1.0 Scale and Accuracy

1.1 Subject Discussion

Map Scale

Map Scale specifies the amount of reduction between the real world and the graphic representation on a map. It is usually expressed graphically, as a fraction (1/20,000), a ratio (1:20,000), or equivalence (1mm = 20m). Since map scale is most often used to describe paper map products, it is often assumed that the scale is fixed, and cannot change. However, a digital map in a GIS can be reduced or enlarged on the screen by zooming in or out. This implies that geographic data in a GIS does not really have a true "map scale".

When scale is used to describe digital data, it is often referring to the scale of the source data or the scale at which the digital data looks "right". As a result, this display scale influences the amount of detail that can be shown (Foote et. al. 1995). Digital data viewed at inappropriate display scales within a GIS can be misleading. A map or view can be created in the GIS that have a scale well beyond the accuracy of the original mapping, thus misrepresenting the accuracy of spatial relationships between objects.

Map scale is defined by the U. S. Geological Survey (USGS) in its USGS Fact Sheet 038-00, April 2000, as follows:

> "*To be most useful, a map must show locations and distances accurately on a sheet of paper of convenient size. This means that all things included in the map – ground area, rivers, lakes, roads, distances between features, and so on – must be shown proportionately smaller than they really are. The proportion chosen for a particular map is its scale*."

When thinking of smaller scale or larger scale, it is best to think of scale as a fraction. As the number represented by the fraction gets larger, so does the scale. Conversely, as the denominator of the fraction gets larger, the scale gets smaller. A map at a scale of 1:100,000 (1" = 8,333') are a smaller scale map than a map at a scale of 1:24,000 (1" = 2,000'). A map at a scale of 1:2,400 (1" = 200') is a smaller scale map than a map at a scale of 1:1,200 (1" = 100'). A representative fraction should not be confused with the common way most engineers and planners refer to map scales, which is: 1 inch equals 2,000 feet (verbal scale) (INDIANA).

The term "small scale map" indicates a large area of the earth is shown in a map, typically requiring significant generalization of detail for map features (for example cities might be represented as point symbols). A map of the entire United States at a scale of 1:12,000,000 (where one inch equals 190 miles) is an example of a small-scale map. Conversely a "large scale map" indicates a map that covers less geographic area and provides much greater map detail such as buildings, manholes, etc. For example, a tax map of 1:2,400 (one inch equals 200 feet) is a large-scale map.

Today many maps are created in a computer environment. Therefore, we can plot the maps at virtually any scale we choose. Scale remains an important factor in the accuracy of a map. Many digital maps are derived from aerial photography or digitized from existing paper maps. The accuracy of these digital maps is a function of the scale of the aerial photography or map. Other digital maps may show features whose locations have been determined by very accurate GPS surveys. The accuracy of GPS features is largely unrelated to the scale of the map.

Map Resolution & Accuracy

Map resolution refers to the accuracy of the location and shape of a map feature shown at a given scale. In general, as map scale increases (e.g. 1:100k to 1:50k to 1:20k), so do map resolution and accuracy. However, accuracy is also affected by the quality of source data used to map a feature (ESRI, 1994).

Features on large-scale maps more closely represent the real world because the amount of reduction (from real world to map) is less. As the level of detail of a paper map increases for a given area of earth, the size of the paper map required to cover the same area also increases. Similarly, as digital map resolutions become more detailed and accurate, file sizes increase because more information is now represented for the same area.

Spatial data can never be any more accurate than the original source from which the data were acquired (and frequently it is less accurate, depending on the method of data conversion). Therefore, if data was digitized from a source map scale of 1” = 2,000’, and a map was created at 1” = 100’, the map accuracy of features shown in the map is still 1” =2,000’.

Map accuracy should be determined by the intended use of the map. Historically, map accuracy determined the scale at which the map would be drawn. Until recently it has been customary to specify the scale of aerial photography for digital orthophotos, planimetric features, and topographic features, and then apply the National Map Accuracy Standard or other similar standard to determine the accuracy of the map (INDIANA).

Recent trends, however, are to treat accuracy as a property of the map to be reported, rather than a specification for producing the map (INDIANA). FGDC-STD-007-1998, Geospatial Positioning Accuracy Standards, Part 3: National Standard for Spatial Data Accuracy (NSSDA) specifies testing methodology and reporting requirements for map accuracy. Section 3.1.2 states:

> *"This standard does not define threshold accuracy values. Agencies are encouraged to establish thresholds for their product specifications and applications and for contracting purposes. Ultimately, users identify acceptable accuracies for their applications. Data and map producers must determine what accuracy exists or is achievable for their data and report it according to NSSDA."*

Section 3.1.4, however, concedes:

> *"Data producers may elect to use conformance levels or accuracy thresholds in standards such as the National Map Accuracy Standards of 1947 (U.S. Bureau of the Budget, 1947) or Accuracy Standards for* Large-*Scale Maps [American Society for Photogrammetry and Remote Sensing (ASPRS) Specifications and Standards Committee, 1990] if they decide that these values are truly applicable for digital geospatial data."*

Entities should consider testing and reporting the accuracy of maps in accordance with the above referenced FGDC-STD-007-1998.

Map Accuracy Defined

The horizontal accuracy of a map is related to the map scale. According to the United States National Map Accuracy Standards (issued by the U.S. Bureau of the Budget June 10, 1941 and revised April 26, 1943 and June 17, 1947), horizontal accuracy is defined:

> *"For maps on publication scales larger than 1:20,000, not more that 10 percent of the points tested shall be in error by more than 1/30 inch, measured on the publication scale; for maps on publication scales of 1:20,000 or smaller, 1/50 inch."*

Vertical accuracy of contour mapping is related to the contour interval, not map scale. The same publication defines vertical accuracy for contour maps as:

> *"…not more than 10 percent of the elevations tested shall be in error more than one-half the contour interval."*

Other types of errors on maps, such as incorrect classification of features or incorrect names of streets or places are called factual errors. It is not possible to classify these errors numerically (INDIANA).

Accuracy relates to how well features on the map correspond to their "real world" counterpart. Following are the spatial accuracy values associated with various scales mapping, as dictated by the National Map Accuracy Standards.

SCALE	1inch = x feet	Horizontal Accuracy (ft)
1:1200	100	3.33
1:2400	200	6.67
1:4800	400	13.33
1;12000	1000	33.33
1:24000	2000	40.0
1:100000	8333	166.67

The selection of a required map scale and accuracy is typically determined by the intended use of the map and the positional accuracy requirements. In local governments, some of the uses that require large scales include:

- Tax assessment: the need to place map text in narrow lots in urban typically requires 1:600 (1 inch equals 50') map scale. In most cases, tax maps range from 1:4,800 to 1:600 to accommodate rural, suburban, and urban areas within a county.
- Public works: mapping of manholes, poles, signs, etc. to support accurate measurements and engineering plans requires 1:600 or 1:1,200 scale mapping.
- Planning: municipal and county planners are typically more interested in the big picture, being able to see the entire jurisdiction shown on a single map in order to visualize patterns in land use or historic resources, for example. So, the map scale and accuracy is typically less critical than for other local government needs. The exception to this statement would be in zoning reviews where setback measurements must be supported.

Producing high-resolution digital data for a large area of the earth results in very large files. Larger file sizes result in larger amounts of data to organize and manage. A fundamental challenge for a regional GIS is to provide data for a very large area at a scale detailed enough to enable resource managers to make sound decisions, yet not so detailed that the amount of data becomes too large to manage.

Relationship of map accuracy & scale to digital GIS data

Many of the popular GIS software packages can store the coordinates of map features to an extremely high level of precision. In this case, precision and accuracy are not necessarily related.

If the GIS map was derived from aerial photography, then these definitions *do* apply. The map scale depends on the scale of the aerial photography and the scale of the enlargements used for the planimetric mapping. A highly accurate planimetric map might be made from aerial photography flown at a scale of 1:10,800 (1" = 840'), and enlarged to a scale of 1:1,200 (1" = 100') for planimetric mapping. A planimetric map that meets the United States National Map Accuracy Standards will have an accuracy of +/- 1/30 inch or +/- 3.3 feet.

Digital Orthophotos

Digital orthophotos combine the image characteristics of a photograph with the geometric qualities of a map. (USGS Fact Sheet 057-01, March 2001)

Digital orthophotos also have a property called resolution. This is reported as a linear dimension such as one meter or 6 inches and is the size of the square on the ground represented by each pixel in the digital orthophoto. The resolution depends on the scanning aperture used in the image scanning process and is not necessarily related to the accuracy of the digital orthophoto.

Digital orthorectified imagery derived from scanned aerial photography has assumed prominence in the marketplace as the preferred "land base" for many AM/FM/GIS applications. This renown has precipitated numerous different sets of specifications but no "Standards" for the preparation of uniform image products. Most agencies contracting the production of orthorectified image sets rely on existing accuracy specifications originally designed for line maps. Others have argued that by virtue of the characteristics of digital imagery, such specifications do not apply. It is our contention that these accuracy specifications are appropriate but require supplementary qualification and discussion of accuracy testing procedures. (Michaels)

John Michael,http://www.gisqatar.org.qa/conf97/links/h1.html)

Cadastral Features (parcels, corporate boundaries, etc.)

The accuracy of these features is much more difficult, if not impossible to state. For example, if a parcel boundary described by metes and bounds is entered into your GIS by using coordinate geometry, its accuracy will be as good as the accuracy of the metes and bounds survey and the accuracy of the beginning point referenced by the survey.

If parcels were originally drawn by hand over unrectified aerial photography enlargements at a scale of 1” = 200’, their accuracy cannot be derived from the United States National Map Accuracy Standards because the unrectified aerial photography enlargements have a varying amount of distortion which is greater at the edges than at the center. If these parcel maps are then scanned and rubber sheeted to fit digital orthophotography or other planimetric mapping, the accuracy of the parcel layer is still difficult to state because of initial errors, errors introduced by rubber sheeting, and uncertainties in fitting the parcels to the planimetric map.

The best way to state the accuracy of cadastral features is to describe the methods used in creating them.

Surveyed Features

These features are as accurate as the survey that determined their location. Features such as this should have their accuracy stated individually unless you are certain that all of the features in the map layer have the same accuracy.

Contours

There is disagreement in the industry about what scale aerial photography is required to produce contours that meet the United States National Map Accuracy Standards. For example, some believe 1:10,800 (1" = 840') scale aerial photography can be used to generate 2-foot contours meeting United States National Map Accuracy Standards (+/- 1 foot accuracy). Others argue that 1:7,920 (1" = 660') scale aerial photography is the smallest scale that can be used to generate 2-foot contours meeting United States National Map Accuracy Standards. References on this topic from Earth Observation Magazine include:

- http://www.eomonline.com/Common/Archives/June97/john.htm
- http://www.eomonline.com/Common/Archives/Oct97/fowler.htm
- http://www.eomonline.com/Common/Archives/Nov97/fowler.htm
- http://www.eomonline.com/Common/Archives/July00/rick.htm

1.2 Recommendations

1. All new mapping acquired by local governments should adhere to the Federal Geographic Data Committee (FGDC) Geospatial Positioning Accuracy Standards.
2. The initial investment in map accuracy can be compromised over time if proper updating practices are not followed. Therefore, updates to local government mapping should be capable of preserving the same level of accuracy over time.
3. Local governments can acquire new digital ortho-photo images as a land base, and then digitize planimetric features as required by various departments (refer to the Digital Ortho-photo Section). This approach requires available human resources within the County to perform data conversion work. If this approach is taken, it is recommended that the local government perform random field checks the accuracy of the digitized features using GPS or traditional surveying techniques in order to certify the digitized features conforming to National Map

Accuracy Standards. Planimetric detail extracted from "heads up" digitizing procedures is less accurate that photogrammetric stereo compilation procedures.

4. Alternatively, local governments can contract photogrammetric firms to perform all aerial photograph acquisition, field controls, and feature digitizing. All reputable photogrammetry firms will certify their mapping deliverables to be in conformance with National Map Accuracy Standards based on the specified scale of mapping.
5. For digital ortho-photography, refer to the Digital Ortho-Photography Section (6.0) for definitions of pixels and image resolution.
6. Generally, any GIS system intended to support multiple local government department objectives must accommodate the most accurate scale requirement across all departments.

1.3 References

1. FGDC-STD-007-1998 , Geospatial Positioning Accuracy Standards, Hyperlink available at: http://www.fgdc.gov/standards/documents/standards/accuracy/preface.pdf
2. The National Map Accuracy Standard can be obtained from the USGS at the following web site: http://rockyweb.cr.usgs.gov/nmpstds/nmas.html
3. National Society of Professional Surveyors Positional Accuracy Definitions and Procedures can be found at http://www.acsm.net/nsps/definproc.html
4. Positional Accuracy Handbook: Using the National Standard for Spatial Data Accuracy to measure and report geographic data quality, October 1999 (33 pages, 920K, PDF) This document describes how positional accuracy can be measured and reported for databases that contain geographic features like roads, rivers and property lines. Five practical examples are provided using databases developed at Minnesota Departments of Transportation and Natural Resources, the City of Minneapolis, Washington County and Lawrence Mapping. All the mathematics needed to calculate vertical and horizontal accuracy statistics is made easier with worksheets available to be downloaded from the LMIC site (Two files in one self-extracting executable, 30K, Excel format).
5. *A Methodology for Measuring and Reporting Positional Accuracy in Spatial Data*. Minnesota Office of Technology, June 12, 2000. The link to the Positional Accuracy Handbook is: http://www.ot.state.mn.us/ot_files/handbook/standard/std19-1.html
6. *Geospatial Positioning Accuracy Standards Part 1: Reporting Methodology* (FGDC-STD-007.1-1998). Federal Geographic Data Committee, Federal Geographic Subcommittee. The National Standard For Spatial Data Accuracy can be downloaded from

http://www.fgdc.gov/standards/documents/standards/accuracy/. The Federal Geographic Data Committee (FGDC) Standards web site can be found at http://www.fgdc.gov/standards/status/swgstat.html

7. (ESRI) Environmental Systems Research Institute, Inc. (1994) Map Projections, Georeferencing spatial data.
8. Snyder, J. P. 1987, Map projections--a working manual: U.S. Geological Survey Prof. Paper 1395, 383 p. Reprinted 1989 and 1994 with corrections. [General work superseding Snyder, 1982, Map projections used by the U.S. Geological Survey: U.S. Geological Survey Bull. 1532.]
   8.) Kenneth E. Foote and Donald J. Huebner, The Geographer's Craft Project, Department of Geography, University of Texas at Austin. All commercial rights reserved. Copyright 1995 Kenneth E. Foote and Donald J. Huebner.
9. USGS Fact Sheet 038-00, April 2000. Hyperlink available at: http://mac.usgs.gov/mac/isb/pubs/factsheets/fs03800.html
10. USGS Fact Sheet 057-01, March 2001. Hyperlink available at: http://mac.usgs.gov/mac/isb/pubs/factsheets/fs05701.pdf
11. Indiana GIS Initiative, Map Scale/Accuracy Standard Web Site, http://www.in.gov/ingisi/metadata/map_scale_accuracy_standard.html
12. (Michael, John, Digital Orthophotography - Principles, Project design Issues, Utility, Accuracy, Ecomnomics http://www.gisqatar.org.qa/conf97/links/h1.html