Lab 2: Coordinate Reference Systems (CRS) and Measurement

1. Introduction

Coordinate Reference Systems (CRS), also referred to as Spatial References, are mathematical functions that link data to locations on the Earth's (or any other planet) surface. You must establish the correct CRS before executing any spatial measurement or overlay analysis. Misalignment between a file's metadata and its underlying mathematical coordinates can invalidate subsequent geoprocessing outputs and cause headaches in the future.

ArcGIS can project “on the fly”, meaning that it automatically adjusts the CRS of each layer to match that of your Map. This is really convenient, but increases processing time and can lead to unexpected issues when editing features or calculating geometries. The best practice is to use a single CRS for all of the data in your Map. This takes a little time to set up, but saves you from annoying and difficult-to-catch errors down the line.

In this lab, you will evaluate datasets related to the 2018 Ellicott City, MD flood. You will distinguish between geographic coordinate systems, which use angular units on a spherical model, and projected coordinate systems, which utilize Cartesian grids to minimize distortion over specific regional areas. You will diagnose coordinate errors, apply the correct geoprocessing tools to manipulate metadata and underlying geometry, and quantify the mathematical failure that occurs when planar measurements are applied to angular coordinate frameworks.

Learning Goals

By the end of this lab you will be able to:

- Diagnose CRS problems, including distinguishing an "Unknown CRS" from an incorrectly defined CRS.
- Apply the Define Projection tool versus the Project tool correctly.
- Import XY tabular data correctly by matching longitude/latitude and easting/northing to their respective coordinate systems.
- Explain the physical and mathematical reasons why planar area calculations derived from geographic coordinates (degrees) are meaningless.

Key Concepts

- **CRS (Coordinate Reference System):** The framework used to define locations on Earth. A Geographic CRS uses angular units (degrees of latitude and longitude) on a spherical model. A Projected CRS mathematically flattens the Earth onto a 2D plane using linear units (meters or feet).
- **Define Projection:** A data management tool that updates the metadata label of a dataset. It *does not* alter the underlying geometric coordinates. It is used to fix data that has missing or incorrect metadata.
- **Project:** An analysis tool that mathematically transforms the underlying coordinates of a dataset from one CRS to another. It changes the actual geometry of the file.

Datasets Provided (in /raw/)

- EllicottCity_HistoricDistrict.shp (polygon): Correct CRS.
- EllicottCity_StreamGages.shp (points): Correct CRS (use as a trusted spatial reference).

- NAIP_EllicottCity_WGS84.tif (raster): Correct geographic CRS.
- Lab02_EllicottCity_HistoricDistrict_UnknownCRS.shp (points): Missing CRS metadata.
- EllicottCity_Floodplains_WrongCRS.shp (polygons): CRS metadata defined incorrectly.
- EllicottCity_HighWater_2018.csv: Tabular data with columns [Site_ID, WaterDepth_m, Longitude_N, Latitude_E, Easting_m, Northing_m, Elevation_m].

A. Project Setup and CRS Inspection
Before manipulating spatial data, you must understand its current geometric state. Mixing projected and geographic coordinate systems without awareness leads to silent analytical errors where data appears correct but measurements are flawed.

1. Initialize Project
- Create a folder named lab02_lastname. Inside, establish the raw, working, outputs, and docs subdirectories.
- Copy the provided datasets into your /raw/ folder.
- Create an ArcGIS Pro project named lab02_lastname and a default geodatabase named lab02.gdb in your /working/ folder.

2. Inspect CRS Metadata
- Load all datasets into your map.
- For each dataset, open Layer Properties -> Source -> Spatial Reference.
- Why do this? You must verify what mathematical framework the software is currently using to interpret the file. Record the CRS, Datum, and linear/angular Units. For the raster files, also look under Raster Information to record the cell size and verify whether the extent values represent degrees (small numbers like -76) or meters (large numbers in the millions).

3. Set Map Coordinate System
- Right-click the map in the Contents pane -> Properties -> Coordinate Systems.
- Set the map to NAD 1983 StatePlane Maryland FIPS 1900 (Meters).
- Note that you can see the coordinate systems of the current layers in your map here
- Why do this? The Map frame CRS dictates how all layers are visually rendered and how on-the-fly measurements are calculated. State Plane is optimized for local accuracy within Maryland, minimizing the scale distortion found in global or regional projections like UTM.

B. Import XY data
Tabular data (like a CSV) lacks inherent spatial geometry. To map it, you must tell the GIS which columns represent coordinates and exactly which CRS those numbers belong to.

4. Import EllicottCity_HighWater_2018.csv
- Correct Import (Geographic): Longitude and Latitude are angular measurements. Use the XY Table To Point tool. Set X to Longitude_N and Y to Latitude_E. Because these are angular measurements, set the Coordinate System to a geographic framework: WGS 1984. Output the result to hwm_geo. Verify the points land along the Tiber and Hudson branches.

- Correct Import (Projected): Easting and Northing are linear measurements representing a grid. Rerun the tool. Set X to Easting_m and Y to Northing_m. Set the Coordinate System to the matching projected framework: NAD 1983 StatePlane Maryland (Meters). Output to hwm_stateplane.
- Incorrect Import (Intentional Failure): Rerun the tool. Use Easting_m and Northing_m for X and Y, but intentionally assign WGS 1984 (geographic) as the Coordinate System. Output to hwm_wrong. Zoom to this new layer and observe its location.
- Why do this? This demonstrates what happens when the GIS is instructed to read linear meters as if they were angular degrees. The points will plot wildly outside the study area. Take notes on the geometric reason for this failure for the final questions.

C. CRS Triage

Datasets often arrive with missing or incorrect metadata. You must fix the metadata label before you can transform the data.

5. Fix Lab02_EllicottCity_HistoricDistrict_UnknownCRS.shp

- Open the layer properties and look at the spatial extent values. Determine if the raw numerical values correspond to decimal degrees (e.g., 39, -76) or State Plane meters (values in the millions).
- Step 1: Fix the Metadata. Use the Define Projection tool to assign the correct CRS based on your observation. Output to failures_defined. *Note: This does not move the points; it only tells ArcGIS how to read the existing numbers.*
- Step 2: Transform the Geometry. Now that the software correctly understands the data, use the Project tool to mathematically convert the dataset into your working Maryland State Plane CRS. Output to failures_projected.
- Verification: Use the Generate Near Table tool against the trusted EllicottCity_StreamGages layer. If the calculated distances between the structural failures and the gages are absurd (e.g., thousands of kilometers), your initial definition in Step 1 was incorrect.

6. Fix EllicottCity_Floodplains_WrongCRS.shp

- Inspect the extent values in the layer properties. If the values are in the millions but the CRS metadata says WGS 1984, the file was defined incorrectly by a previous user.
- Use Define Projection to overwrite the incorrect geographic definition with the actual projected CRS (Maryland State Plane). Verify that the polygons now overlap the Ellicott City stream network accurately.

D. Measurement and Planar Distortion

7. Calculate Geometry

- Create a new polygon feature class in your geodatabase named measurements_poly. Digitize a rough polygon covering the historic downtown district.
- Use the Calculate Geometry Attributes tool to compute planar_area_m2 and geodesic_area_m2 using the State Plane CRS. Open the attribute table and note how these values compare

8. Mathematical Failure of Geographic Area

- Use the Project tool to mathematically transform measurements_poly into the WGS 1984 geographic coordinate system.
- Open the attribute table for this new geographic polygon and attempt to calculate its planar area.
- Why we do this: You will notice the resulting units are in "Square Decimal Degrees." Because lines of longitude converge at the poles and are widest at the equator, a "square degree" represents a drastically different amount of physical land depending on your latitude. Planar measurements require a Cartesian grid (meters/feet) to be physically meaningful.

E. Raster Cell Size
Like vector polygons, raster pixels represent area. If a raster is stored in a geographic CRS, its pixels are measured in degrees.

9. Project Raster

- Check the cell size of NAIP_EllicottCity_WGS84.tif in its layer properties. Note that it is measured in tiny fractions of a degree.
- Use the Project Raster tool to convert NAIP_EllicottCity_WGS84.tif into Maryland State Plane Meters. Output to naip_projected_m.tif.
- Why we do this: Projecting the raster converts the pixel dimensions into standardized linear units. Open the properties of your new projected raster and observe the cell size. It should now be an interpretable distance in meters, which is required for accurate spatial analysis and area calculations.

F. Questions

1. Explain the technical distinction between the Define Projection tool and the Project tool. How does each tool interact with the underlying coordinate geometry of the dataset?

2. In 2.4, you calculated the planar area of a polygon in a geographic coordinate system (WGS 1984). State the mathematical reason these planar area values are invalid for representing real-world surface area.

3. The original raster dataset in 2.4 reported a cell size in decimal degrees. Explain why angular units (degrees) cannot provide a consistent, interpretable ground resolution for linear measurements across different latitudes.

4. You received a point feature class of structural failures with an "Unknown Coordinate System." Describe the verification method you used to confirm that your newly assigned projection was accurate, and explain why visual estimation (eyeballing) is an insufficient validation method.