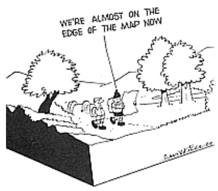
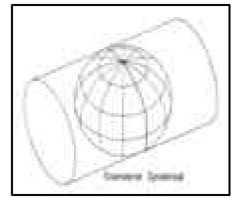
UTM, State Plane Coordinates & Map Scale



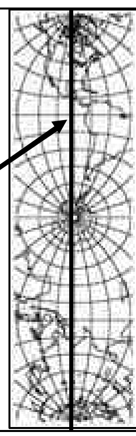
Coordinate Systems - UTM

- Convenience of a plane rectangular grid on a global level
- A section from a transverse Mercator projection is used to develop separate grids for each of 60 zones
- Low distortion along the tangent central meridian, increasing E & W
- Works great for large scale data sets.

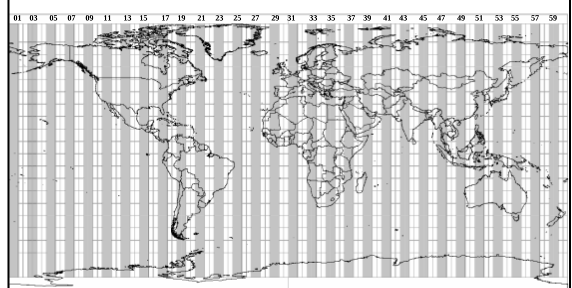


Beginning at 180°, Transverse Mercator projections are obtained every 6 degrees of longitude along a central meridian

Transverse Mercator

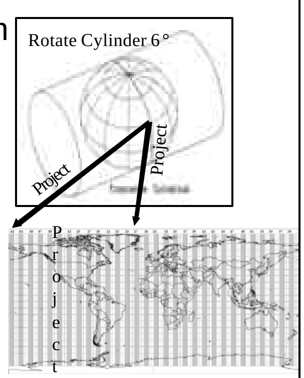


UTM Zones



UTM Grid System

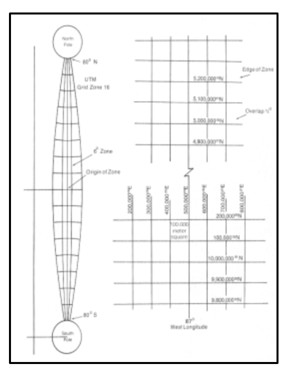
- UTM Grid System:
  - Established in 1936 by International Union of Geodesy and Geophysics.
  - Used by US Army since 1947.
  - Provides geo-referencing at high level of precision for entire globe.
  - Commonly used for thematic, topographic, and satellite maps.



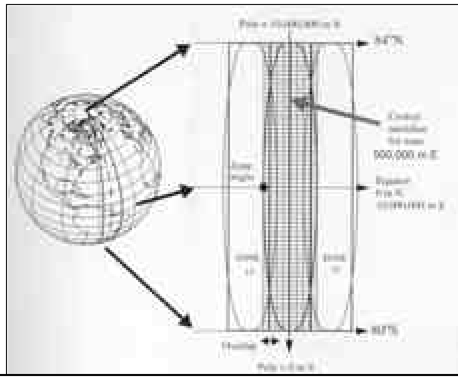
UTM Grid System

Universal Transverse Mercator

- Each zone has an origin, central meridian, and false origin
- False origins for N zones lie on Equator & 500,000m W of zone
- False origin for S zones lies 10,000,000 m S of N false origin

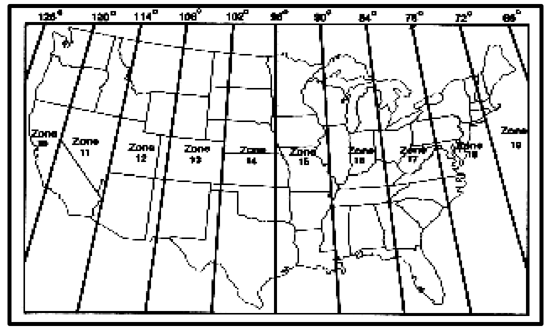


UTM Zone Overlap



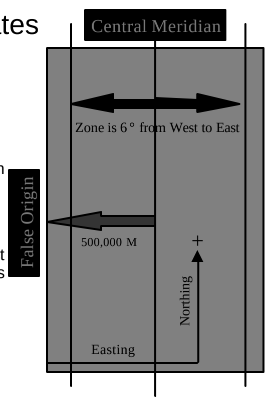
UTM Grid System

Universal Transverse Mercator for Lower 48



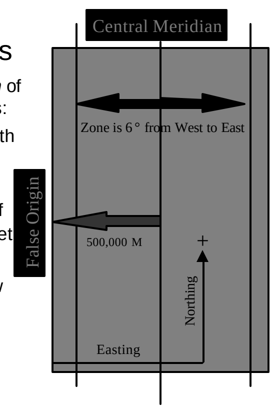
UTM Grid Coordinates

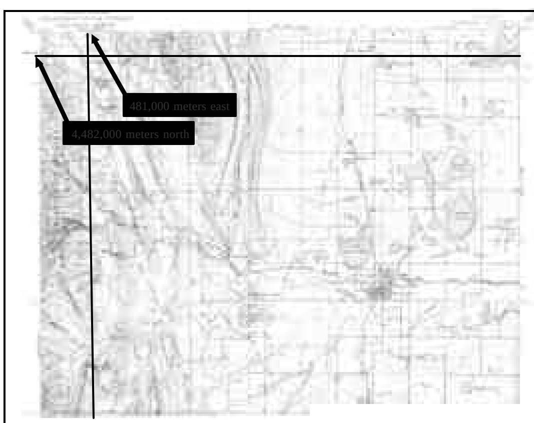
- Specify number of zone.
- Northing:
  - Northern hemisphere: equator is origin. All coordinates in meters north of equator.
  - Southern hemisphere: false origin of 10,000,000 meters south of equator.
- Easting:
  - All coordinates are measured east from a false origin 500,000 meters west of central meridian.



Reading UTM Grid Coordinates on Maps

- Northing: Displacement ***north*** of 0°. Add three 0s to get meters: 4400 = 4,400,000 meters north [some maps show entire number].
- Easting: Displacement ***east*** of false origin. Add three 0s to get meters east: 498 = 498,000 meters east [some maps show entire number].



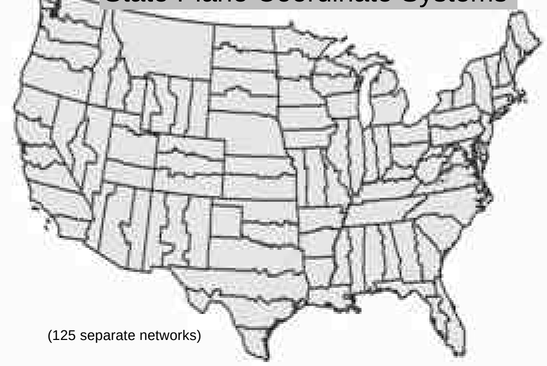


State Plane Coordinates

State Plane Coordinate Systems

- SPCS created in the 1930's
- Widely used in public works and land surveys in the US, Puerto Rico, Virgin Islands, Samoa
- Uses plane coordinates instead of Lat./Long.
  - Square grid with constant scale - distortion over small areas is minimal
  - Don't have to deal with negative numbers
- Made up of many grids (125 separate networks)
  - Smaller and N-S or E-W states usually have fewer zones, e.g., NJ, NH, TN, all have 1 zone
  - Larger states may have several zones, e.g., TX - 5, CA - 7, AK – 10
- **<u>NJ State Government has most GIS data in NJ-SPCS</u>**

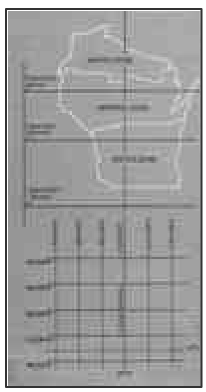
State Plane Coordinate Systems



(125 separate networks)

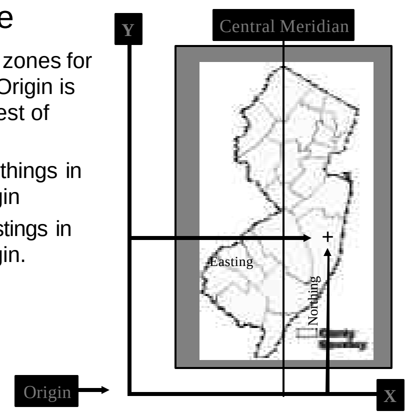
State Plane Coordinate Systems

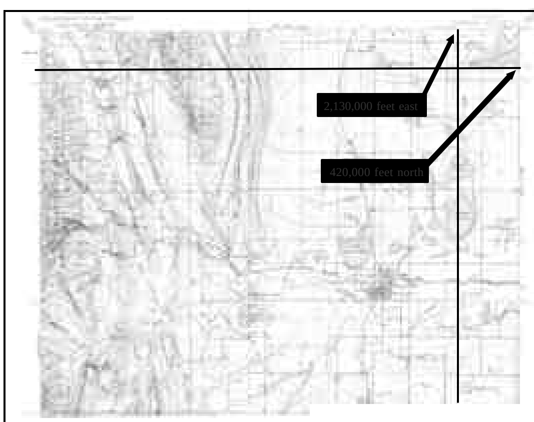
- Zone boundaries follow state and county boundaries
- Each zone has its own projection: Lambert's Conformal Conic (E-W) or Transverse Mercator (N-S)*
- Each zone has a centrally located *origin*, and a *central meridian* passing through it
- A *false origin* is established W and S of the zone
- Coordinates are read to the E and N of the false origin
- 2,065,000 feet E; 600,000 feet N; NJ



State Plane

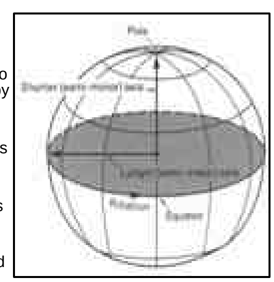
- One or more zones for each state. Origin is south and west of state.
- Measure Northings in feet from origin
- Measure Eastings in feet from origin.





Map Datums

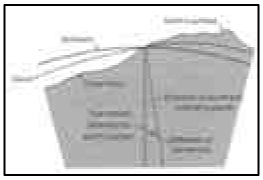
- The Earth's shape is not truly spherical
- There is a slight bulging at the equator and flattening at the poles (only about 1 in 298) due to the centrifugal force generated by the Earth's rotation
- The closest mathematical approximation of Earth's shape is an ***oblate spheroid*** or an ***ellipsoid***
- No problem for small scale maps of Earth - a sphere is sufficient
- In order to be accurate, larger scale maps must use an ellipsoid as a base



Map Datums

If you thought that was complicated ...

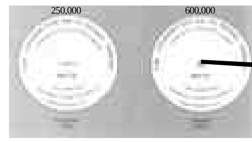
- There are variations in density in Earth's crust that lead to a warping of the equigravitational (mean sea level) surface
- This warping very slightly influences the shape of Earth's surface
- This shape is referred to as the ***geoid***
- Compared to the difference between the sphere and the ellipsoid, the ellipsoid-geoid difference is very small, but significant in large scale mapping



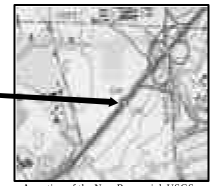
A plumb bob points perpendicular to the geoid, not necessarily toward the center of Earth

Map Datums

- The US and other parts of North America are covered by a vast geodetic control network
- The network is made up of thousands of surveyed monuments for which coordinates have been recorded



Geodetic control monuments are 3-1/2" bronze disks set in concrete or bedrock



A portion of the New Brunswick USGS quad showing a vertical control point or benchmark

Map Datums

- Since 1929 many miles of leveling surveys (establishing new elevation data) have been run
- To incorporate these data, to account for movements in Earth's crust, and to correct elevations of erroneous benchmarks, a new vertical datum was created
- The North American Vertical Datum of 1988 (NAVD 88)- completed in early 90's!
- Only a slight change in mean sea level calculation resulted

So why does this matter?

- GIS programs must know what projection type is being used during map creation.
- Use of GPS requires knowledge of Lat./Long. or UTM.
- Maps or satellite images in different projections, coordinate systems, or referenced to different datums will not overlay properly.

Map Scale

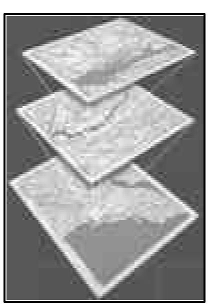
things look large at large scale

Large

↕

Small

things look small at small scale



1:24,000

1:500,000

1:3,000,000

Objectives & Overview of Map Scale

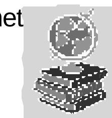
- Review various meanings of the term ***scale:***
  - Scale of study
  - Scale of study area.
  - Map scale
- Understand three types of map scale:
  - Verbal
  - Representative fraction
  - Graphic
- Know advantages and disadvantages of each type of scale.
- Learn to manipulate map scale [conversions]:

Contexts of Term ***Scale***

- Scale of study:
  - Pilot
  - Comprehensive
- Scale [size] of area being studied.
  - Micro: small area using large scale maps.
    - Study of intra city transport patterns. City as area.
  - Macro: large area using small scale maps.
    - Study of inter city transport patterns. City as point.
- ***Map Scale: ratio of map distance to Earth distance***.

Scale of a Globe

- Measure a distance on the globe for whic you know the corresponding Earth distance.
- Convert all measurement to one met [inches, feet].



- Calculate:
  - (globe distance / globe distance)
    (earth distance / globe distance)
- Scale of globe is 1: (earth distance / globe distance)

Example of Globe Scale Calculation

- Sixteen inch globe:
  Circumference = π * D
  or
  - 50.265 inches = 3.14159 * 16
- Earth has circumference of 24,901.56 miles or 1,577,762,842 inches. [Inches = miles * 5,280 * 12].
- Scale of globe:
  - (50.265 / 50.265) / (1,577,762,842 / 50.265)
- RF = 1 : 31,388,895.68
- Verbal scale: 1” to 495 miles [Miles = inches / 5280 / 12]

Nominal Scale

- Scale on globe is true at every location.
- Scale on map varies from place-to-place.
- **BUT** every map is actually or figuratively a projection from a globe [generating globe] of known scale.
- Map has point, line, or lines of **tangency** along which scale is **true.**
- The scale at this point or along this line or lines is the ***nominal scale*** of the map***.***

Scale Specification Methods

- Verbal or word statement
- Representative fraction
- Graphic.

Verbal Scale

- ***This*** many units on the **map** represent ***that*** many units on **Earth.**
  - One inch to 20 miles.
  - One inch to 400 miles.
- Unless you want to sound very ungeographical avoid saying *“One inch equals twenty miles”* because clearly it doesn’t!!

Representative Fraction

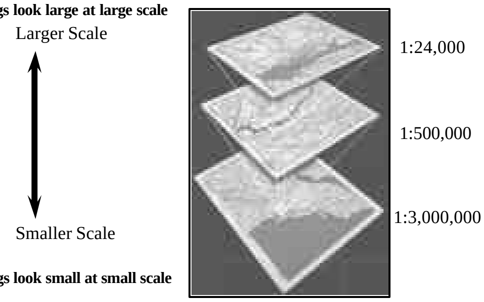
And I thought I was finished with fractions after eighth grade!

Representative Fraction

- Ratio between distance on the **map** and distance on the **Earth.**
  - 1:1 [Very large scale] (Steven Wright)
  - 1:1,000 [Large scale] or 1/1,000
  - 1:24,000 [Medium scale]
  - 1:1,000,000 [Small scale] or 1/1,000,000
- Large scale versus small scale maps, a common point of confusion.

Map Scale

things look large at large scale



things look small at small scale

Representative Fraction

- This method of specification is ***"unit free."*** It matters not whether you are talking about inches, centimeters, miles, or cubits--the idea is the same: this much on the map [an inch for instance] represents that much on the ground [1,000 inches for instance].
  - In which case the RF = 1:1,000

Calculating Representative Fraction

- Measure ***map distance*** between two points [map units].
- Measure ***earth distance*** between the same two points [earth units].
- Convert all measurements to the ***same metric*** [feet, meters].
- Solve:

  $$\frac{\text{Map Distance}}{\text{Earth Distance}} = \frac{1}{X}$$

  X = (Earth Distance / Map Distance)

- RF = 1 : (Earth Distance / Map Distance)
  OR

Approaches to finding earth distances

- Great circle distance [you know how to do this].
- Length of a degree of latitude.
- Length of a degree of longitude.
- Comparison to known map.

Great Circle Arc Distance

Given the latitude and the longitude of two locations on the globe. How do you measure the distance in **degrees** of great circle arc?

$$\theta° = \text{Arccos}\,(\text{Sine}(\text{lat}_1)*\text{Sine}(\text{Lat}_2)) + (\text{Cosine}(\text{Lat}_1)*\text{Cosine}(\text{Lat}_2)*\text{Cosine}(|\text{Long}_1 - \text{Long}_2|))$$

Great Circle Arc Distance

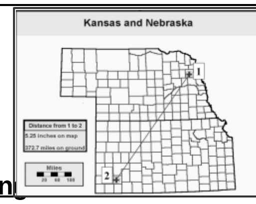
Given the great circle **arc** distance between two locations on the on the globe. How do you measure the **distance in miles**?

$$\text{Distance in miles} = 69*\theta°$$

Calculating Great Circle Distance

- Given latitude and longitude of two places 1 and 2.
- Great Circle Distance:
  - Cos D = (Sin Lat 1 * Sin Lat 2) + (Cos Lat 1 * Cos Lat 2 * Cos |Long 1 - Long 2|)
  - Degrees = Arccos D
  - Miles = 69 * Degrees

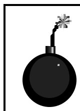
Calculating GC Distance from Latitude & Longitude



- **Place** **Latitude** **Lon**[g]

Place	Latitude	Longitude
1	42.00	-96.70
2	37.49	-100.57

- Cos D =(Sin 42 * Sin 37.49) + (Cos 42 * Cos 37.49 * Cos 3.87)
- Cos D = .9955
- Degrees = Arccos D = 5.40176



Working it out

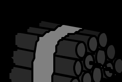
Cos D = (Sin Lat 1 * Sin Lat 2) + (Cos Lat 1 * Cos Lat 2 * Cos |Long 1 - Long 2|)

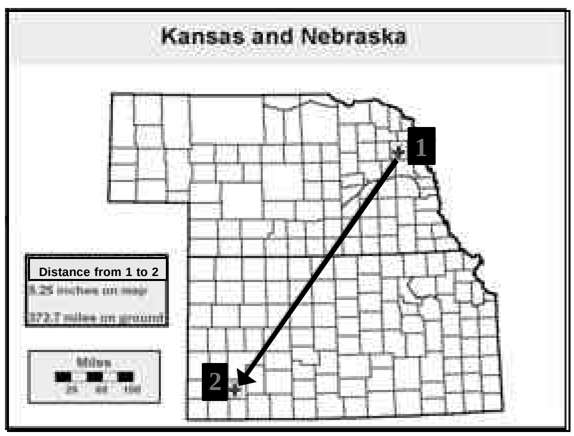
Cos D = (Sin 42 * Sin 37.49) + (Cos 42 * Cos 37.49 * Cos 3.87)
= (.66913 * .60862) + (.74315 * .79346 * .99772)
= (.40725) + (.58832)

Cos D = .99557

ArcCosD = 5.40176

Distance in miles = 69 * 5.40176
= 372.72





Calculation of Representative Fraction

- Map units = 5.25 inches
- Earth units = 372.7 miles
- Convert all measure to same metric [miles to inches]:
  - Earth Units to Inches = miles * 5,280 * 12
    = 372.7 * 5,280 * 12
    Inches = 23,614,272
- Solve: $\frac{5.25}{23,614,272} = \frac{1}{X}$
  X = 4,497,956.6
- RF = 1:4,497,957

Length of a degree of latitude

- Large scale maps:
  - 111.573 km or 68.71 miles at 0°
  - 111.132 km or 69.06 miles at 45°
  - 111.694 km or 69.41 miles at 90°
- Small scale maps:
  - 111.133 km or 69.06 miles [average length of a degree of latitude].

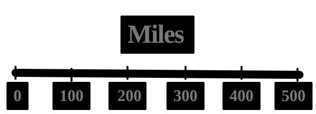
Length of a degree of longitude

- Length of a degree of longitude = average length of a great circle degree times the Cosine of the latitude.
  - Example length of a degree of longitude at:
    - 45° North = 69.06 x Cosine of 45
      = 69.06 x .7071068
      = 48.8327 miles
    - 60° North = 69.06 x Cosine of 60
      = 69.06 x .5
      = 34.53 miles
    - 89.5° North = 0.6026 miles → you could walk around the earth in 216.956 miles!

Graphic Scale

Graphic Scale

- Part of map legend
- Draw line on map and divide into segments so that each segment represents a certain distance on Earth.
- Use easily comprehended units.

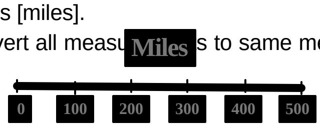


Why Use Graphic Scale

- Remains accurate when map is enlarged or reduced.
- Easy to transfer map units to Earth distance to answer, "How far is A from B?"
- Easy to plot specified Earth distance on map.
  - Where should the stops on our trip be if we want to drive 400 miles each day?

Graphic Scale Construction

- Determine the scale ***metric*** and the scale ***divisions***:
  - **Metric**: miles, feet, kilometers
  - **Divisions**: number of metric units [miles, feet, etc.] in one division of the scale.
- Measure an arbitrary map distance between two points [inches].
- Determine Earth distance between same two points [miles].
- Convert all measu s to same metric.



Graphic Scale Construction

- Convert the ground distance of one ***scale division*** to inches:
  100 miles * 5,280 * 12 = 6,336,000 inches.
- Calculate the RF of the map:
  1: <u>Earth Distance in Inches</u>
  Map Distance in Inches
- Calculate the length of a bar interval:

$$\frac{1}{RF} = \frac{X}{\text{Ground Distance of One Scale Division in Inches}}$$

Graphic Scale Construction Example

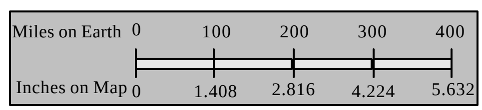
- Metric of scale = miles
- Each scale division = 100 miles
- Map distance = 5.25 inches
- Earth distance = 372.7 miles
  Earth distance in inches = 23,614,272
- Calculate RF of map: 1: [23,614,272 / 5.25]
  = 1 : 4,497,956.6
- Calculate length [on ground] of one scale division in inches = 100 miles * 5280 *12 = 6,336,000 inches.

Graphic Scale Construction Example

- Calculate the length of one bar interval:

$$\frac{1}{4{,}497{,}956.6} = \frac{X}{6{,}336{,}000}$$

- X = 1.408 inches.
- Each segment of the graphic scale represents 100 miles and is 1.408 inches long on the map.



Scale Conversions

Scale Conversion: RF to Graphic

- Suppose that you want to place a graphic scale on a map that has an RF of 1:24,000.
- You want the bar scale divided into 1,000 foot segments of earth space.
- How large in map units [inches] is each 1,000 foot segment of the bar scale?

Scale Conversion: RF to Graphic

- Convert bar scale segment size in ground units [1,000 feet in this case] to inches:

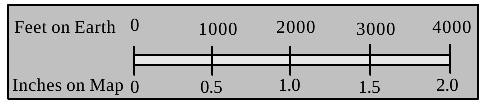
  12,000" = 1,000 feet * 12

  Solve: If 1 inch on the map is 24,000 inches on earth, then how many map inches is 12,000 inches on earth?

  $$\frac{1}{24{,}000} = \frac{X}{12{,}000}$$

  X = .5
- .5 inches on map represents 1,000 feet [12,000 inches] on ground. Each 1,000 foot scale division is .5 inches long on map.

Resulting Bar Scale



Scale Conversion: Graphic to RF

- Measure an arbitrary distance on the map. [Five inches for instance].
- Use existing graphic scale to convert map measure [5 inches] to earth distance [say it's 60 miles].
- Convert to uniform units [inches].
- Solve:

  $$\frac{\text{Map Inches}}{\text{Earth Inches}} = \frac{1}{X}$$

Scale Conversion: Graphic to RF

- Five inches on the map represents 60 miles on earth.
- Sixty miles is 60 * 5,280 * 12 inches or 3,801,600 inches.
- Solve:

  $$\frac{5}{3{,}801{,}600} = \frac{1}{X}$$
- X = 760,320
- RF = 1:760,320

Scale, Accuracy, and Resolution in a GIS

- Because GIS data is stored in a very different way than paper map data, the relationships between map scale, data accuracy, resolution, and density are very different between GIS and paper maps.
- **Note:** See Error, Accuracy, and Precision at The Geographer's Craft Project for a much more comprehensive treatment.

Map scale in GIS

- Map scale specifies the amount of reduction between the real world and its graphic representation. Since a paper map is always the same size, its scale is fixed when it is printed, and cannot change.
- However, a map in a GIS can be shrunk or enlarged at will on the screen or on paper. You can zoom in until the screen displays a square meter or less, or zoom out until the screen displays all of NJ. This means that geographic data in a GIS doesn't really have a 'map scale'.

Display scale

- The display scale of a map is the scale at which it 'looks right'. Because a paper map is created at certain scale, its 'map scale' and 'display scale' are the same. The display scale influences two things about a map :
  - The amount of detail.
  - The size and placement of text and symbols.
  - If you put a 1:20,000 scale paper map on an reducing photocopier, you can make it into a 1:100,000 map (ie reduce it by a factor of 5).
  - A GIS map's annotation (ie text and symbols) must be designed with a display scale, just like a paper map. There is a range of scale in which it will 'look right', even though it is possible to display it at other scales with the GIS software.

Data accuracy and uncertainty

- Data accuracy is an statement of how closely a bit of data represents the real world. What features have been omitted ?
- What non-existent features are represented ?
- How correct is their classification ?
- How current is the data ?
- How far away is a map feature from its actual location in the world ?
- This last, or 'locational' accuracy is of interest here, and is generally stated in terms of uncertainty. Locational accuracy includes :
- absolute accuracy: How close is the location on the map or data representation to its real location on the earth ? For example, '95% of the well locations are within 50 meters of their surveyed locations'.
- relative accuracy: How similar is a shape on the map or data representation to the shape of the object on the earth. For example, 'cutblock boundaries do not vary by more than 10 meters from their actual shape'.
- These are separated because a map object may have a very accurate shape, but not be registered (located) correctly. A rigorous statement of accuracy will include statistical measures of uncertainty and variation, as well as how and when the information was collected. Spatial data accuracy is independent of map scale and display scale, and should be stated in ground measurement units.

Data precision

- Data precision is the smallest difference between adjacent positions that can be recorded and stored. Most GIS store locations in ground units (eg UTM coordinates, or Longitude/Latitude) with a precision of a metre, centimetre or less. This precision is far greater than the resolution of any of MSRM's data, except for some cadastral data. See MSRM GIS Storage Precision for a detailed discussion

Data resolution

- Resolution is the degree to which closely related entities can be discriminated. Since a paper map is always the same size, its data resolution is tied to its scale. Resolution also limits the minimum size of feature that can be stored. Generally, a line cannot be drawn much narrower than about 1/2 a millimetre. Therefore, on a 1:20,000 scale paper map, the minimum distance which can be represented (resolution) is about 10 metres. On a 1:250,000 scale paper map, the resolution is 125 metres.
- Usually, it is desirable to specify the resolution of a dataset as a minimum feature size. For example, 'no lakes of less than 5 hectares surface area should be captured'. In a GIS, this is the most important reason for having the same data represented at different 'scales'.
- For example, MSRM has five different representations of essentially the same topographic and planimetric data. Although we are all accustomed to saying that this data was captured at five different *scales*, it would be more meaningful to say that we have the same data at five different *resolutions*.

Raster data resolution

- Raster data is stored as (usually square) pixels, which form a grid or mesh over an area of the earth. The size of these pixels determines the resolution of the raster, because it is impossible to store anything which falls 'between' the pixels. A GIS allows raster pixels to be any size, although they should not be smaller than the uncertainty of the data. If a raster coverage is derived from vector linework, its pixels should not be smaller than the uncertainty in the linework. If it comes from an air-photo or satellite image, its pixels should not be smaller than the resolution of the camera that recorded it.

Data density

- Data density is a measure of how many features per area are stored, and may imply a minimum feature size. Greater density implies more features in a given area, and therefore the features may be smaller. The density of paper map's data is limited by its scale (and therefore its resolution). Areas (polygons) cannot be shown if they are smaller than the lines which draw them. For example, a polygon less than 250 metres wide cannot be drawn on a 1:250,000 scale map. This minimum size also limits the number of polygons that can be represented in a given area of a paper map.
- A GIS stores its data digitally, so the minimum size of a feature is limited only by the precision, which is effectively infinitesimal. Where the degree of detail in a coverage is arbitrary (eg soil polygons), a data definition or convention should specify the minimum size of features, and therefore their density, or resolution. Without this, different parts of the same coverage may have widely varying degrees of detail, influencing analysis results.

Data detail

- Data detail is a measure of how much information is stored for each feature. A GIS stores lines (eg, a lake shoreline) as a sequence of point locations, and draws it with the edges that join them. There is no limit to how many points can be stored, or how close together they may be.
- The amount of detail on line features should be limited just like data density. It does not make sense to store points at intervals which are shorter than the accuracy of their locations.

GIS analysis

- In a GIS, analysis is done at the precision of the data, not at any display scale. For example, the area of a habitat polygon is calculated to the nearest square centimetre. The GIS will carry much more precision through its calculations than are justified by the data's accuracy. The results of these calculations should be rounded to a value appropriate to the uncertainty of the data for reporting. Some operations may result in features which are smaller than the data uncertainty. For example, overlaying rivers and forest polygons may create 'slivers' along the riverbanks which are 10 metres wide, when the uncertainty of the data is 20 metres. These slivers should be ignored, or included with their neighbours before the results of the overlay are used for further analysis.

Separation of data and annotation

- In a GIS, it is common to display the same data (eg wildlife management unit boundaries) at several different scales for different purposes. It is also possible to create symbols and text that 'look right' at several different scales, and store them apart from the data they label. For example, management unit boundaries could be stored in one provincial coverage, and annotation layers could be developed for labelling them at display scales of 1:20,000, 1:250,000, and 1:2,000,000.
- If done carefully, this avoids duplication of the same data for display at different scales.

Generalization

- In a GIS, it is possible to create a new coverage by reducing the amount of detail in existing coverage. This 'generalizing' may or may not reduce the number of objects in the coverage. For example, a detailed forest cover map may be generalized by combining polygons with similar characteristics. This reduces the number of objects in the coverage.
- Conversely, a detailed ecosystem classification map may be generalized by reducing the amount of detail in the boundaries between regions, without reducing the number of regions.
- Generalizing a raster image usually reduces both the number of objects, and the amount of detail.