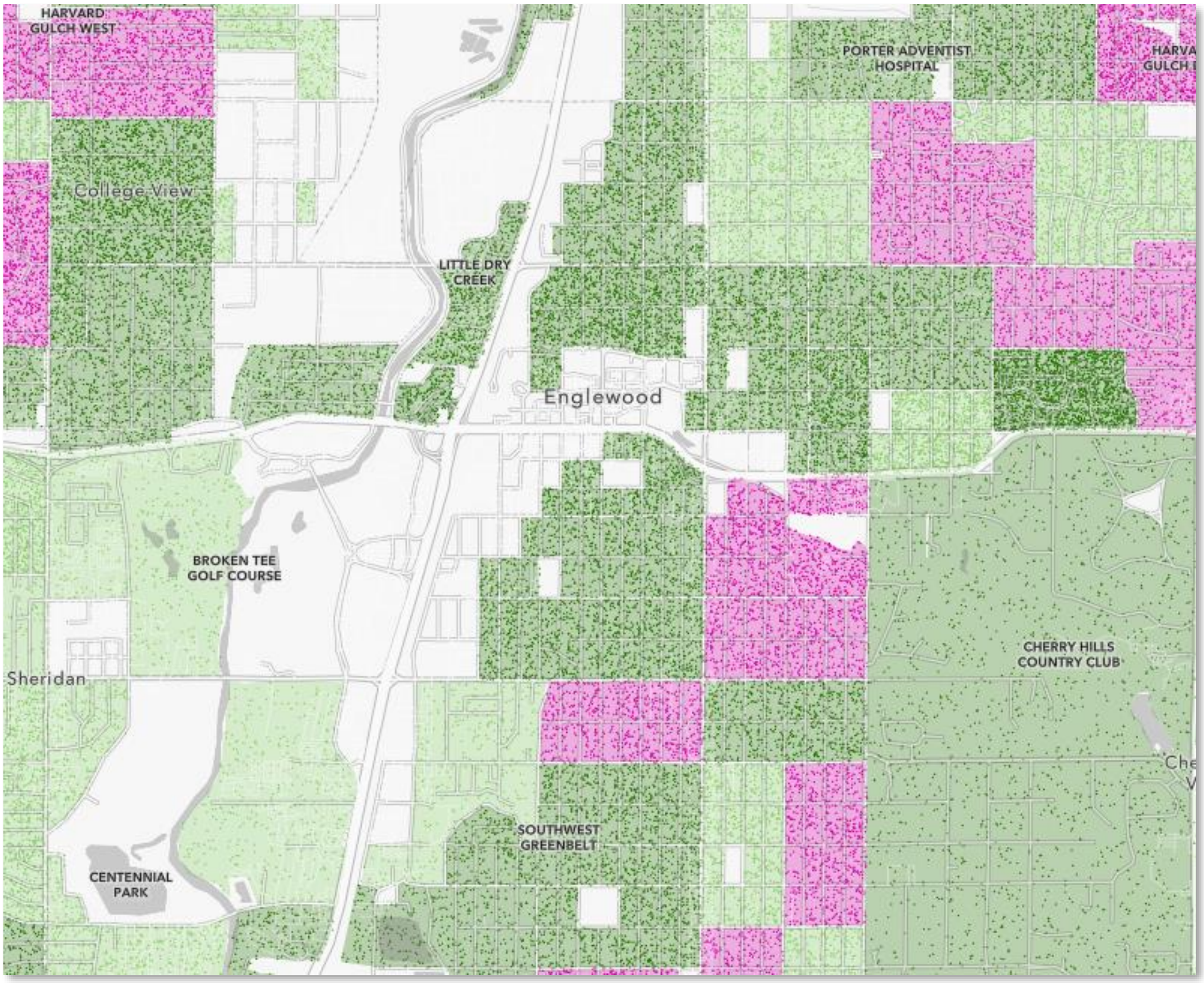
In this activity, you will have the opportunity to work with dot density maps. Open the following dot density map in the new map viewer in ArcGIS Online:
https://www.arcgis.com/apps/mapviewer/index.html?webmap=fa51679e7df644cc918a419cd73861a8

This map combines dot density with a color indicating projected increase or decrease in population.

Pan to a metropolitan area (south Denver Colorado is shown below) and examine the patterns of density, and projected increase and decrease in population.

Discuss and respond to the following:

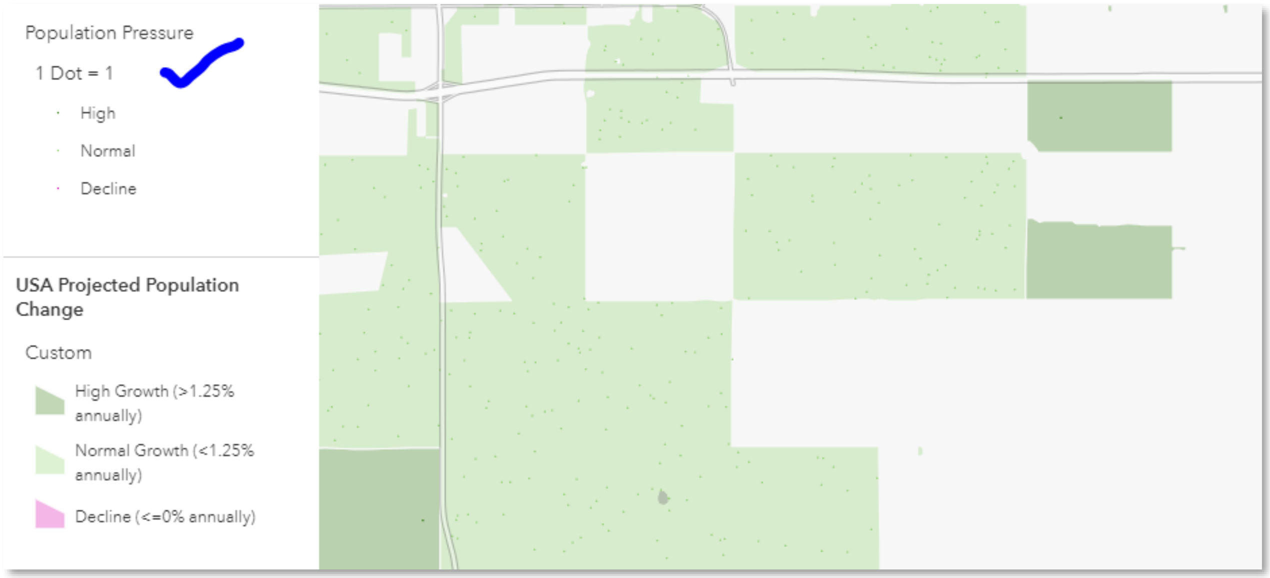
(1) Based on what you know about urban centers, suburban sprawl, and rural settlement, do any of the densities you examined surprise you?
(2) In the image below, what do you think the areas in white represent: The areas that have no dots in them?
(3) Based on your knowledge of where people are moving to and from in the USA, do the projected changes over time surprise you?




*Dot density of population with increases and decreases in population shown in color.*

Pan to a rural area; below is an area southeast of Goodland Kansas.

Consider the following: See the legend that shows 1 dot for 1 person. Do you think this represents where that 1 person actually lives? Or is it just a randomly placed dot in a sparsely populated area? What are the implications if a map reader interpreted the dots as the actual location where people live? What if the dots happen to fall in a river or a lake?




*Dot density of population with increases and decreases in population shown in color, zoomed in to a large scale with 1 dot per "person".*

**Common Thematic Map Types: Activity 3: Mapping Isolines with Axis Maps contour tools.**

In this activity, you will work with an online isolines mapping tool and consider why and how this type of map is important in building understanding about specific phenomena about the Earth.

Cartographers routinely map the surface of the Earth. The surface can be mapped as a series of basemaps, which you may have already seen and used in ArcGIS Online or in another GIS package. The surface can also be mapped in raster form, as a grid of elevations, including a commonly used data set called a Digital Elevation Model, where the surface is gridded into cells, and each cell has a value (in this case, an elevation). DEMs can be generated from topographic data (contour lines), imagery such as Lidar or UAS (drone), and other means. The surface can also be represented as contour lines.

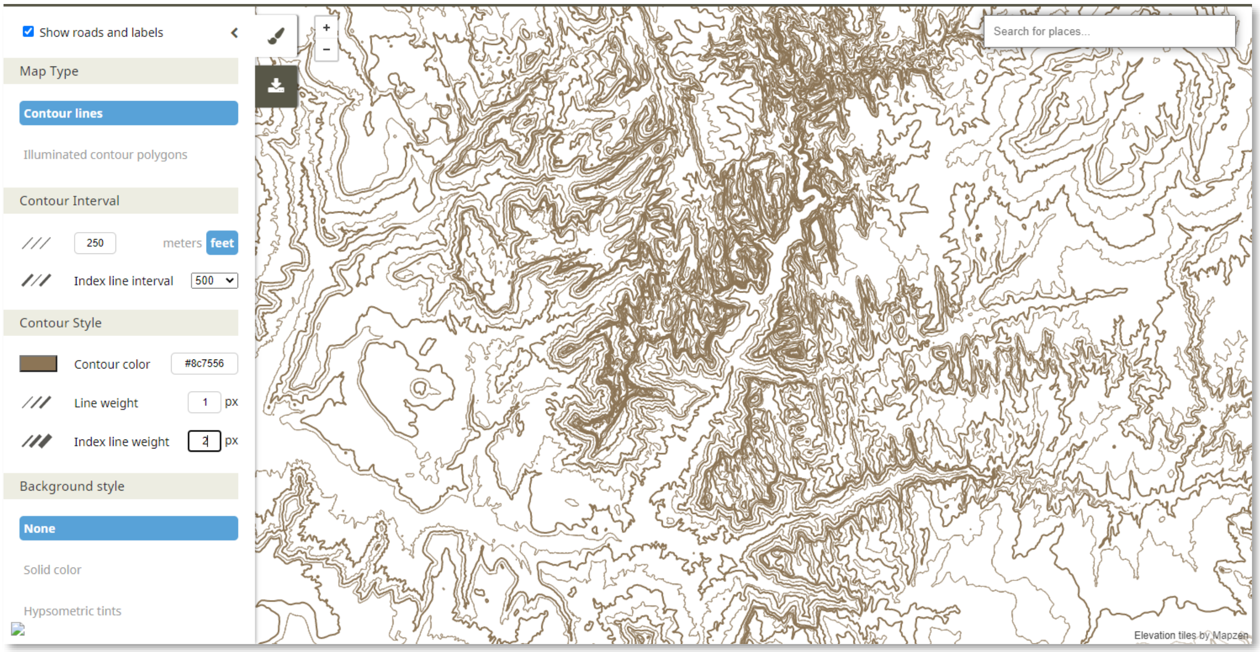
Contour lines are a type of isoline. Isolines (iso="same") are lines running through locations on a map that connect variables that have the same value. You've no doubt seen weather maps. These often show isolines that connect areas that currently have the same temperature or pressure. You may have gone hiking and taken topographic maps so you know how steep your trail will be--on these maps, contour lines show all land that has the same elevation of x feet or meters above sea level, in a specific area. Under water, lines of bathymetry connect areas with the same ocean, lake, or river depth.

Now think outside the box--isolines are not just for showing elevation on the land: They can also show frequency of crime in a city, frequency of diseases in a region, or the number of earthquakes around the world. The manner in which these isolines are symbolized and the interval between each value (on topographic maps, this is called the contour interval and could be 20 feet, 40 feet, 40 meters, or other intervals and units) affects the user's perception of how that variable changes across a particular area of the Earth. Think about the decisions that you make as a mapmaker and spatial analyst as you experiment with changing topographic isolines, typically referred to as contour lines.

In a web browser tab, open the following Axis Maps contour symbolizing tool:

https://contours.axismaps.com/#12/37.2341/-113.0180.

The map will look similar to that below:




*Axis Map contouring map tool.*

The map is centered (note the latitude-longitude coordinates in the above URL) on Zion National Park in Utah. Using the toolbars provided, experiment with changing the contour interval, line weights, background style, and tints. As you do, think about how your perception of the landscape changes as you change these items. Now think about how the perception could be influenced by similar changes of isolines on maps of crime, health, natural hazards, and so on.

Think about: Can you determine what an index line is from this Axis mapping tool? How does symbology of the index line enhance your understanding of the landscape?

Change the location that you are analyzing to focus on another part of the world (the folded mountains and valleys northwest of Harrisburg Pennsylvania, The Himalayas, the Chalk Cliffs in England, the steppes of Russia, or whatever place in which you are interested). How does the contour interval need to change to effectively show an area that is flatter than Zion National Park? Or, an area that is steeper than Zion National Park?

The bottom line: Symbology and cartography in GIS are powerful tools! Adjusting cartographic elements such as line weight, color, symbology, text, projections, and so on, greatly affects your map reader's understanding of the phenomena you are showing.

*-----End-----*