Guidance for Flood Risk Analysis and Mapping

Projections and Coordinate Systems

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FEMA

Requirements for the Federal Emergency Management Agency (FEMA) Risk Mapping, Assessment, and Planning (Risk MAP) Program are specified separately by statute, regulation, or FEMA policy (primarily the Standards for Flood Risk Analysis and Mapping). This document provides guidance to support the requirements and recommends approaches for effective and efficient implementation. Alternate approaches that comply with all requirements are acceptable.

For more information, please visit the FEMA Guidelines and Standards for Flood Risk Analysis and Mapping webpage (www.fema.gov/guidelines-and-standards-flood-risk-analysis-and-mapping). Copies of the Standards for Flood Risk Analysis and Mapping policy, related guidance, technical references, and other information about the guidelines and standards development process are all available here. You can also search directly by document title at www.fema.gov/library.

Document History

Affected Section or Subsection	Date	Description
First Publication	May 2016	Initial version of new transformed guidance. The content was derived from the Guidelines and Specifications for Flood Hazard Mapping Partners, Procedure Memoranda, and/or Operating Guidance documents. It has been reorganized and is being published separately from the standards.

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1.0 Overview

This guidance document provides information about projections, coordinate systems, datums, and other spatial reference information used in Geographic Information Systems (GIS) and information about their application to Flood Risk Projects. More detailed technical information is available from the Environmental Systems Research Institute (ESRI) ArcGIS Help site: http://resources.arcgis.com/en/help or the National Geodetic Survey (NGS) website: http://www.ngs.noaa.gov/. Additional information on these topics is also available from numerous on-line GIS knowledge-sharing communities.

1.1 Spatial Reference

In order to properly display, interpret, analyze, and combine spatial data sets, every dataset needs a spatial reference. A spatial reference defines how location is stored for features in the dataset and how those locations relate to the earth. A spatial reference is a series of parameters that define the coordinate system, projection, horizontal datum and other spatial properties for each dataset. All datasets within the same geodatabase use a common spatial reference definition. The spatial reference includes the following:

- Coordinate system
- Coordinate precision with which coordinates are stored (often referred to as the coordinate resolution)
- Processing tolerances, such as the cluster tolerance
- Spatial extent covered by the dataset (often referred to as the spatial domain)[1]

2.0 Background on Datums, Coordinate Systems, and Projections

All data need a horizontal datum that defines the starting point for measuring locations relative to the earth's surface. Building on the horizontal datum, there are two common types of systems for storing horizontal position information:

- A projected or planimetric coordinate system that maps locations on the earth's three-dimensional surface onto a two-dimensional plane. Data stored in planimetric must have the projection, coordinate system, and datum clearly defined to be useable.
- A global or spherical coordinate system such as latitude-longitude. These are often referred to as geographic coordinate systems (GCS). A GCS uses a three-dimensional surface to define locations on the earth. Data stored in a GCS are said to be "unprojected" because there is no conversion from three-dimensional space to a two-dimensional plane required. Data stored in GCS must have the datum and coordinate system clearly defined to be useable.

Together, the datum, coordinate system, and projection form an interconnected system for defining how coordinates assigned to features in the dataset match to locations on earth. There are many different datums, datum realizations, projections, and coordinate systems. Many of

[1] Esri ArcGIS v10 Help

these exist for historical reasons with new versions being created as science and technology improve. New horizontal datums are generally the result of improvements in science and technology.

Choosing which spatial reference system to use for a dataset may involve numerous factors. Specific computations or applications are much easier to perform or are best supported by certain spatial references and not others. There may also be historical reasons for choosing one system over another. Generally, the selection of a projection is usually based more on advantages or disadvantages for particular purposes.

Historically, all datums were local with no systems for merging data for the whole United States (U.S.) or the globe. The North American Datum of 1927 (NAD 27) synthesized surveys from the entire U.S. to create a datum for the whole continent. Advances in satellite measurement of the earth and related technology advances drove the need to create the North American Datum of 1983 (NAD 83). More recently, NAD 83 has been updated with several “datum realizations.”

Projections allow data users to work in two dimensions, displaying the data on flat maps and on-screen, and making measures of distances and angles easy. However, every map projection introduces distortion in one or more measurement properties: shape, distance, true direction, or area. Whenever one type of distortion is minimized, there is a corresponding increase in the distortion of one or more of the other properties. Projections that minimize distortion in shape are called conformal. Those that minimize distortion in distance are known as equidistant. Those that minimize distortion in area are known as equal-area. And those that minimize distortion in direction are called true-direction.[2]

The two most common systems used in the United States are State Plane and Universal Transverse Mercator (UTM). The State Plane system minimizes accuracy distortions by defining projections that fit each state (or portion of a state) the best. The UTM system is a global system that has fewer zones, and as a result has fewer boundaries than State Plane system. Two-dimensional coordinate systems are also split between feet and meters for historic reasons, with most State Plane units in feet and UTM units in meters.

One of the biggest difficulties in working with projected data is dealing with boundary issues where the area you are working in crosses the boundaries of projection zones (i.e., State Plane or UTM zones). An un-projected GCS allows for a single global coordinate system without any boundary issues, but the data must be projected in some way to display on a normal two-dimensional map, and the computations for distances and direction are more complex than with projected data.

The result of this variety of datums, coordinate systems and projections is that care must be taken to define the spatial reference for all data used and account for the differences in spatial reference in each dataset used. Generally, software will account for most of these issues as long as the dataset’s spatial reference is defined correctly.

[2] The University of Washington School of Forest Resources, Introduction to Geographic Information Systems in Forest Resources

One area where this can be particularly challenging is with the multiple “datum realizations” for NAD 83. Conceptually, NAD 83 is a single coherent way to define a measurement system for the Earth. In the realization of NAD 83, the collection of published coordinates for benchmarks around the U.S. has been updated numerous times as measurement science has continued to improve. Each update of coordinates has been given a “datum tag” to distinguish data referenced to each iteration or realization.

Functionally, data referenced to a different datum realization is like data referenced to a different datum. A conversion must be performed on the coordinates to make them compatible with each other. In many cases, the differences between different realizations of NAD 83 are on the order of a few inches and will not impact the accuracy of a Flood Risk Project. However, the difference between the initial realization of NAD 83 (i.e., NAD 83 (1986)) and the more recent realizations (e.g., NAD 83 (National Spatial Reference System [NSRS] 2011)) are significant. Standard GIS software is often not designed to automatically deal with the differences between different NAD 83 realizations and care must be used when integrating datasets used on a Flood Risk Project to account for the potentially significant difference in datum realization and clearly define the realization used for the finished product.

The NGS will be replacing the datums of the NSRS in year 2022, including NAD 83 and the North American Vertical Datum of 1988 (NAVD 88). NAD 83 and NAVD 88 have been identified as having shortcomings that are best addressed through defining new horizontal and vertical datums. NGS will provide the tools to easily transform between the new and old datums.

3.0 Applicability to Flood Risk Projects

All Flood Risk Projects include some form of geospatial data and analysis at each of the data development stages outlined in the Mapping Information Platform (MIP) workflow. Different projections and coordinate systems will likely be used at different stages in a project’s lifecycle. Mapping Partners should consider the best spatial reference system to use for the geospatial data required for each of the workflow steps.

There are specific spatial reference requirements for how newly acquired elevation data and the Flood Insurance Rate Map (FIRM) Database, Flood Risk Database (FRD), and National Flood Hazard Layer (NFHL) data are delivered to FEMA.

- The FIRM Database Technical Reference, Flood Risk Database Technical Reference, Elevation Guidance, and NFHL Guidance documents provide the specifics of the required spatial reference for the delivered datasets.
- Refer to the FIRM Database Guidance document for information relevant to FIRM Database projections and topology issues that Mapping Partners may encounter when projecting FIRM Database data from UTM or State Plane to GCS. Several specific recommendations are also described below.
- Refer to the Vertical Datum Conversion Guidance document for additional information about converting elevation data between the National Geodetic Vertical Datum of 1929 (NGVD 29) and NAVD 88 for Flood Risk Projects.

- As specified in Standard #181, a metadata file must be submitted with each Data Capture submittal.
- As specified in Standard #549, within each metadata file the Spatial Reference Information section must be included. This important metadata section documents information such as the relevant coordinate system, to include the resolution and units, projection, projection parameters, horizontal datum and ellipsoid, and vertical datum of the submitted dataset. This information is critical to anyone who will receive the data so that they can appropriately display and work with the data in their own environment.

During Discovery, it is likely that the numerous datasets that are found, evaluated, and used will be in various spatial reference systems. Terrain data, orthoimagery, and other base map data will most likely be acquired in a spatial reference system using either State Plane or UTM. National Agriculture Imagery Program (NAIP) imagery is typically in UTM projection but imagery acquired by individual states may be in State Plane. Field survey data are likely to be collected in a State Plane system. Hydrologic and hydraulic modeling and FIRM mapping need to be performed using data in a projected spatial reference system that uses State Plane or UTM. However, FIRM Database, FRD, and NFHL data must be submitted in GCS.

As noted above, if a Flood Risk Project crosses projection zone boundaries this could cause problems. Therefore the Mapping Partner should use the single projection zone that contains the largest portion of the jurisdiction. Multiple State Plane or UTM zones should not be used within a single jurisdiction for FIRM panel or FIRM Database production.

It is up to the Mapping Partner to decide when the conversion from working in a spatial reference system to GCS takes place in their individual workflow process. However, topology verification will need to be performed on the FIRM Database data once they have been projected to GCS before the data are submitted to the MIP in order for the data to pass the Database Verification Tool (DVT) topology checks. Simply projecting and exporting the data from a geodatabase to Shapefiles will not maintain the required FIRM Database topology. Topology verification may need to be performed on other submitted Flood Risk Project datasets as well if they are projected during the workflow process to ensure that topology errors that may be introduced during the projection process do not affect the resulting analyses or products.

The reason topology errors may be introduced during a map projection is that spatial or topological relationships change when data are projected. Another related aspect is cluster tolerance and X, Y resolution. In ArcGIS, the cluster tolerance or X, Y tolerance is the minimum distance between vertices. Vertices that are closer together than the cluster tolerance distance are snapped together during certain operations, including topology verification. X, Y resolution determines the number of digits used to store coordinate values. If the X, Y resolution is not adequate, coordinate value digits could be dropped, thus causing the coordinates to be displaced or to snap together. During map projection operations, as coordinates are transformed from one coordinate system to another, the distances between them may fall below the cluster tolerance causing them to be snapped together, causing topology errors.

When projecting from a projected coordinate system (i.e. State Plane or UTM) to the required GCS for submittal, Mapping Partners are advised to load their data into a geodatabase that is defined with the required coordinate system (GCS), horizontal and vertical datums, and the required cluster tolerance and spatial resolution. A FIRM Database Extensible Markup Language (XML) file with these items defined is available online at FEMA.gov in the "Templates and Other Resources" link (www.fema.gov/media-library/assets/documents/32786?id=7577).

Once the data have been projected to GCS and loaded into this pre-defined geodatabase, specific ArcGIS tools such as Repair Geometry and Planarize can be run to try to automatically correct topology errors that may be introduced during projection. Topology rules can then be loaded and run on the dataset to identify any remaining topology errors.

In addition to maintenance of FIRM Database topology, it is important to remember that a simple projection is not always sufficient to perform the necessary coordinate conversion between one spatial reference to another. The conversion has to account for datums, including datum realizations, projection, and coordinate systems.

If data have been provided in a realization of NAD 83 such as the High Accuracy Reference Network (NAD 83 [HARN]) or NAD 83 (NSRS 2007) by communities or other sources, a geographic transformation will be required when projecting data.

This may involve several transformation steps. For example, to go from NAD 83 to NAD 83 (NSRS 2007) requires one step from NAD 83 (NSRS 2007) to World Geodetic System 1984 (WGS 84) and a second step from WGS 84 to NAD 83 because a single transformation option is not available. Failure to perform this transformation correctly could result in an unwanted shift in data. Note that in ArcGIS, when projecting data, applying a geographic transformation is optional. However, Mapping Partners should not assume that it is not necessary. Research may be required to determine the best transformation step(s) to apply.

Related Templates associated with this Guidance

Note: Some templates are available to help practitioners comply with the guidance contained in this document and assist with overall program consistency. The templates are available on FEMA.gov under the "Templates and Other Resources" section: http://www.fema.gov/media-library/assets/documents/32786?id=7577.