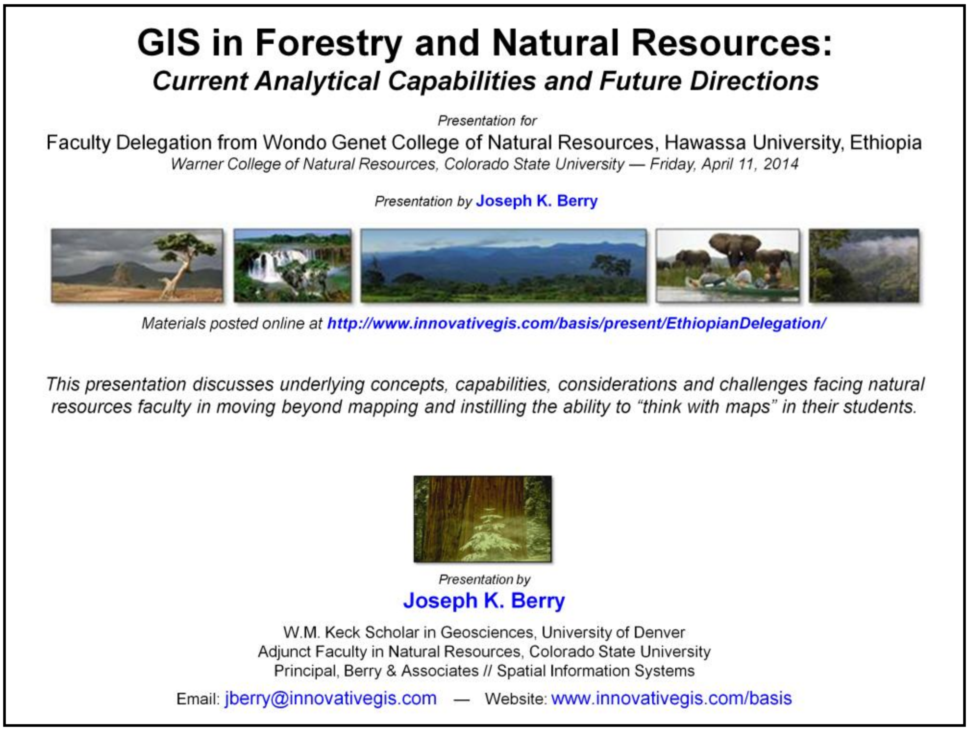
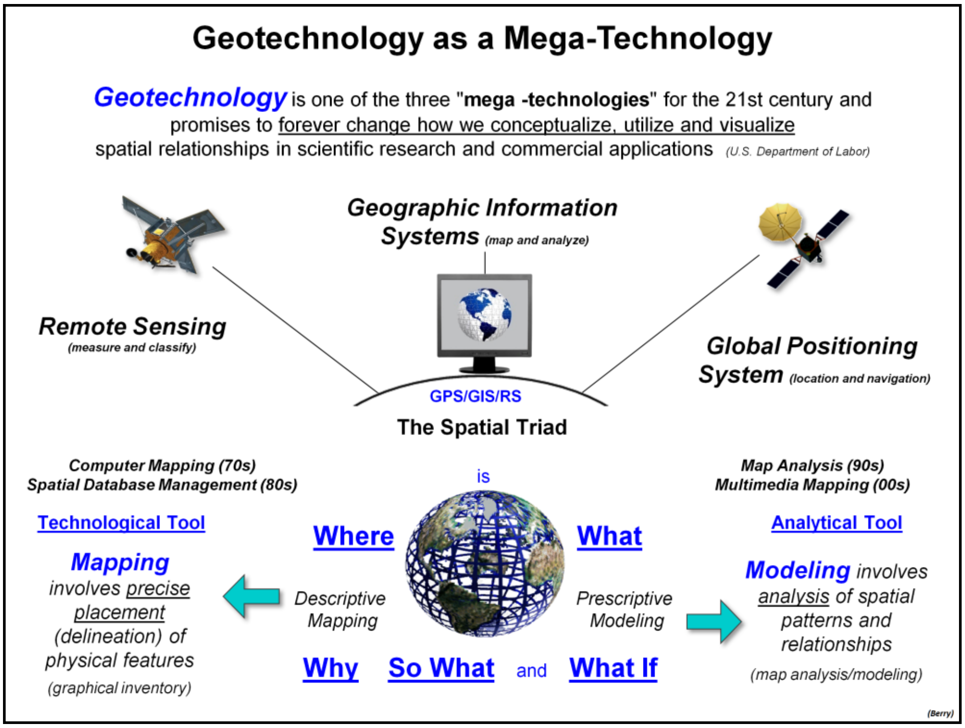


This PowerPoint with notes is posted online at—
www.innovativegis.com/basis/Present/EthiopianDelegation/

All of these slides have presenter notes discussion the points made in each slide. Online **links to further reading** for the material are identified on the handout.

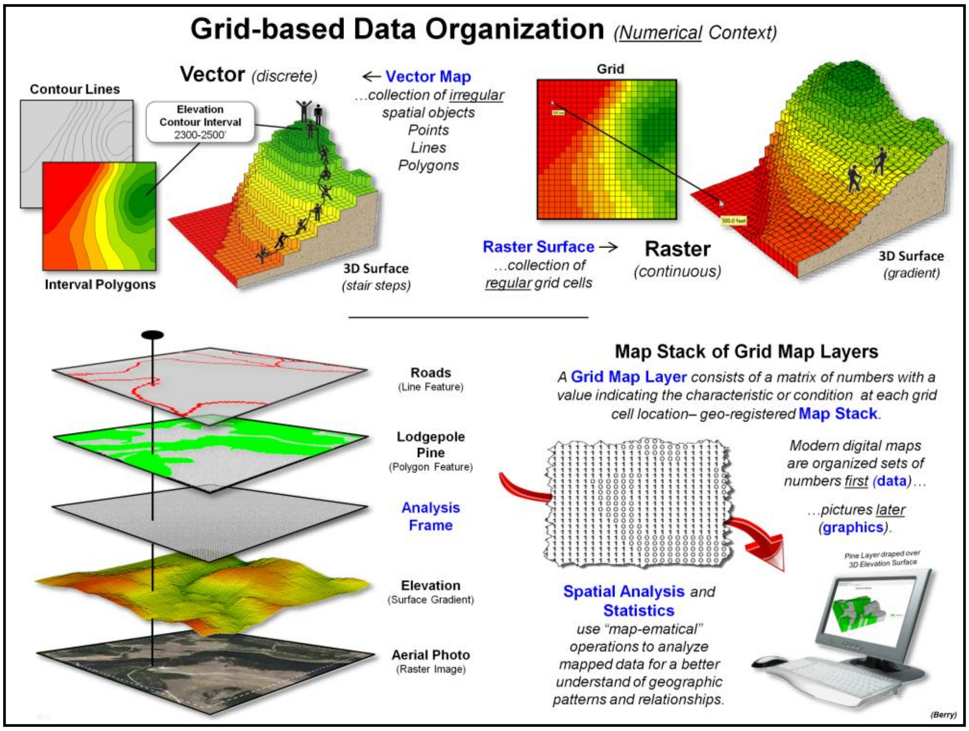


In just four decades, the geospatial science and technology has progressed from an era of *Computer Mapping* to *Spatial Database Management*, then to *Map Analysis and Modeling* and finally to *GeoWeb Interactions*. Today it has matured to a point where the US Department of Labor has identified Geotechnology as “one of the three most important emerging and evolving fields, along with nanotechnology and biotechnology.”

The top portion of the figure relates Geotechnology to “spatial information” in a broad stroke similar to biotechnology’s use of “biological systems” and nanotechnology’s use of “control of matter.”

The middle portion identifies the three related technologies for mapping features on the surface of the earth— GPS, GIS and RS. The bottom portion identifies the two dominant application arenas that emphasize Descriptive Mapping (“Technological Tools” for*Where* is *What*) and Prescriptive Modeling (“Analytical Tools” for*Why* and *So What*).

What is most important to keep in mind is that geotechnology, like bio- and nanotechnology, is greater than the sum of its parts—GPS, GIS and RS. While these individual mapping technologies provide the enabling capabilities, it is the application environments themselves that propel geotechnology to mega status. For example, precision agriculture couples the spatial triad with robotics (Intelligent Implements) to completely change crop production.



The top portion of the slide depicts the fundamental concepts supporting raster data. As a comparison between vector and raster data structures consider how the two approaches represent an Elevation surface. In vector, contour lines are used to identify lines of constant elevation and contour interval polygons are used to identify specified ranges of elevation. While contour lines are exacting, they fail to describe the intervening surface configuration.

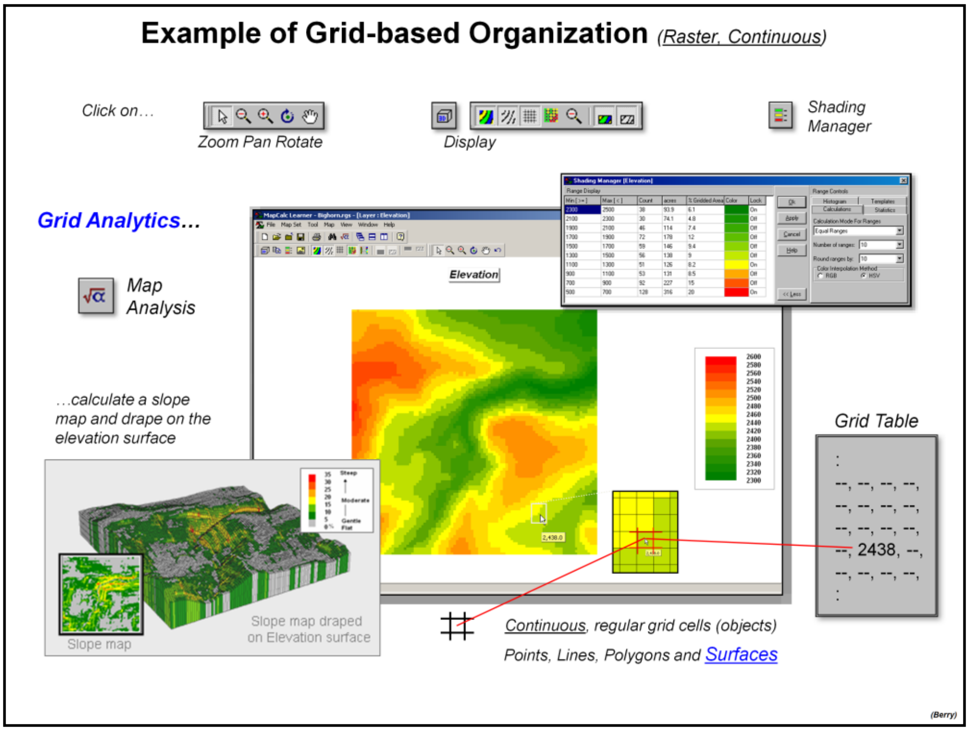
Contour intervals describe the interiors but overly generalize the actual "ups and downs" of the terrain into broad ranges that form an unrealistic stair-step configuration (center-left portion of figure 3). As depicted in the figure, rock climbers would need to summit each of the contour interval "200-foot cliffs" rising from presumed flat mesas. Similarly, surface water flow presumably would cascade like waterfalls from each contour interval "lake" like a Spanish multi-tiered fountain.

The upshot is that within a mathematical context, vector maps are ineffective representations of real-world gradients and actual movements and flows over these surfaces— while contour line/interval maps have formed colorful and comfortable visualizations for generations, the data structure is too limited for modern map analysis and modeling.

The bottom portion of the slide illustrates a broad-level view of the organizational structure for grid-based data. Within this construct, each grid map layer in a geographically registered analysis frame forms a separate theme, such as roads, cover type, image and elevation. Each point, line and polygon *map feature* is identified as a grid cell grouping having a unique value stored in implied matrix charactering a discrete spatial variable. A *surface gradient*, on the other hand, is composed of fluctuating values that track the uninterrupted increases/decreases of a continuous spatial variable.

The entire set of grid layers available in a database is termed a *map stack*. In map analysis, the appropriate grid layers are retrieved, their vales map-ematically processed and the resulting matrix stored in the stack as a new layer— in the same manner as one solves an algebraic equation, except that the variables are entire grid maps composed of thousands upon thousands of geographically organized numbers.

The major advantages of grid-based maps are their inherently uncomplicated data structure and consistent parsing within a holistic characterization of geographic space—just the way computers and math/stat mindsets like it. No sets of irregular spatial objects scattered about an area that are assumed to be completely uniform within their interiors… rather, continuously defined spatial features and gradients that better align with geographic reality and, for the most part, with our traditional math/stat legacy.

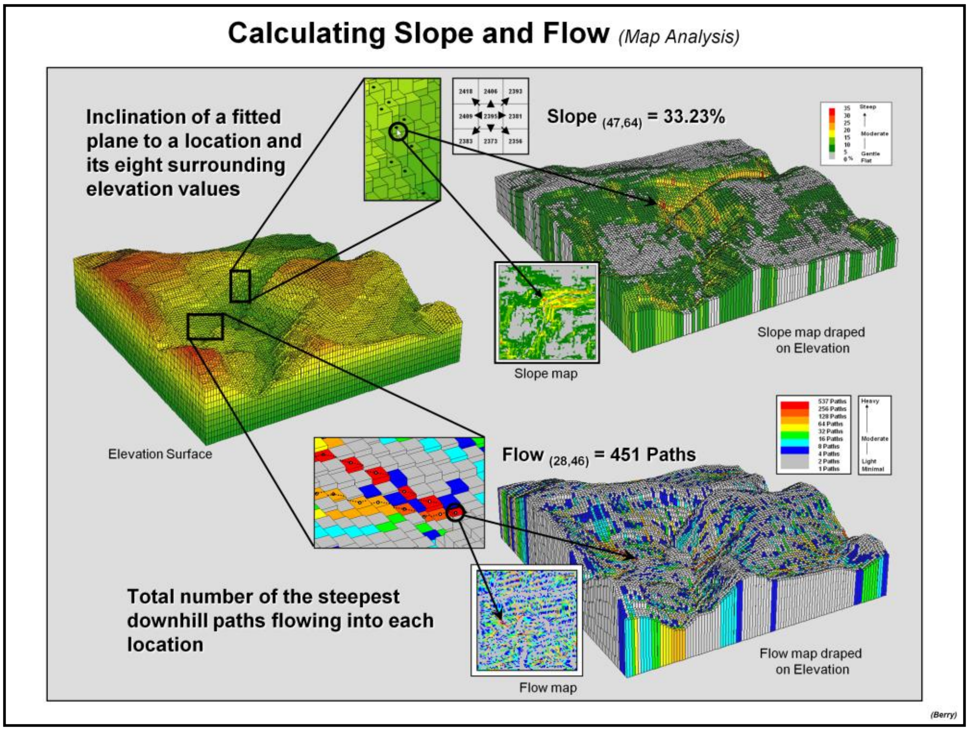


Real-time demo of the basic data structure, drill-down, display and analysis (slope) procedures used in grid-based map analysis and modeling systems.

See **http://www.innovativegis.com/basis/Senarios/**, select "Short Video Demos" for online videos demonstrating…

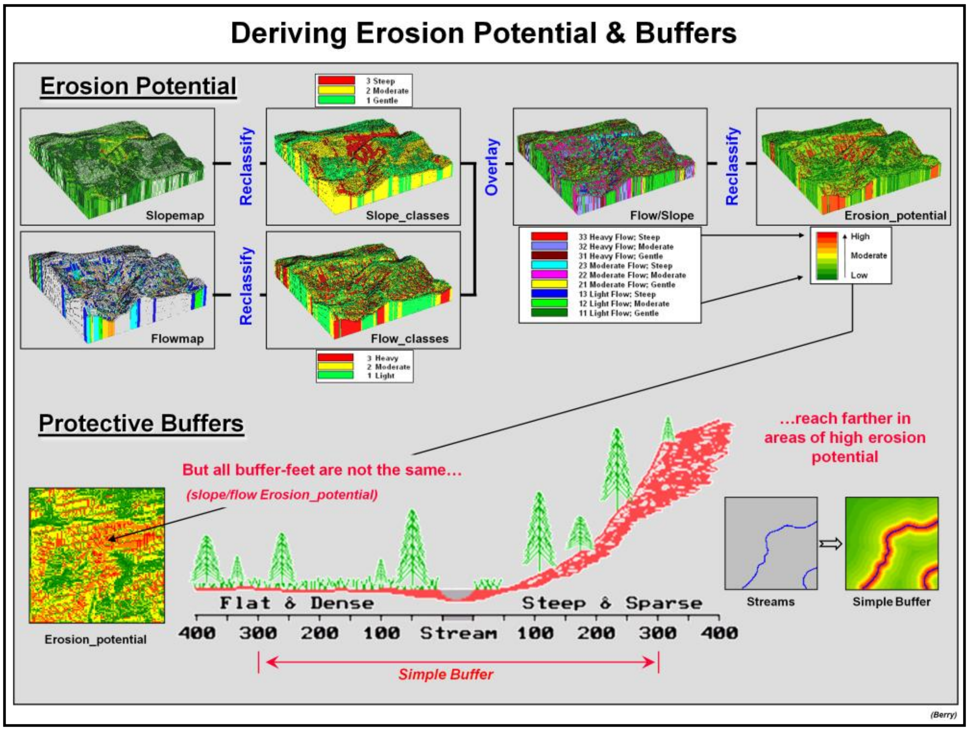
MapCalc Basics …demonstrates some of the basic display and map handling features. For more information, see "Applying MapCalc Map Analysis Software" section in the online applications examples.

Calculating Slope and Surface Flow …demonstrates map analysis procedures for generating slope and surface flow maps. For more information, see "Mapping Surface Flows and Pooling" application example and Topic 11, "Characterizing Micro-Terrain Features" in the Map Analysis online book.



The top portion of the slide shows the processing for generating map of terrain steepness (Slopemap). Inclination of a fitted plane to a location and its eight surrounding elevation values determines the steepness of a grid location in either slope percent or degrees. The "roving 3x3 window" is systematically moved over the project area until all grid locations have received a steepness value. Locations at the border "mirror" the elevation values to account for the missing data.

The bottom portion shows the processing for generating a map of accumulated surface flow (Flowmap). The total number of the steepest downhill paths flowing into each location is recorded. The computer goes to a location on the elevation surface and searches the eight cells around it for the steepest slope and then moves to that location and repeats the process until there are no surrounding downhill locations. A "running sum" is kept for each grid location indicating the number of uphill locations passing through it. A location with the value 1 indicates a flat area or depression that has no downhill neighbors. Higher values indicate increasing surface flow through a location (higher number of flow paths) hence more surface flow.



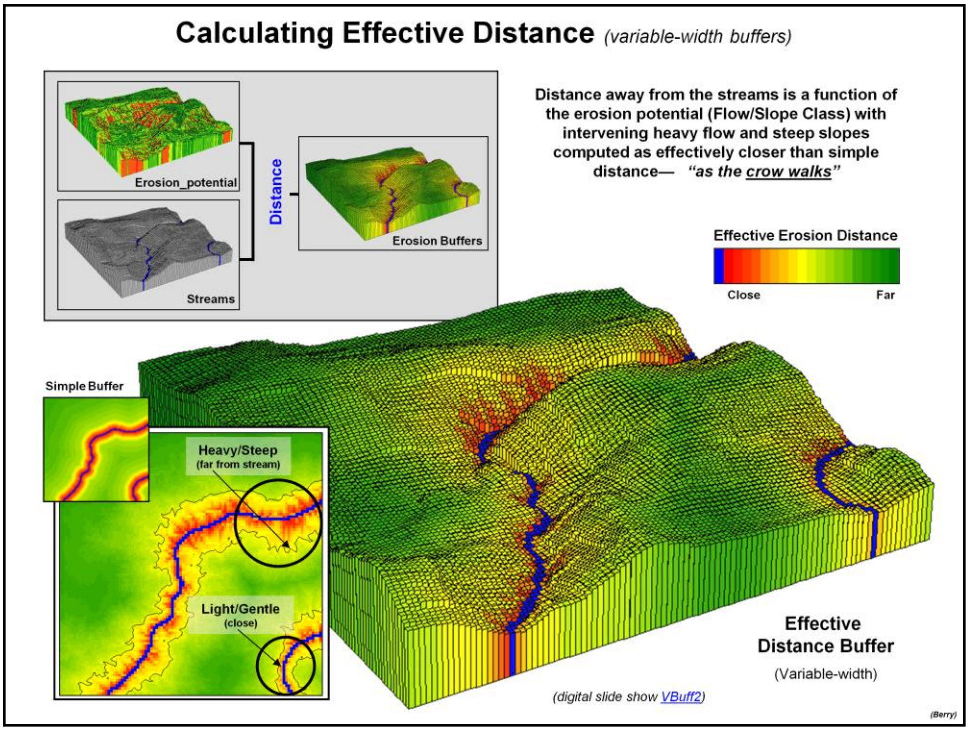
The slide shows the processing logic for generating a map of potential erosion for part of a large watershed. The first step calculates a slope map that is then for the second step interpreted (Reclassified) into three classes of relative steepness—gentle (green), moderate (yellow) and steep (red) terrain. Similarly, an accumulation flow map is generated and then interpreted (Reclassified) into three classes of surface confluence—light (green), moderate (yellow) and heavy (red) overland flows. The reclassified slope and flow maps are shown draped over the terrain surface to help visually verify the results. How the slope and flow maps were discussed in the previous slide. What is important for this discussion is the realization that realistic spatial considerations beyond our paper-map legacy can be derived and incorporated into map processing logic.

The third step combines the two maps into nine possible coincidence combinations by multiplying the flow_classes map times 10 an adding the slope classes_map. The result is a map containing values representing a 2-digit code– the “tens” digit identifying flow class and the “ones” digit the slope class (e.g., a 12 is a grid location having flow class= 1 and slope class= 2.

The fourth step interprets the Flow/Slope combinations into relative erosion potential. For example, areas with heavy flows and steep slopes have the greatest potential for erosion while areas that have light flows and gentle slopes have the least. The result is an Erosion Potential map that identifies a gradient from 1= low to 9= high erosion potential. The solution map clearly shows that not all locations have the same potential to get dirt balls rolling downhill.

However, the lower portion of the slide shows the result of a “simple buffer” around a stream assumes buffer-feet are the same by reaching out from the stream a fixed distance regardless of the intervening erosion potential. It is common sense that a fixed distance likely would be an insufficient setback in areas of high erosion potential with heavy flows and steep intervening conditions. Similarly the buffer would reach too far in conditions of light flow and gentle slopes. Also a vector buffer representation doesn’t differentiate between a location that is adjacent to a stream from one that is at the extreme reach while in reality there are important sediment loading differences between the two.

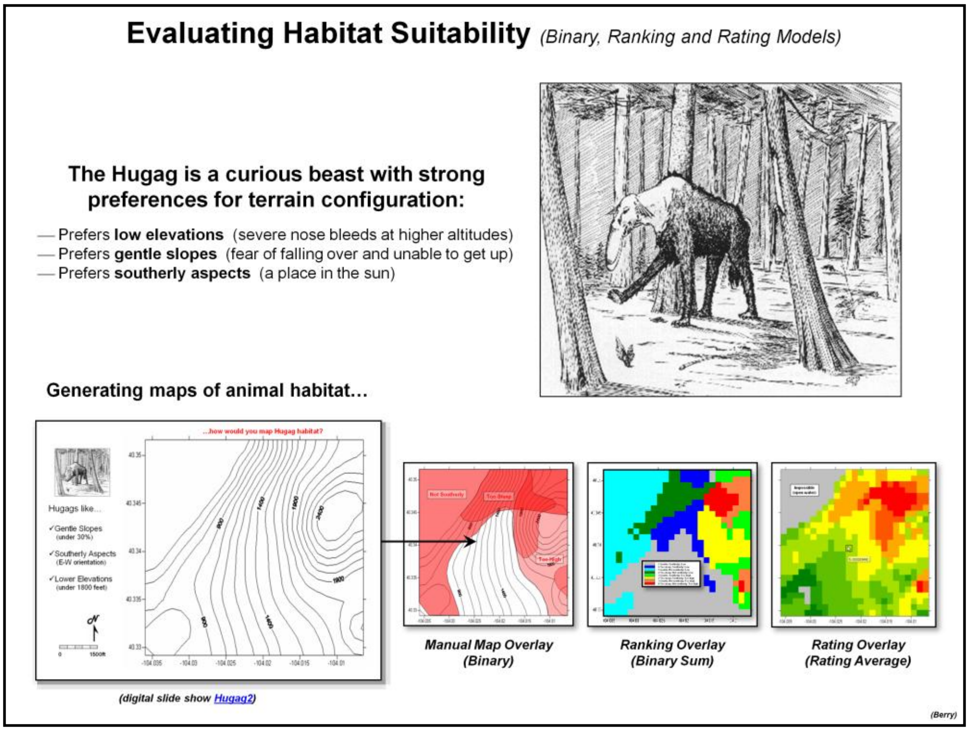
The upshot is that “simple distance” buffers are just that– to simple (stupid) to be effective in realistic sediment loading modeling and in most NR decision-making. Even a series of simple buffers based on planimetric distance would be ludicrous for protecting against sediment loading to streams as each step is the same distance regardless of intervening terrain conditions..



This slide illustrates an extension of the "simple distant" buffer using a grid-based model. The "effective distance" buffer reaches farther away from the stream under highly erodible conditions (high flow; steep slope) and not very far under low erodible conditions (low flow; gentle slope)

The result is a variable-width buffer that constricts and expands as a function of the erosion potential around the streams. While this "rubber-ruler" approach to establishing protective buffers isn't part of our traditional map paradigm, it is part of real-world experience that recognizes "all buffer-feet are not the same."

This simple example of a Spatial Analysis application illustrates how the evolution of GIS from mapping to map analysis is changing our perspective of what maps are and what we can do with them—thinking out of the paper map box.



A binary habitat model of Hugag preferences is the simplest to conceptualize and implement. It is analogous to the manual procedures for map analysis popularized in the book *Design with Nature*, by Ian L. McHarg, first published in 1969. This seminal work was the forbearer of modern map analysis by describing an overlay procedure involving paper maps, transparent sheets and pens.

For example, if avoiding steep slopes was an important decision criterion, a draftsperson would tape a transparent sheet over a topographic map, delineate areas of steep slopes (contour lines close together) and fill-in the precipitous areas with an opaque color. The process is repeated for other criteria, such as the Hugag's preference to avoid areas that are northerly-oriented and at high altitudes. The annotated transparencies then are aligned on a light-table and the "clear" areas showing through identify acceptable Hugag habitat.

An analogous procedure can be implemented in a computer by using the value 0 to represent the unacceptable areas (opaque) and 1 to represent acceptable habit (clear). As shown in figure 2, an *Elevation* map is used to derive a map of terrain steepness (*Slope_map*) and orientation (*Aspect_map*). A value of 0 is assigned to locations Hugags want to avoid— Greater than 1800 feet elevation = 0 *…too high;* Greater than 30% slope = 0 *…too steep;* North, northeast and northwest = 0 *…to northerly* —with all other locations assigned a value of 1 to indicate acceptable areas.

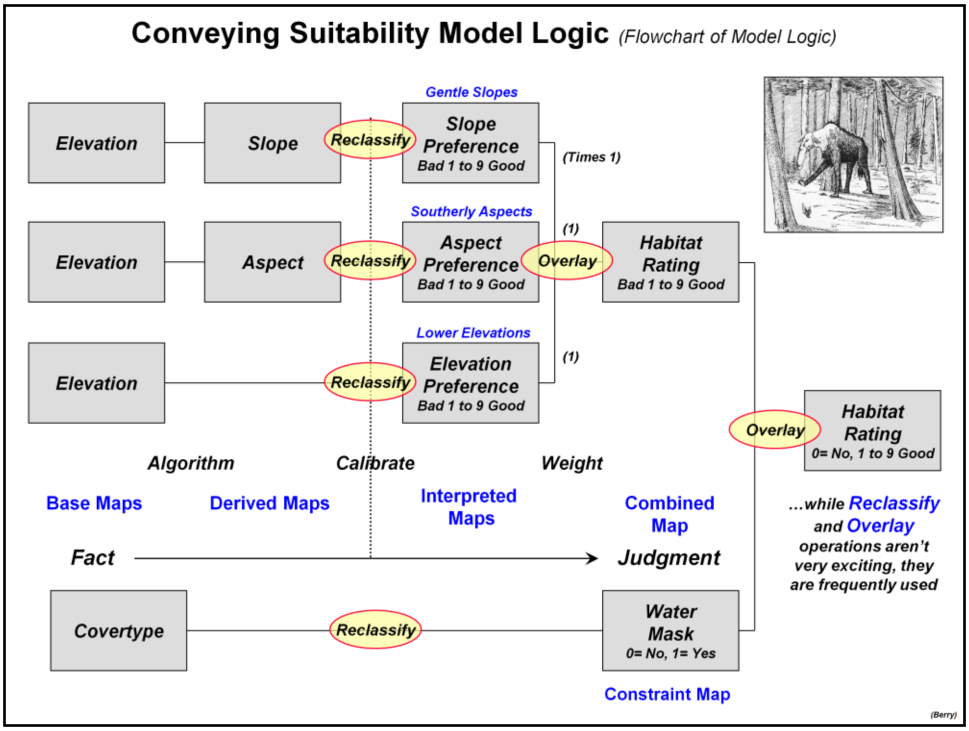
A simple ***Binary*** suitability map of Hugag habitat is generated by multiplying the three individual binary preference maps. If a zero is encountered on any of the map layers, the solution is sent to zero (bad habitat). For the example location on the right side of the figure, the preference string of values is 1 * 1 * 0 = 0 (Bad). Only locations with 1 * 1 * 1 = 1 (Good) identify areas without any limiting factors—good elevations, good slopes and good orientation. These areas are analogous to clear areas showing through the stack of transparencies.

A ***Ranking*** suitability map of Hugag habitat is generated simply by added together the individual binary maps for a count of the number of acceptable locations. Note that the areas of perfectly acceptable habitat (light grey= 1 * 1 * 1= 1; 1 + 1+ 1= 3) on both the binary and ranking suitability maps have the same geographic pattern.

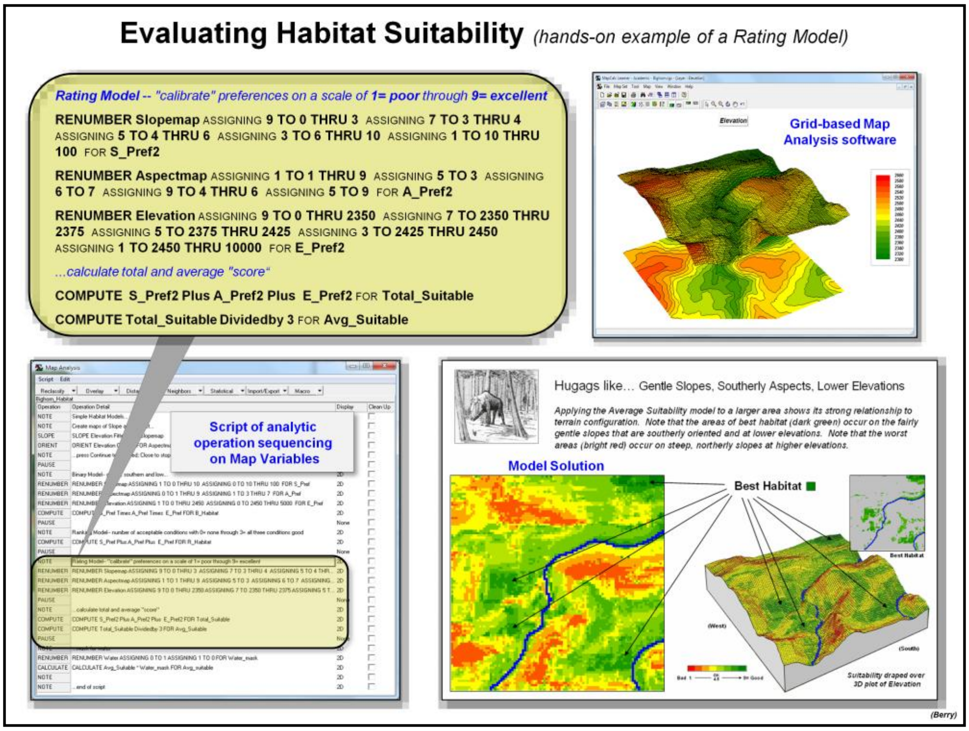
A further extension of the binary techniques uses a mathematical trick for a ***Binary Sum*** suitability map. The criteria maps are reclassified to a binary progression of numbers (1, 2 and 4) instead of all 1's for acceptable habitat. When these maps are summed the result is a unique value for each combination of values. For example, a location with a sum of 3 can only occur if it is gently sloped (1) plus southerly exposed (2) plus too high (0). The best habitat is indicated by the value 7 (1+2+4= 7).

A ***Rating Average*** suitability map depicts an alternative procedure where each of criteria layers are "graded" on a scale from 1= very bad to 9= very good. For this example the calibration was—
  <u>Slope Map</u>: >40%= 1 (very bad); 30-40= 3; 20-30= 5; 10-20= 7; 0-10= 9 (very good)
  <u>Aspect Map</u>: N, NE, NW= 1 (very bad); E, Flat= 5; W= 6; SE, S, SW= 9 (very good)
  <u>Elevation Map</u>: >1800ft= 1 (very bad); 1400-1800= 3; 1250-1400= 5; 900-1250= 7; 0-900= 9 (very good)
…then the individual criteria maps are averaged for an overall score. In addition, lakes are masked as they represent impossible habitat (drowned Hugags).

The resulting ***Average*** suitability map contains an overall score for each map location. Note the results for the example location in both figure 1 and 2. The Binary Progression solution ranks it as totally acceptable (7= gentle, southerly, low), while the Average Suitability solution rates it as mediocre habitat (5.3= mid-range on a 1 to 9 scale). The dark green locations, on the other hand, identify very good habitat (8-9 rating) and the bright red locations indicate the worst habitat (1-2 rating).



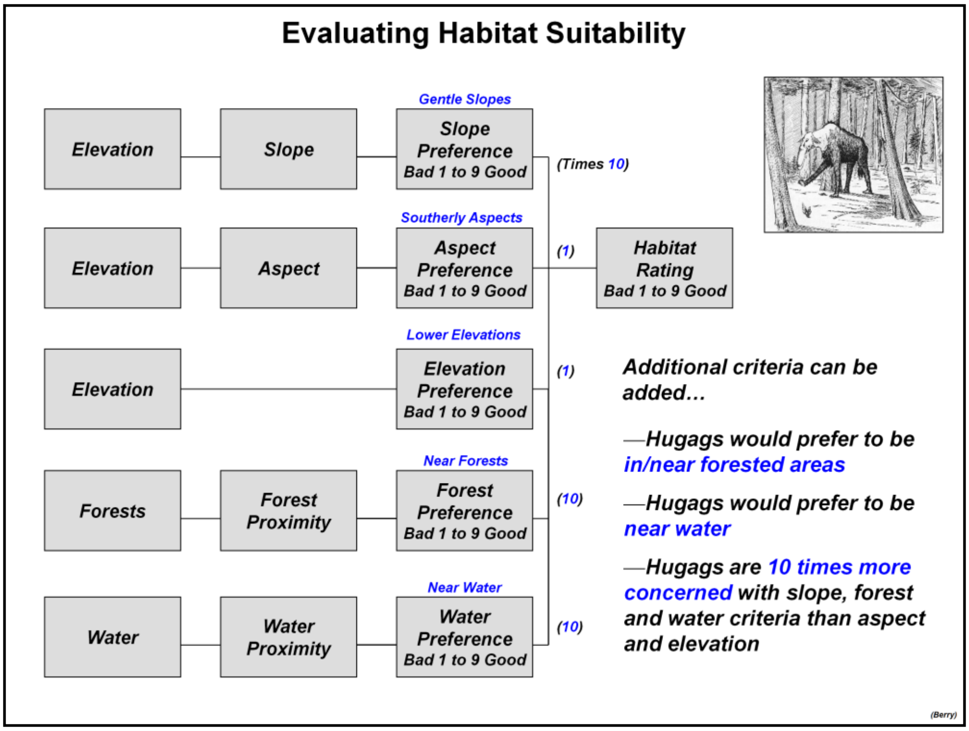
The previous slide on suitability modeling used wildlife habitat mapping to illustrate the development of progressively more powerful modeling approaches—binary, ranking, progressive and rating models. All four approaches used the same set of basic criteria—Hugag preference for gentle slopes, southerly aspects and lower elevations. While processing approach is an important consideration, the model logic and extent can be even more important in determining model accuracy. In practical applications, an operational habitat model would likely consider many more factors than simply terrain configuration.



Real-time demo of the basic procedures used in suitability modeling. In executiong the model a stored "command script" is used. To simulate different calibrations and weighting, the script can be accessed a command line at a time, edited to reflect different parameter assumptions and then executed. The result is a new suitability map that can be compared (subtract the two maps) to identify locations that were changed (and how much they were changed) for every location in a project area.

For a related annotated example of a suitability model for determining the best locations for a campground, see **http://www.innovativegis.com/basis/Senarios/**, scroll down to "Application Examples" and select…

Identifying Campground Suitability: *A recreation specialist needs to generate a map that identifies the relative suitability for locating a campground. In an initial planning session it was determined that the best locations for the campground is on gently sloping terrain, near existing roads, near flowing water, with good views of surface water and oriented toward the west. (uses standard MapCalc* ***Tutor25.rgs*** *database and standard* ***Campground.scr*** *script).*



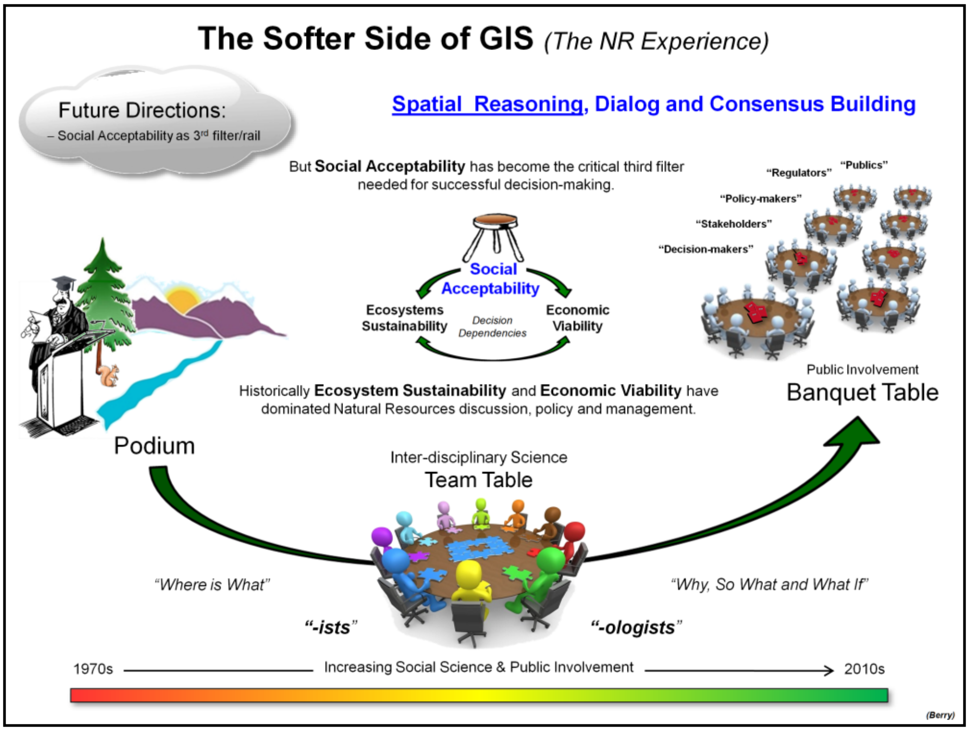
This slide shows a flowchart of the extended model logic to evaluate the additional criteria that "Hugags would prefer to be in forested areas" (Forest map), that "Hugags would prefer to be near water" (proximity to Water map) and that "Hugags think slope and proximity to forested areas and water sources are more important.

In suitability modeling, these considerations are treated as separate sub-models to derive the necessary criteria, then calibrated on the 1 to 9 preference scale and averaged with the basic set of terrain considerations for an overall habitat map shown in the figure.

Note that a large part of the model's strength or weakness is established in step on the left side of the flowchart—*calibrate criteria maps*. As much as possible, the identification of map criteria needs to reflect good science and/or expert opinion to capture factors that are both important and easily measurable. Similarly, the calibration of the maps into the 1-9 preference range needs to capture realistic relative values, not whimsical or biased assignments.

The right side of the flowchart—*combine calibrated maps*—is another area requiring considerable understanding of the system being modeled. A simple average of the calibrated map layers assumes that all of the criteria are equally important. The right inset in Figure 3 shows the use of a weighted-average to incorporate expert thinking that Hugags are "10 times more concerned about slope, forest and water considerations than they are about aspect and elevation considerations."

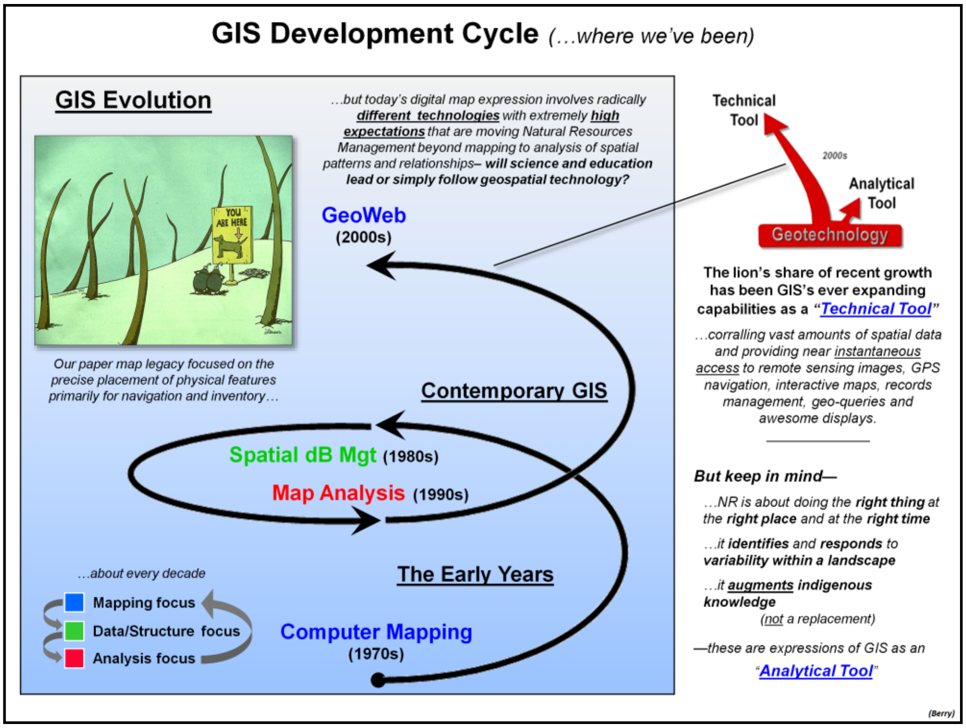
The weighted-average of the six map layers is analogous to a professor's grading some exams more important than others in determining a class grade. In this case, the map values correspond to student grades on each exam; each student is represented as a grid cell on the map, kind of like their desk seats in the classroom floor plan.



In 1970s individual disciplinary scientists controlled the "podium" of discussion, and social science, its issues and human dimensions, were primarily backstage in natural resource research, planning and management. In the 1980s, the podium became a "team table" with a diversity of disciplines collaboratively engaged in science-based discussion for assessing management options to include social science's theories and understandings of human values, attitudes and behaviors. The "*-ists*" in the group pragmatically focused on programs emphasizing a GIS specialist's command of the tools needed to display, query and process spatial data (Data and Information focus). The "*-ologists*," on the other hand, had a broader vision of engaging users (e.g., ecologists, sociologists, hydrologists, epidemiologists, etc.) who understand the science behind the spatial relationships that support decision-making (Knowledge and Wisdom focus). During the 1990s, the team table expanded further to a room full of "banquet tables" containing a broad diversity of interests promoting direct and active engagement of scientists, managers, stakeholders and representative publics in the conversation.

What dramatically changed over the years is the role of human dimensions in addressing natural resource issues from its early "backstage" position to a "front and center" involvement and an increasingly active voice. Today and into the future**, *Social Acceptability*** has fully joined ***Ecosystem Sustainability*** and ***Economic Viability*** as a critical third filter needed for successful decision-making in Forestry and Natural Resources management.

Maps are being viewed less and less as static wall hangings depicting "*where is what*" and more as sets of organized numbers that can be quantitatively analyzed for dynamic spatial expressions of "*why, so what and what if…*" within the context of alternative management and policy options. In this role, GIS is seen more as an "analysis tool" than a "technology tool." It provides for better understanding and communication of the complex spatial interplay of edaphic, topographic, biological, ecological, environmental, economic and social considerations.



Left Portion: In the 1970s the research and early applications centered on *Computer Mapping* (display focus) that yielded to *Spatial Data Management* (data structure/management focus) in the next decade as we linked digital maps to attribute databases for geo-query. The 1990s centered on *GIS Modeling* (analysis focus) that laid the groundwork for whole new ways of assessing spatial patterns and relations, as well as entirely new applications such as precision agriculture and geo-business.

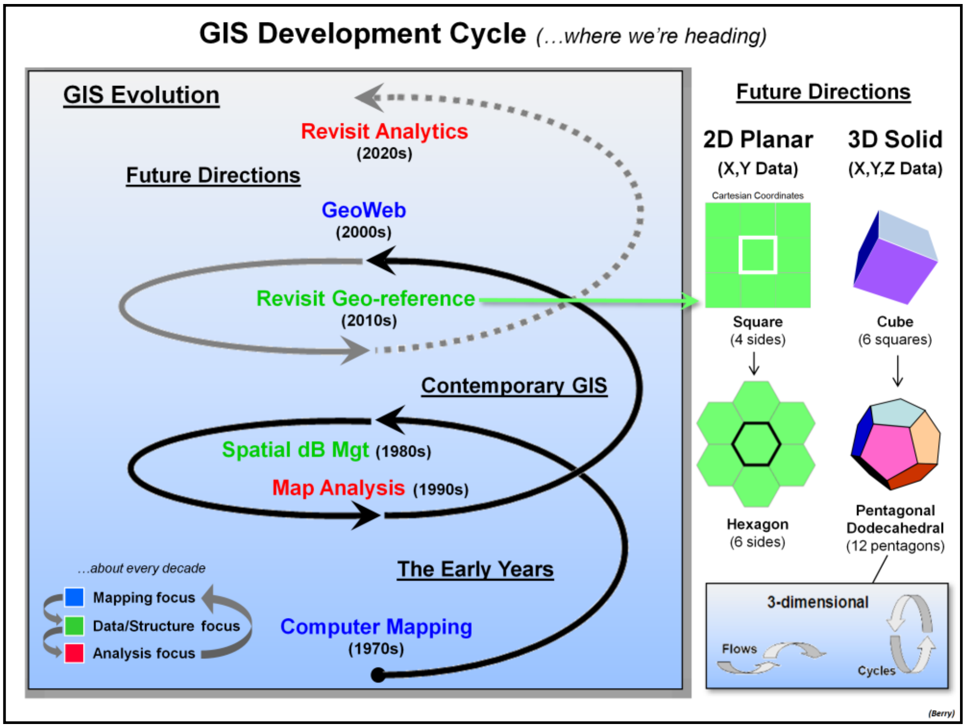
Today, GIS is centered on the *GeoWeb and Mobile Devices* (mapping focus) which brings us full circle to our beginnings. While advances in virtual reality and 3D visualization can "knock-your-socks-off" they represent incremental progress in visualizing maps that exploit dramatic computer hardware/software advances. The truly geospatial innovation waits the next re-focusing on data/structure and analysis.

The bulk of the current state of geospatial analysis relies on "*static coincidence modeling*" using a stack of geo-registered map layers. But the frontier of GIS research is shifting focus to "*dynamic flows modeling*" that tracks movement over space and time in three-dimensional geographic space. But a wholesale revamping of data structure is needed to make this leap… see slide #26 for a continuation of this discussion.

Right Portion: The lion's share of geotechnology's growth has been GIS's ever expanding capabilities as a "*technical tool*" for corralling vast amounts of spatial data and providing near instantaneous access to remote sensing images, GPS navigation, interactive maps, asset management records, geo-queries and awesome displays. In just forty years GIS has morphed from boxes of cards passed through a window to a megabuck mainframe that generated page-printer maps, to today's sizzle of a 3D fly-through rendering of terrain anywhere in the world with back-dropped imagery and semi-transparent map layers draped on top—all pushed from the cloud to a GPS enabled tablet or smart phone. What a ride!

However, GIS as an "*analytical tool*" hasn't experienced the same meteoric rise—in fact it might be argued that the analytic side of GIS has somewhat stalled over the last decade. I suspect that in large part this is due to the interests, backgrounds, education and excitement of the ever enlarging GIS tent.

However, the backbone of successful Precision Ag applications involves and understanding of the spatial patterns and relationships that responds to the inherent variability in a field. This requires an "analytical tool" for the necessary map analysis and modeling used to derive the relationships and implement them on-the-fly throughout a field.



The previous slide focused on early GIS technology and its expressions as four evolutionary phases— *Computer Mapping* (1970s), *Spatial Database Management* (1980s) and *Map Analysis/Modeling* (1990s) established the underlying concepts, structures and tools and more recently the *GeoWeb and Mobile Devices* (2000s) driving the broad adoption of GIS in large part the result of new and exciting display capabilities.

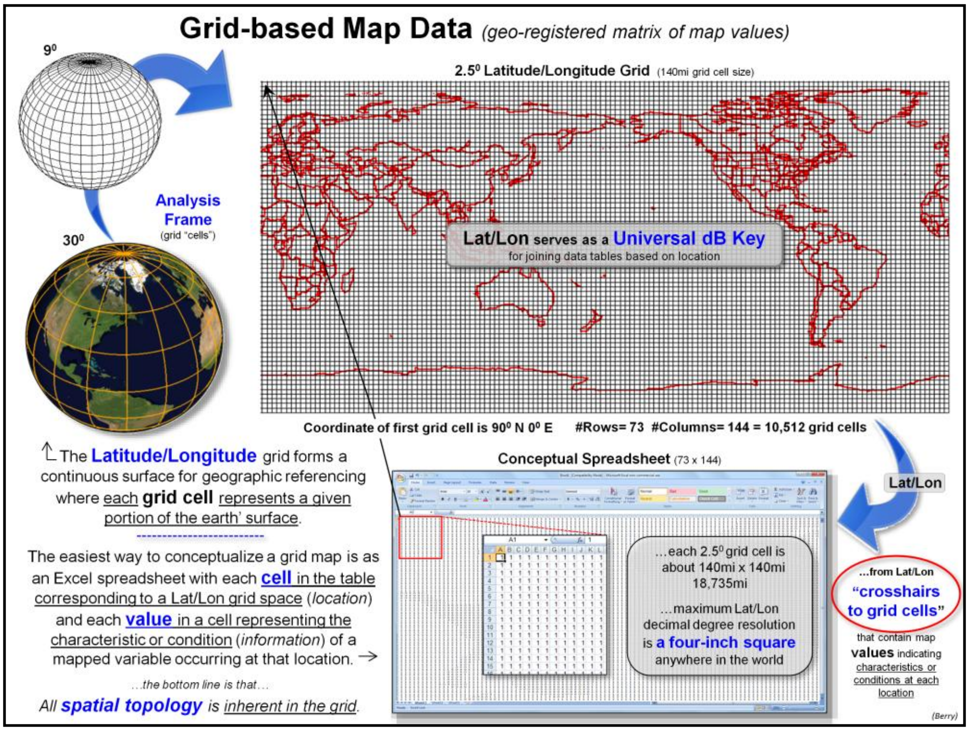
In addition to the changes in the processing environment, contemporary maps have radical new forms of display beyond the historical 2D planimetric paper map. Today, one expects to be able to drape spatial information on a 3D view of the terrain. Virtual reality can transform the information from pastel polygons to rendered objects of trees, lakes and buildings for near photographic realism. Embedded hyperlinks access actual photos, video, audio, text and data associated with map locations. Immersive imaging enables the user to interactively pan and zoom in all directions within a display.

However the impact of the next decade's evolution (2010s) will be huge and shake the very core of GIS—the Cartesian coordinate system itself …a spatial referencing concept introduced by mathematician Rene Descartes 400 years ago.

The current 2D square for geographic referencing is fine for "static coincidence" analysis over relatively small land areas, but woefully lacking for "dynamic 3D flows." It is likely that Descartes' 2D squares will be replaced by hexagons (like the patches forming a soccer ball) that better represent our curved earth's surface …and the 3D cubes replaced by nesting polyhedrals for a consistent and seamless representation of three-dimensional geographic space. This change in referencing extends the current six-sides of a cube for flow modeling to the twelve-sides (facets) of a polyhedral—radically changing our algorithms as well as our historical perspective of mapping (2020s).

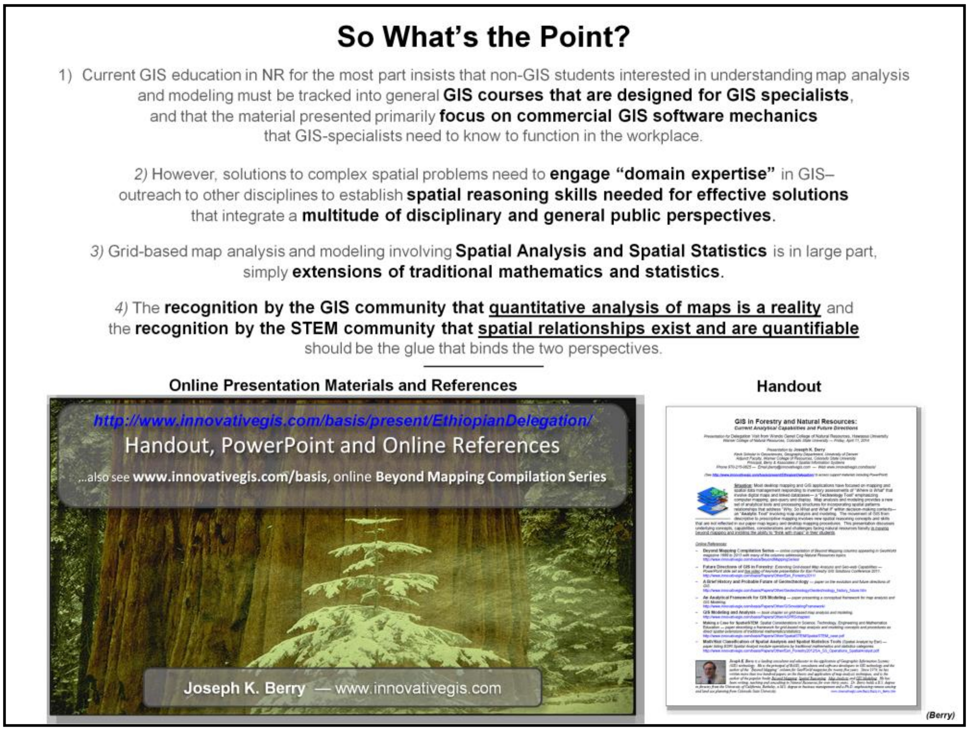
The new geo-referencing framework provides a needed foothold for solving complex spatial problems, such as intercepting a nuclear missile using supersonic evasive maneuvers or tracking the air, surface and groundwater flows and concentrations of a toxic release. While the advanced map analysis applications coming our way (2020s) aren't the bread and butter of mass applications based on historical map usage (visualization and geo-query of data layers). The new analytical tools will represent natural extensions of geospatial conceptualization and analysis …built upon an entirely new set analytic tools, geo-referencing framework and a more realistic paradigm of true 3-dimensional geographic space.

4D GIS (XYZ and time) is the next major frontier. Currently, time is handled as a series of stored map layers that can be animated to view changes on the landscape. Add predictive modeling to the mix and proposed management actions (e.g., timber harvesting and subsequent vegetation growth) can be introduced to look into the future. Tomorrow's data structures will accommodate time as a stored dimension and completely change the conventional mapping paradigm that will spawn entirely new analytical capabilities (2020s).



(Top) The most fundamental and ubiquitous grid form is the Latitude/Longitude coordinate system that enables every location on the Earth to be specified by a pair of numbers. The Prime Meridian and Equator serve as base references for establishing the angular movements expressed in degrees of Longitude (X; east/west movement) and Latitude (Y; north/south movement) of an imaginary vector from the center of the earth passing through any location on the surface of the earth. Longitude coordinates vary from 0 (Greenwich, England) to 180 decimal degrees E and W; Latitude coordinates vary from 0 (Equator) to 90 decimal degrees N and S. The intersecting Lat/Lon lines form a grid covering the globe that progressively becomes more refined with increasing decimal places-- double-precision binary floating-point has from 15 - 17 significant decimal digits precision, resulting in less than .5 foot maximum locational precision for the Lat/Lon grid.

(Bottom) The Lat/Lon grid can be conceptualized as a large spreadsheet with a map value entered into the table at each grid space location. In turn, additional map layers could be stored as separate spreadsheet pages to form a map stack for analysis. While a spreadsheet form is useful to conceptualize the Lat/Lon grid it is an impractical storage mechanism except for small grid maps of significantly less than 100r x 100c= 10,000 cells.



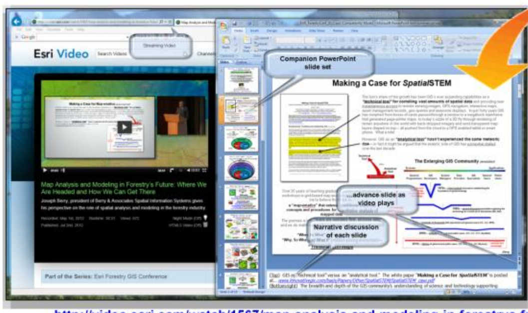
You also are encouraged to visit **http://www.innovativegis.com/** for numerous other papers, books and other on Geotechnology and grid-based map analysis and modeling.

Where to Go from Here

www.innovativegis.com/basis/Papers/Other/Esri_Forestry2012

The future of GIS in forestry is moving from a "down the hall and to the right" specialist's role providing mapped data, to a broader and more active role providing spatial information through analysis and modeling that directly interacts with research, policy formation, planning and management decisions. The shifting emphasis from data–centric tools for mensuration (*Where* is *What*) to application-specific constructs of prescriptive mapping (*Why*, *So What* and *What If*) infuses consideration of geographic patterns and relationships within problem-solving contexts. The paradigm shift replaces spatially-aggregated tools and models that assume uniform or random distribution of typical conditions in geographic space, with spatial reasoning and analytical procedures that capitalize on the variation within and among map variables. The result is a "map-ematical" structure that enables resource professionals from various disciplines to better understand and communicate complex spatial interplay of edaphic, topographic, biological, ecological, environmental, economic and social considerations. **This presentation describes a comprehensive framework for grid-based map analysis and modeling concepts and procedures as direct spatial extensions of traditional mathematics and statistics enabling individuals with minimal or no GIS background to develop spatial reasoning skills—thinking with maps.**

(13 slides with presenter notes)



The keynote address was video recorded and available for live streaming.

However in the live feed, the graphics are poor. You are encouraged to download the companion PowerPoint from the InnovativeGIS link noted above and view it in a separate side-by-side window while advancing the slides with the presenter.

(39 minutes)

http://video.esri.com/watch/1567/map-analysis-and-modeling-in-forestrys-future-where-we-are-headed-and-how-we-can-get-there

You also can access these materials by accessing…
http://www.innovativegis.com/basis/present/EthiopianDelegation/

…download the Esri keynote presentation PowerPoint and live Streaming Video on "Map Analysis and Modeling in Forestry's Future."