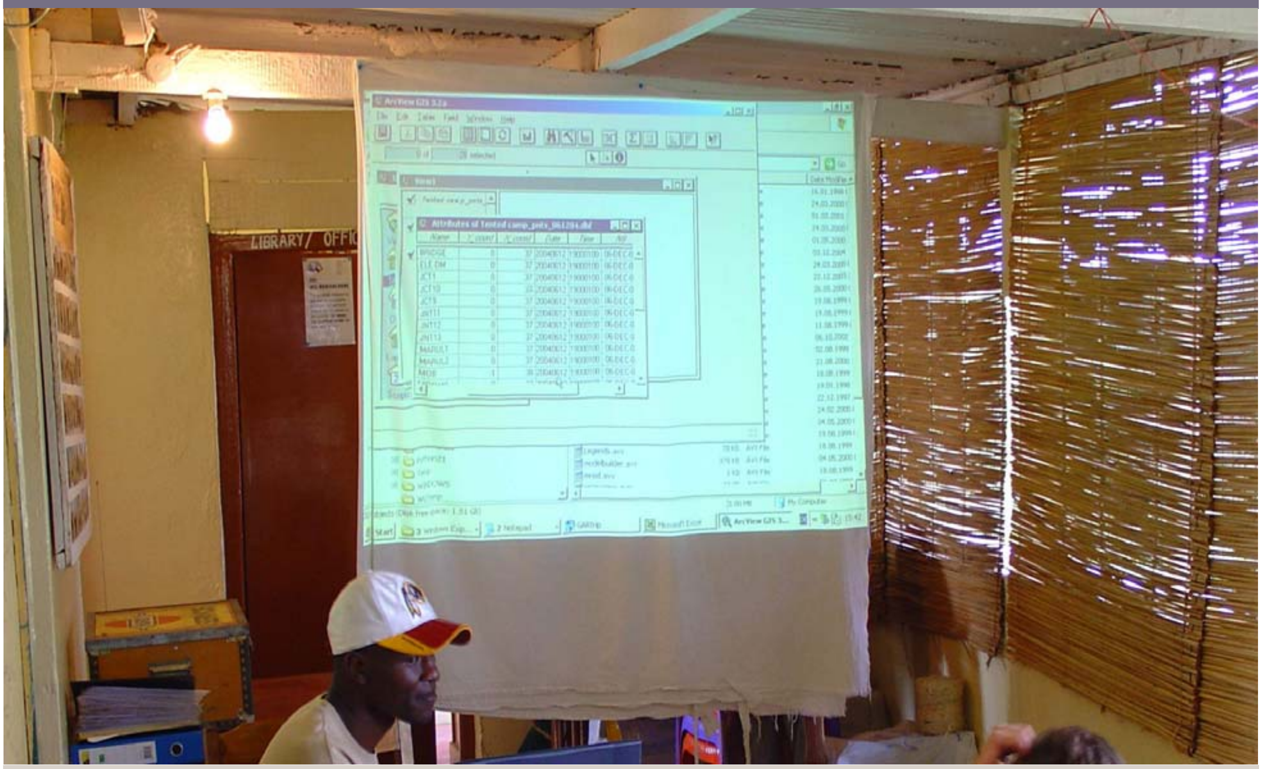
Eastern and Southern Africa Partnership Programme

Capacity Building in Geoprocessing

Module 1

Introducing GIS

Centre for Development and Environment



centre for development and environment

Training Concept

This training module is part of a Geoprocessing Training Concept elaborated by the Centre for Development and Environment (CDE). Each module looks into GIS or RS methods and functions. A course in any of the two disciplines can be composed of a varying number of selected modules, depending on the participant's requirements and the duration of the course. Additional modules will be added to the Training Concept based on concrete requests, or on the basis of enhanced expertise of the CDE Geoprocessing unit. Each Training Module is divided into three main parts:

T	Theory	Theoretical background and concepts, as well as available references on the module's main topics
A	Applications	Specificities of selected GIS and RS software regarding the module's main topics. Currently the Training Modules are designed for use with ESRI's ArcGIS 9.x software family, but will be stepwise expanded, depending on the specific requirements of course participants.
E	Exercises	Concrete exercises on the module's main topics for implementation by the course participants with use of selected software

Module 1 of the GIS training kit is called "Introducing GIS" and is mainly theoretical in nature, providing information on the conceptual basis of Geographic Information Systems. A first part of the module deals with basic definitions and the scope of application of GIS. It also puts GIS into relation with other tools of spatial analysis like Remote Sensing (RS) and Global Positioning Systems (GPS). A second part looks into data particularities, namely spatial data concepts and format as well as issues of quality and scale. Finally, a third part introduces the concepts of spatial references and projections. This part is more practical than the others two before, but it was felt that this topic is of fundamental importance and is strongly related to the data aspects treated in the second part. Together with Module 2 dealing with aspects of GIS management, database maintenance, personnel and capacity building concepts, etc., Module 1 lays the theoretical and organisational basis needed for the implementation and the management of a successful GIS unit.

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Introducing GIS

Theory

T.1. Definitions and scope

T.1.1. What is GIS and what are its components

A geographic information system (GIS) is a computer-based tool for mapping and analyzing things that exist and events that happen on earth. GIS technology integrates common database operations such as query and statistical analysis with the unique visualization and geographic analysis benefits offered by maps. These abilities distinguish GIS from other information systems and make it valuable to a wide range of public and private enterprises for explaining events, predicting outcomes, and planning strategies. In short, a GIS is an instrument for:

- collection,
- visualization,
- analysis,
- presentation, and
- management of spatial data

It is a database that links information to location. A GIS stores information about the world as a collection of thematic layers that can be linked together by geography. This simple but extremely powerful and versatile concept has proven invaluable for solving many real-world problems.

The ITC in the Netherlands summarizes the definition of GIS as follows:

"*In a nutshell, we can define a geographic information system as a computerized system that facilitates the phases of data entry, data analysis and data presentation especially in cases when we are dealing with geo-referenced data. This means that a GIS user will expect support from the system to enter (geo-referenced) data, to analyse it in various ways, and to produce presentations (maps and other) from the data.*" (ITC, 2001)

A working GIS integrates five key components: hardware, software, data, people, and methods. ***Hardware*** is the computer on which a GIS operates. Today, GIS software runs on a wide range of hardware types, from centralized server workstations to desktop computers used in stand-alone or networked configurations. Apart from the processing unit (the computer) GIS also often requires a range of peripheral hardware: Printers or plotters are used for the production of hardcopies; CD-ROM drives, or DVD-ROM drives and the adequate media are used to issue digital data to project partners, or clients; GPS receivers can be used to reference aerial photos, or satellite images and to measure spatial features in the field; etc. GIS ***software*** provides the functions and tools needed to store, analyze, and display geographic information. Key software components are:

- Tools for the input and manipulation of geographic information
- A database management system (DBMS)
- Tools that support geographic query, analysis, and visualization
- A graphical user interface (GUI) for easy access to tools

Possibly the most important component of a GIS is the ***data***. Geographic data and related tabular data can be collected in-house or purchased from a commercial data provider. A GIS will integrate spatial data with other data resources and can even use a DBMS, used by most organizations to organize and maintain their data, to manage spatial data. GIS technology is of limited value without the ***people*** who manage the system and develop plans for applying it to real-world problems. GIS users range from technical specialists, who design and maintain the system to those who use it to help them perform their daily work. A successful GIS operates according to a well-designed ***plan*** and ***business rules***, which are the models and operating practices unique to each organization.

T.1.2. Realms of GIS application

Geographic Information Systems are in use in a wide variety of professional disciplines. Basically, all activities and decision making processes relying on spatial information can to various degrees make use of GIS. Among those activities and decision making processes one can mention (in disorder): real time traffic monitoring and route optimisation, urban planning and development, land use planning and sustainable management of natural resources, target consumer marketing, agricultural production, hydrologic modelling, evacuation and other emergency plans, geo-information education and teaching, etc. Research and the understanding of spatial processes also have a wide range of areas of interest in which GIS are used to analyse and model real-world data. All these disciplines, whether applied, or academic in nature, use GIS and other spatial analysis and decision support systems along five important lines:

- Mapping
- Measuring
- Monitoring
- Modelling
- Managing

These activity lines have been called (LONGLEY et al., 2001) as the 5 “M’s” of GIS.

When focusing on the data, general purpose geographic information systems essentially perform five processes or tasks:

Input: Before geographic data can be used in a GIS, the data must be converted into a suitable digital format. The process of converting data from paper maps into computer files is called digitizing. Modern GIS technology can automate this process fully for large projects using scanning technology; smaller jobs may require some manual digitizing (using a digitizing table, or on-screen). In conjunction with GPS technology, that allows measuring the coordinates of a punctual or linear feature, GIS can also integrate locational information gathered during field work in a simple and efficient manner.

Management: For small GIS projects it may be sufficient to store geographic information as simple files. However, when data volumes become large and the number of data users becomes more than a few, it is often best to use a database management system (DBMS) to help store, organize, and manage data. A DBMS is nothing more than computer software for managing a database. There are many different designs of DBMS's, but in GIS the relational design has been the most useful. In the relational design, data are stored conceptually as a collection of tables. Common fields in different tables are used to link them together. This surprisingly simple design has been so widely used primarily because of its flexibility and very wide deployment in applications both within and without GIS.

Manipulation: It is likely that data types required for a particular GIS project will need to be transformed or manipulated in some way to make them compatible with your system. For example, geographic information is available at different scales. Before this information can be integrated, it must be transformed to the same scale (degree of detail or accuracy). This could be a temporary transformation for display purposes or a permanent one required for analysis. GIS technology offers many tools for manipulating spatial data and for weeding out unnecessary data.

Query and Analysis: GIS provides both simple point-and-click query capabilities and sophisticated analysis tools to provide timely information to managers and analysts alike. GIS technology really comes into its own when used to analyze geographic data to look for patterns and trends and to undertake "what if" scenarios. Modern GIS's have many powerful analytical tools, but two are especially important:

- *Proximity Analysis:* How many houses lie within 100 m of this water main? To answer such a question, GIS technology uses a process called buffering to determine the proximity relationship between features.
- *Overlay Analysis:* The integration of different data layers involves a process called overlay. At its simplest, this could be a visual operation, but analytical operations require one or more data layers to be joined physically. This overlay, or spatial join, can integrate data on soils, slope, and vegetation, or land ownership with tax assessment.

Visualization: For many types of geographic operation the end result is best visualized as a map or graph. Maps are very efficient at storing and communicating geographic information. While cartographers have created maps for millennia, GIS provides new and exciting tools to extend the art and science of cartography. Map displays can be integrated with reports, three-dimensional views, photographic images, and other output such as multimedia.

T.1.3. GIS and other spatial analysis tools

GIS is a tool that is often used in conjunction with other spatial analysis tools. Sometimes the boundaries between the disciplines that involve the use of these different tools are not clear-cut. There has been, in recent years, a tendency towards an integrative use of various tools like GIS, ***remote sensing (RS)*** and ***GPS*** technology into a working process that tries to address specific information analysis requirements.

Remote Sensing involves the analysis and representation of data that was generated by observing the Earth's surface from a distance, typically from aircrafts, or satellites. A separate Modular Training Concept on Remote Sensing is being developed by CDE and will be available for use as from mid 2006. The most frequent data used in this discipline are aerial photographs and satellite images. While Remote Sensing technology provides tools for the analysis of these images and the understanding of underlying spatial patterns and processes, GIS can easily integrate raw or processed images into its environment. This can be done for the sole purpose of display, or in order to visually identify spatial features. For example, a high-resolution satellite image of a town can be used in a GIS environment to digitize buildings, roads and other elements of the urban infrastructure. However, a working process through which all vegetated urban areas would be automatically filtered out is typically not done in a GIS but with use of remote sensing software.

Global Positioning Systems (GPS): Module 3 of this training concept on GIS deals with the generation of spatial data. Apart from digitizing, scanning, editing and other data generation techniques the combination of GIS with Global Positioning Systems (GPS) technology offers an additional powerful way of easily importing spatial data into a GIS environment. GPS receivers allow measuring the exact coordinates of any point on the Earth's surface. A sequence of points can be combined into a track, for example along a road, river or foot path. Data collected by GPS can easily be integrated into a GIS and converted into a format that can be accessed and further manipulated with most GIS software. GPS is also often used to help referencing an existing spatial dataset. By measuring the exact location of a feature that is visible both on the data set and in the field, the geo-reference of the spatial dataset can be improved.

T.2. Data basics

T.2.1. Logical definition of spatial elements

Elements on the Earth's surface are positioned in certain locations, processes spread over a certain area and different elements interact with each other. Climatic components interact with the topography; there are correlations between the occurrence of accidents and the status of roads; the distribution of police posts may have an influence on crime rates; etc. The underlying concept has first been formulated by Waldo Tobler and is called spatial autocorrelation. Its importance for GIS will be further discussed in Module 3.

When trying to organise information in a GIS, one usually has to state ***what*** it is that we are observing and describing and ***where*** it takes place. Additionally, one has to state whether the observed phenomena are geographic ***fields***, i.e. occur everywhere in the study area (rainfall amounts, soil types, land cover, etc.), or whether they are geographic ***objects***, i.e. occur only at specific locations (crime incidents, wildlife migratory routes, etc.). (ITC, 2001)

In a GIS, information is usually organised in ***thematic layers*** (see Figure T.1 below). One layer for example describes the land use divided into different categories (e.g. agricultural use, settlements, forests, etc.), while another layer describes administrative entities like provinces, districts and municipalities and a third layer describes average annual temperatures at specific locations in the study area, or – when interpolated – at any location in the same area. Most GIS software use data formats that are suited for the representation of geographical elements and phenomena as thematic layers.

Some software (e.g. ArcGIS) go one step further in organising the various thematic layers into integrated spatial databases in which relations of different types can be defined between elements and phenomena belonging to different layers (e.g. a provincial boundary always has to be identical with sections of different district boundaries, or the presence of a one-way traffic regulation has an influence on delivery area, or network calculations, etc.

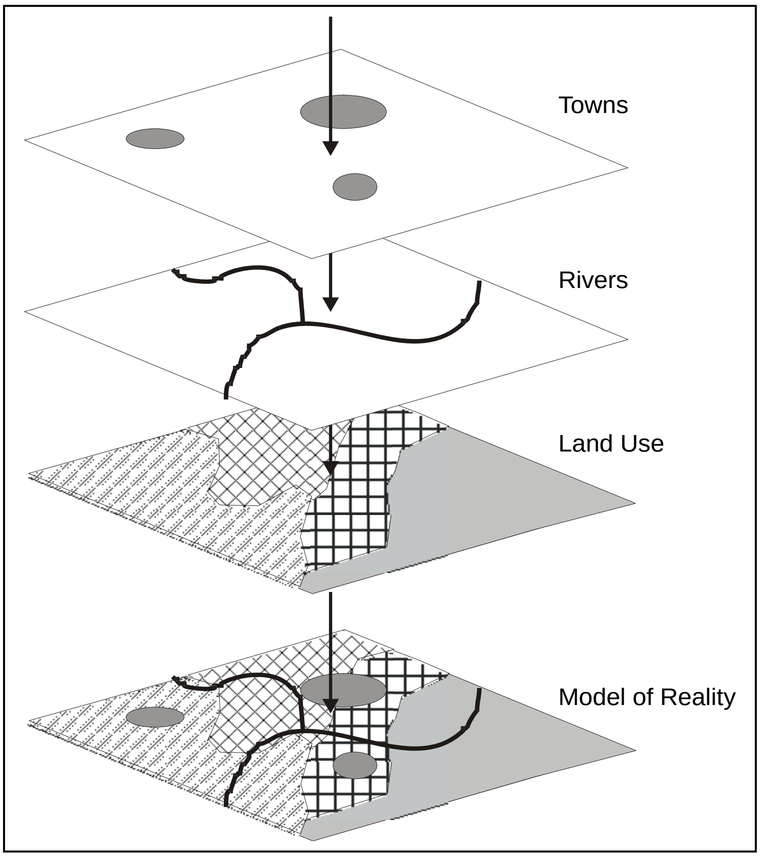


Figure T.1: *In a GIS spatial elements and phenomena are represented as layers of information. Typically these layers are organised into certain categories. One layer can only contain one type of feature data (points, or lines, or polygons), or it can be an image (raster data model). See the following section for more information on data types.*

T.2.2. Data concepts and formats

As was mentioned above, GIS stores information about the world as a collection of thematic layers that can be linked together by geography. Spatial data is organized thematically into different layers, or themes. There is one theme for each set of geographic features or phenomena for which information will be recorded. For example, streams, landuse, elevation, and buildings will each be stored as a separate spatial data sources, rather than trying to store them all together in one. This makes it easier to manage and manipulate the data, especially as much of the power of working geographically comes from being able to analyze the spatial relationships between different geographic themes.

A GIS links sets of features and their attributes and manages them together in units called themes. A theme is a collection of geographic features, such as cities, roads, rivers, parcels or soil classes, together with the attributes for those features. GIS work with two fundamentally different types of geographic models: The "vector" model and the "raster" model (see Figure T.2).

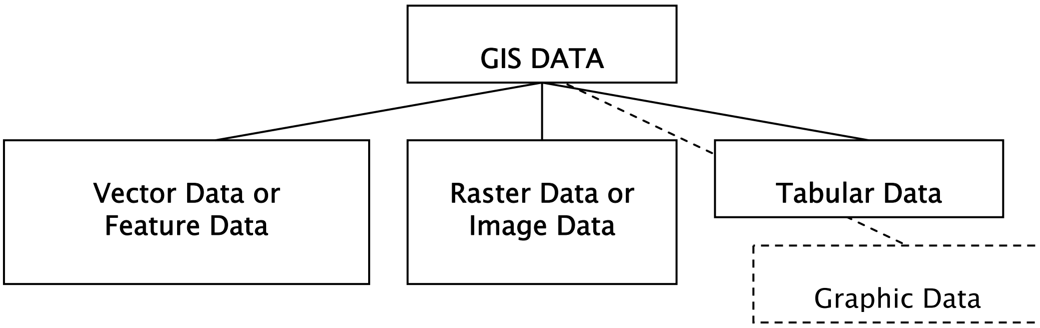


Figure T.2 *Models of GIS data representation*

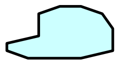
A **vector representation** organizes geographic information using the Cartesian coordinate system. Information about **points, lines, and polygons** (see below) is encoded and stored as a collection of x,y coordinates. Points are stored as single pairs of XY coordinates, whereas lines are stored as a collection of point coordinates. For example, a line representing a road may be described as a series of X and Y coordinates points: one point for the start of the line, one point for the end of the line, and as many points in-between as are required to define the line's shape. Polygonal features, such as river catchments, can be stored as a closed loop of coordinates. Vector representations are often used for representing data with exactly known locations, such as streets, light poles, or the legal boundaries of lots.

Vector data is designed to enable specific geographic features and phenomena to be managed, manipulated and analyzed easily and flexibly to meet a wide range of needs. In vector data or feature data there is an e***xplicit relationship between the geometric and attribute (tabular) information***, so that both are always available when you work with the data. For example, if you select particular features displayed on a view, ArcGIS will automatically highlight the records containing the attributes of these features when the attribute table is displayed.

Real world objects, whether natural or man-made, are called features when they are represented on a map. Each map feature has a location, shape, and symbol that represent one or more of its characteristics. Features are ***points, lines, or polygons***:

Points are depicted as a single pair of x, y-coordinates. Points represent objects that have discrete locations and are too small to be depicted as areas. Towns, schools, and petrol stations are examples of point features.

Lines are a set of ordered, connected x, y- coordinates. Lines represent objects that have length but are too narrow to be depicted as areas. Rivers, streets, and pipelines are examples of line features.



Polygons are enclosed homogeneous areas of regions. They represent a series of line segments connected with the same starting and ending point. Polygons represent objects too large to be depicted as points or lines. Countries, subdivisions, forest, and parks, are examples of polygon features.

In GIS, features are stored in a database along with information describing them. The descriptive information stored with a feature is called the feature's ***attributes***. Attributes of a street might include its name, street type, length, street code, and pavement type. The attributes of a park may be its name, area, hours of operation, and maintenance schedule, etc.

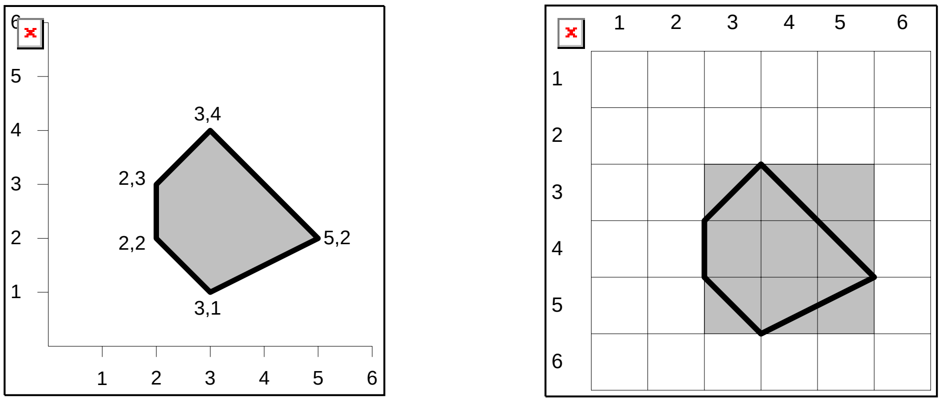


Figure T.3: *The vector data model (left) and the raster data model (right) are the two main types of geometric data representation in a GIS. Both models make use of attribute information to further describe the spatial feature. In the vector data model the polygon shown in the picture could, for example be a plot boundary and thus its attribute table would include information like the size of its area, the name of the plot owner, the type of land use that is permitted on that plot, etc. In the raster data model on the right side, the cells that cover the plot area (from 3,3 to 5,5) all have an attribute value that specifies that they represent that particular plot and not another one.*

A ***raster representation*** organizes geographic data using cells arranged in rows and columns. Each cell has a row number and a column number. The exact location of each cell is not stored, just the origin, cell size, and number of cells from the origin. Values associated with each cell describe the geographic attributes in the region of space covered by the cell. Each cell stores a numeric value representing a geographic feature. Raster representations are often used for geographic data with less discrete locational boundaries. This is often the case with environmental data, such as climatic, or topographic parameters (rainfall, temperature, slope gradient, etc.), where the mapped features may not have sharply definable boundaries. The raster model has evolved to model such continuous features. A raster image comprises a collection of grid cells rather like a scanned map or picture. An image is the simplest form of raster; it stores a single value for each location. A grid is a special type of raster where the value stored is a record in a table that stores additional descriptive information for the cells. Raster data (or image data) can come from photographs, remotely sensed data (aerial photographs, or satellite images), scanned data, satellite data, and graphics. Raster data can also be interpolated from vector data. For example elevation contours stored as vector lines can be used to interpolate a Digital Terrain Model that will provide distinct calculated elevation information for each cell of the analysed area.

Both the ***vector and raster*** models for storing geographic data have unique advantages and disadvantages. Modern GIS are able to handle both models.

A ***tabular representation*** organizes geographic data using a table. A tabular representation is mostly used together with a raster or vector representation. As such it forms the geometry's so-called attribute information (see Figure T.4. below). Tabular data can include almost any data set, whether or not it contains geographic data.

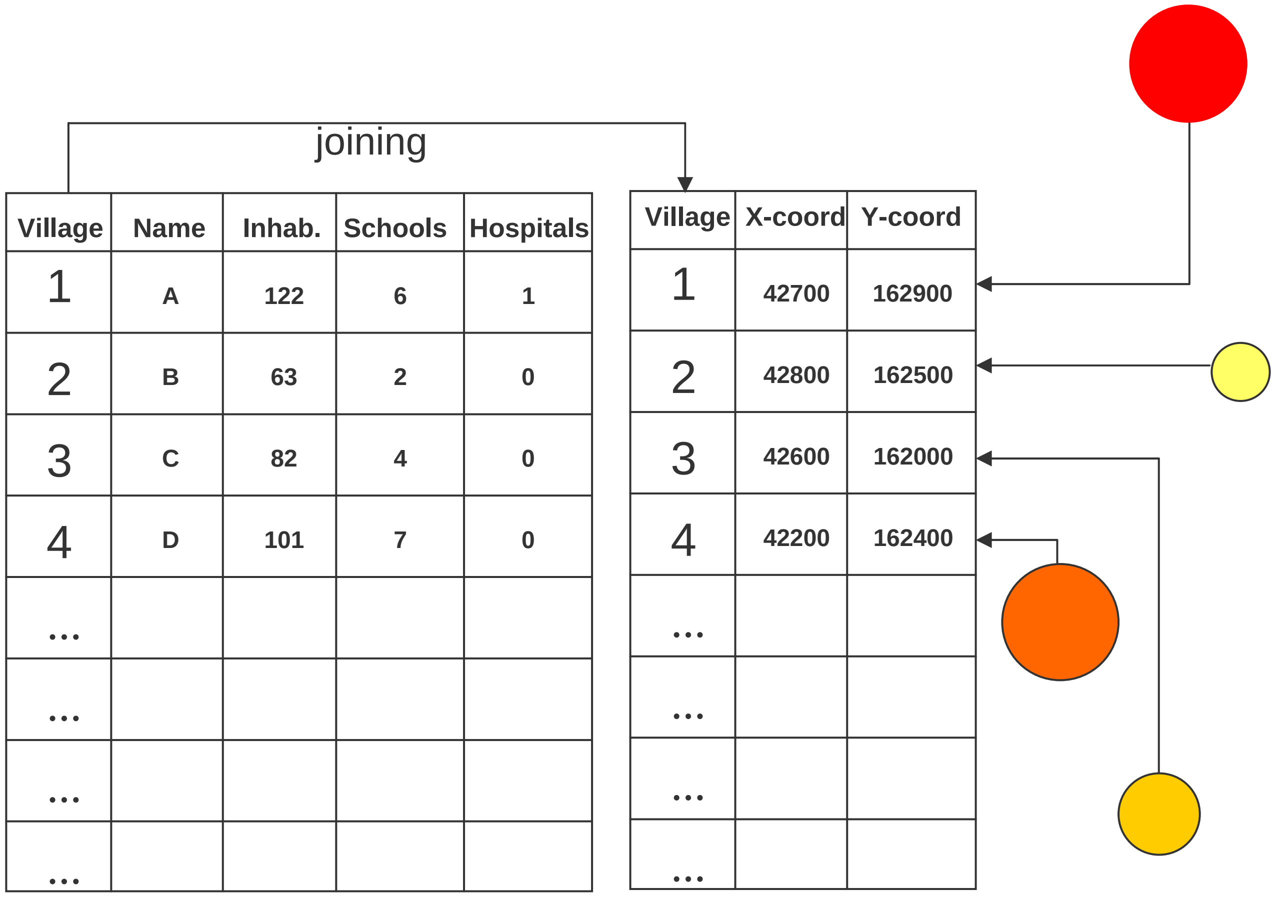


Figure T.4: *Tabular or attribute data contains information that characterises the map features. In the figure, villages are drawn as points on the map. Each point has an entry in a primary attribute table (the one on the right). This table has three columns: the first one contains a code for each village, the second and third ones contain the coordinates in X and Y for each point.*

Secondary attribute tables (the one on the left) can be joined to the primary attribute table, provided that one of their fields is identical to one field in the primary attribute table ("village" – "village"). The information contained in the secondary attribute table can be used in the GIS, e.g. to adapt the symbology of the points on the map (e.g. the bigger the point the higher the number of inhabitants in the village).

T.2.3. Data scale and quality

The area covered when working with GIS can vary greatly: In order to analyse climatic patterns and processes global information has to be used; when conducting cadastral work, small entities like town blocks are being considered. In the first case, the data's range of best possible precision will be at the level of several kilometres, if not hundreds of kilometres. In the second example, the range of required precision is at the level of a few millimetres, or centimetres.

The precision of the data used in a GIS is therefore greatly dependent on the scale of application. The smaller the area under consideration the higher the precision of the data needs to be. A river network at a national level (e.g. map scale 1: 1,000,000) will obviously feature simpler shapes, with less curves and details, than the river network for a single district. Similarly, the cells of a raster data set describing the topography of a sub-catchment of a few square kilometres will be significantly smaller (i.e. more precise) than the cells of a raster data set covering an entire country.

It is important to gain a good notion of the area of interest and of the range of application of the GIS database before embarking into its production. From this reflection one can define the minimum precision requirements for all layers of the database and work towards setting the required quality standards. It is important to understand that a spatial dataset can also be "too precise". Especially when working with raster datasets, this can have tremendous implications on the size of data layers and consequently on the required storage space and on the processing time. Therefore, an adequate level of precision has to be defined and used for a particular project's working processes. If more precise data is available, important base layers can be archived at a higher degree of precision for possible use in subsequent projects focusing on smaller areas. However, intermediate layers and the project's own final products should be generated at an adequately reduced level of precision.

T.3. Spatial references and projections

Projections are flat representations of the Earth drawn on paper or displayed on a computer screen. In other words, projections express a three-dimensional surface in two dimensions. Mathematical formulas are used to transform spherical geographical co-ordinates to the two dimensions of a plane. There are different ways in which such a projection can be conducted (see Figure T.5). The transformation from the three-dimensional ellipsoid to the two-dimensional plane is not possible without some form of distortion. The distortion affects shapes, distances and directions. Each of the many formulae available will result in different distortions. This determines whether each map projection will be suitable or unsuitable for a certain purpose (Kraak, M.J. and F.J. Ormeling, 1998):

Equidistant projections (e.g. Sinusoidal projection) represent distance scaled correctly, but only in one direction (usually north-south). Equidistant projections are aesthetically often more pleasing than other projections for representing large portions of the earth's surface.

Conformal projections (e.g. Universal Transverse Mercator projection) represent angles correctly. The Mercator projection is one example of a conformal projection and it has a primary use in navigation where correct representation of bearings and angular measurement are important.

Equal-area or equivalent projections (e.g. Robinson projection), finally, portray areas on the earth's surface in their true proportion. Such representations have applications where the cartographer wishes to show distributions on the earth's surface which can be compared and contrasted.

Any projection can take only one of the above three forms. It is important noticing, that it is often impossible to determine the true type of projection used without a statement by the cartographer on the map. Therefore, a map should always contain information about the projection used.

A projection always refers to a mathematical approximation of the shape of the earth. This approximation is called ***spheroid, or ellipsoid***. The parameters of such ellipsoids are optimised for local conditions and thus different ellipsoids are used in varying parts of the world. Because of gravitational variations and variations in surface features, the Earth is neither a perfect sphere nor a perfect spheroid. Satellite technology has revealed several elliptical deviations; for example, the South Pole is closer to the Equator than the North Pole. It

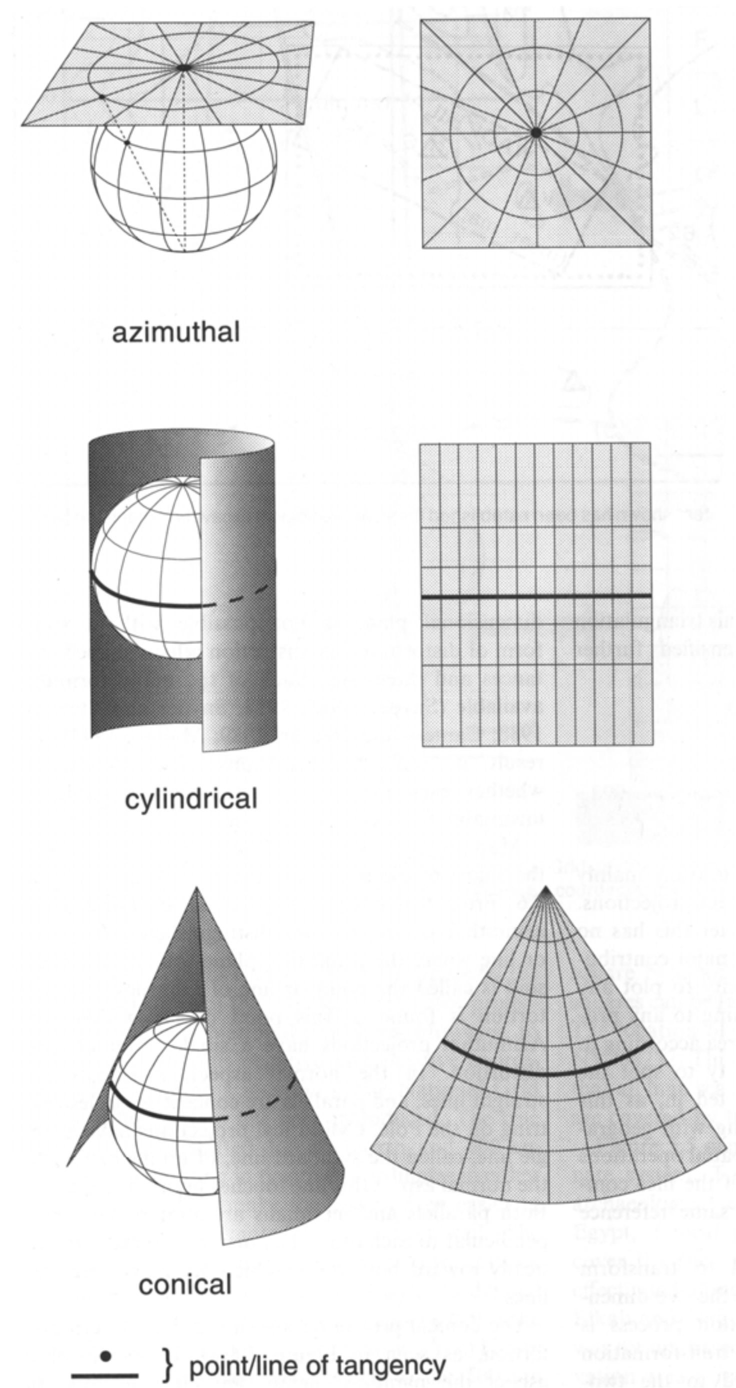


Figure. T.5: Projection methods

Adapted from Kraak, M.J. & F.J. Ormeling, 1996, p. 82.

should be noted that satellite-determined spheroids are starting to replace the older ground-measured spheroids for reference calculations. A factor that must be taken into account before changing spheroids of reference is that it will change all previously measured values. Because of the complexity of changing spheroids, ground-measured spheroids are currently still in use and are still valid.

A ***datum***, finally, is a set of parameters defining a co-ordinate system, and a set of control points whose geometric relationships are known, either through measurement or calculation (Dewhurst 1990). A datum is defined by a spheroid, which approximates the shape of the Earth, and the spheroid's position relative to the centre of the Earth. There are many spheroids representing the shape of the Earth, and many more datums based upon them.

A ***horizontal datum*** provides a frame of reference for measuring locations on the surface of the Earth. It defines the origin and orientation of latitude and longitude lines. A local datum aligns its spheroid to closely fit the Earth's surface in a particular area and its "origin point" is located on the surface of the Earth. The co-ordinates of the "origin point" are fixed and all other points are calculated from this control point. The co-ordinate system origin of a local datum is not at the centre of the Earth. In the last fifteen years, satellite data has provided geodesists with new measurements to define the best Earth-fitting ellipsoid, which relates co-ordinates to the Earth's centre of mass. An Earth-centred, or geocentric, datum does not have an initial point of origin like a local datum. The Earth's centre of mass is, in a sense, the origin. The most recently developed and widely used datum is the World Geodetic System of 1984 (WGS84). It serves as the framework for supporting locational measurement world-wide. GPS measurements are based on the WGS84 datum. (Dorling D. and D. Fairbairn, 1997; ESRI online help documents)

Note: It was described above that the Earth's shape is modelled with help of various ellipsoids, or spheroids; that variations in local gravitational values have an influence on the shape of the Earth. However it is always interesting to recall that if the Earth had the size of a billiard ball, its touch would actually be smoother than the one of the billiard balls we are used to! Even if the highest mountain was 10km high in reality and its cliff plunged straight down to the ocean, when reduced to the size of a billiard ball this cliff would be equivalent to an asperity of approximately 0.04 millimetres!

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Introducing GIS Applications

A.1. Introducing ArcGIS

A.1.1. History

ArcGIS is the latest and most advanced product of the Environmental Systems Research Institute (ESRI) located in Redlands, California. This institution which was founded in 1969 started with the development of GIS tools in the 1980s and has now become the world's biggest GIS producer and supplier.

ArcGIS is based on previous developments created by ESRI, namely PC ArcInfo, UNIX (or Workstation) ArcInfo, ArcView 3.x and finally the ArcInfo 7 and 8 packages (the latter was released in 1999). ArcGIS started at Version 9.0, which was released in May 2004. The latest Version is 9.2. More detailed information on ESRI history can be found on http://www.esri.com/company/about/history.html

ArcGIS is a comprehensive GIS software package that is able to adequately deal with both vector and raster data formats. It can be used for the generation of new spatial data (digitizing, editing, vectorizing), for the analysis of both vector and raster data, as well as for the production of maps and other data display media, like the PMF files readable by non-GIS personnel with help of free standalone spatial data viewing applications. The strength of the software lies rather in its analysis and display functions than in the data generation capabilities. As will be mentioned below, the common vector data format used by ArcGIS (shapefile) presents some limitations in terms of the internal data logic and the lack of a real topology. Inexperienced GIS users will often enter into problems of lost data consistency due to these limitations. Therefore, for large data production processes, another software solution might provide a safer and more efficient way to do things. ArcGIS comes in strongly at a later stage, when data needs to be analysed and presented with use of different media.

A.1.2. Software products

ArcGIS can be deployed as three different software products: ArcInfo, ArcEditor and ArcView. Each product has a different license agreement and contains more or less functions and possibilities. ArcInfo is the high-end product, which contains all the functionalities of ArcView and ArcEditor plus advanced geoprocessing and data conversion capabilities. ArcEditor contains all functionalities of ArcView plus enhanced editing functionalities. ArcView is the basis desktop product that replaces the older ArcView 3.x product line. A fourth product, the ArcReader, is a freely available application that only allows to view spatial data prepared and compiled in ArcGIS, but does not provide any option to change the layers' symbology, or to conduct spatial analysis on this data, or to edit it. ArcReader is used in combination with a data format called PMF (Published Map File), which is created with the Publisher Extension of ArcGIS (see paragraph A.1.4 below). ArcReader can be freely downloaded from ESRIs Internet Homepage (http://www.esri.com/software/arcgis/arcreader/index.html).

A.1.3. Starting software components and tools

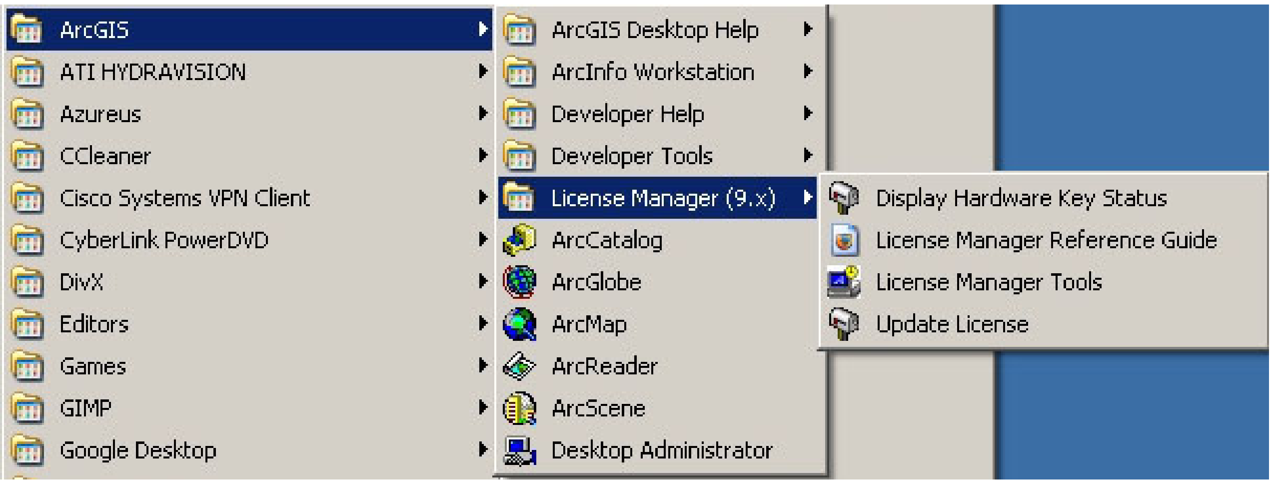

Figure A.1: Starting ArcGIS from the Windows "Start" button. Components and tools contained in the License Manager.

ArcGIS is started from the "Start" button in Windows, or from shortcuts on the desktop, just like any other software. When using the start button (see Figure E.1 above) a number of components are listed, depending on the installed tools and extensions. The two modules ArcMap and ArcCatalog are listed under the available components. ArcToolbox is automatically started with ArcMap and therefore not listed. The list also includes the License Manager used to configure license options and the Desktop Administrator, with which software product (ArcInfo, ArcEditor, or ArcView) are selected depending on the available license and the tasks to be performed. This tool also shows the availability of extensions and gives access to the license management tool. For ArcInfo licenses, the list also contains a link to the ArcInfo Workstation products, if the latter have been installed.

A.1.4. Modules

ArcGIS is composed of three major modules. The main module, in which data is viewed and analysed and maps are composed is called ***ArcMap.*** Its interface is consisting of the table of contents on the left and the map area on the right, as well as of different toolbars and menus for working with the data and map. The hierarchical order of layers in the table of contents is important, since the layers on top of the table of contents will be displayed on top of the layers below them. Therefore, any layers forming the background of the map should be put at the bottom of the table of contents. Generally there are two different views for working with data in ArcMap – the layout view and data view. The data view is meant to explore, edit, query, analyze, and symbolize data. The layout view enables the arrangement of data frames and other map elements, such as scale bars, titles, and legends, to create a map layout that can be print or exported. In data view, only one data frame can be viewed. Not so in layout view, where multiple data frames can be viewed at the same time. Using the yellow diskette symbol in the standard toolbar, any work in ArcMap will be stored in the map document file which has the ***.mxd*** file extension.

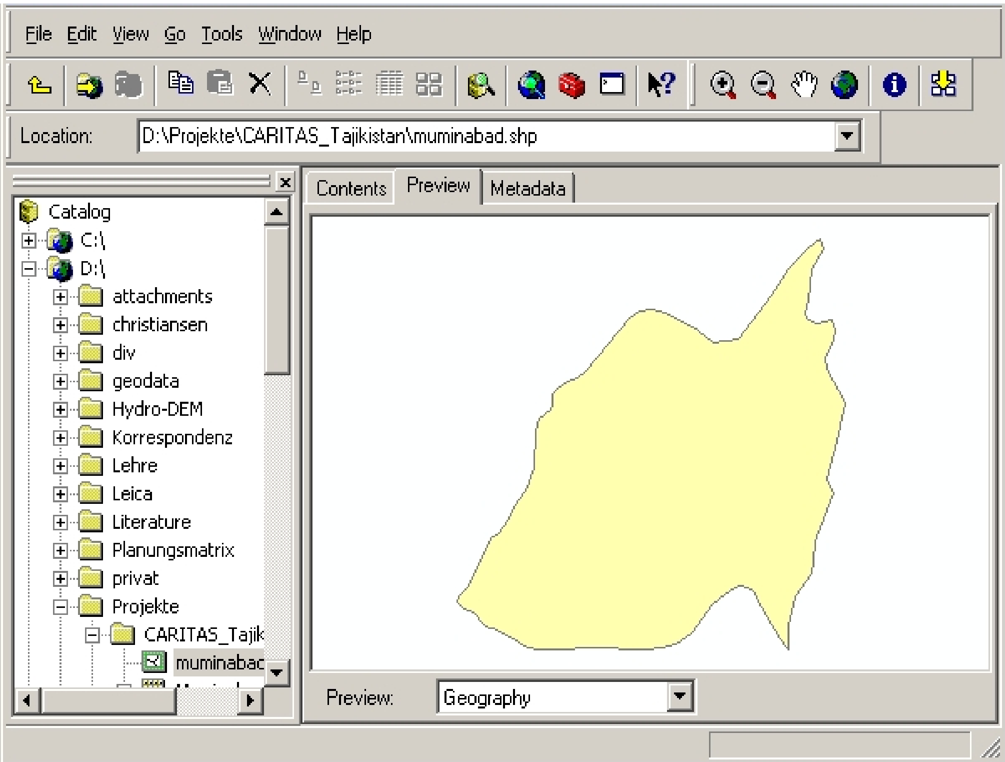

Figure A.2: ArcCatalog view with table of contents and preview pane

The second main component of ArcGIS is the ***ArcCatalog,*** which has an appearance that is similar to the one of Microsoft's Windows Explorer. The ArcCatalog interface consists of the Catalog tree on the left and a preview pane on the right. ArcCatalog is the ArcGIS application designed for browsing, managing, and documenting geographic data. New layers can be created in ArcCatalog and existing layers can be manipulated, for example by defining their projection and reference. This component also offers the possibility to document each data layer by storing its metadata in a comprehensive metadatabase. To access the data a connection to its location has to be established (e.g. a folder on C: drive).

A third component is the ***ArcToolbox***, which contains a collection of GIS analysis, cartography, conversion, data management, geo-coding, statistical and transformation tools. ArcToolbox can be accessed from ArcMap or ArcCatalog. The number of tools available for use depends on the ArcGIS license. ArcView only supports a core set of tools; ArcEditor adds some more while ArcInfo provides the complete set of GIS tools.

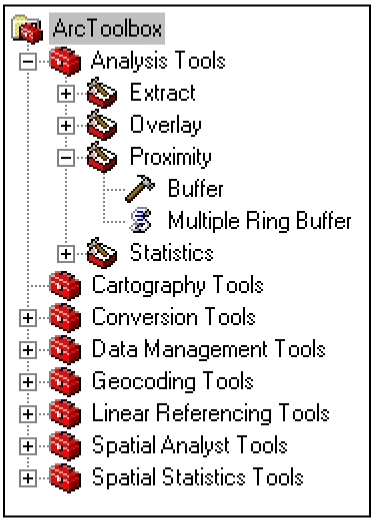

Figure A.3: *ArcToolbox view with toolsets*

ArcGIS Desktop Help

A major criterion when working with software programs is getting help when needed. ArcGIS Desktop Help provides comprehensive explanations of GIS procedures, tools, buttons, and commands. The help is accessible from multiple locations within ArcMap and ArcCatalog.

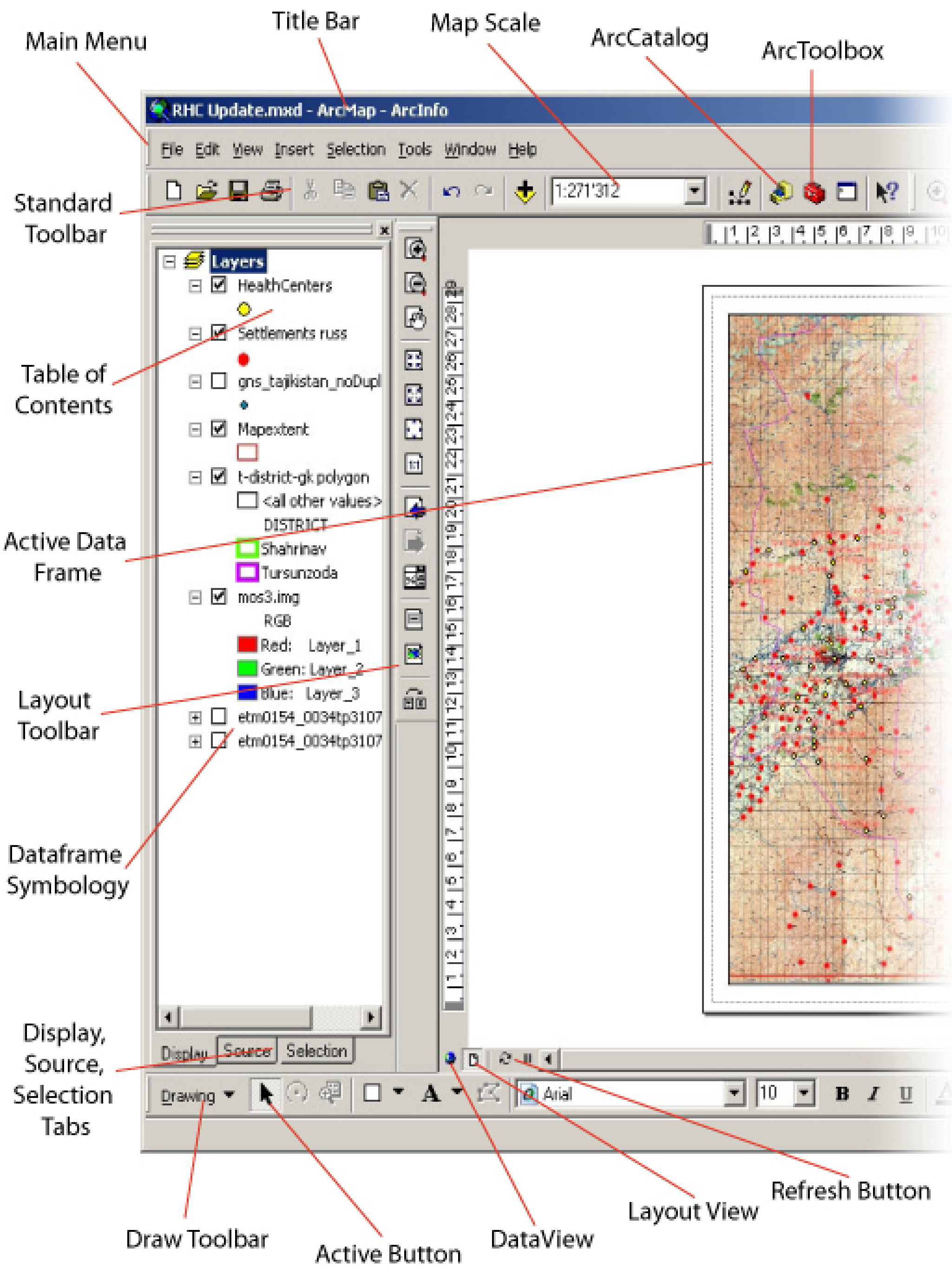

Figure A.4: *The left part and its buttons, tabs and objects…*

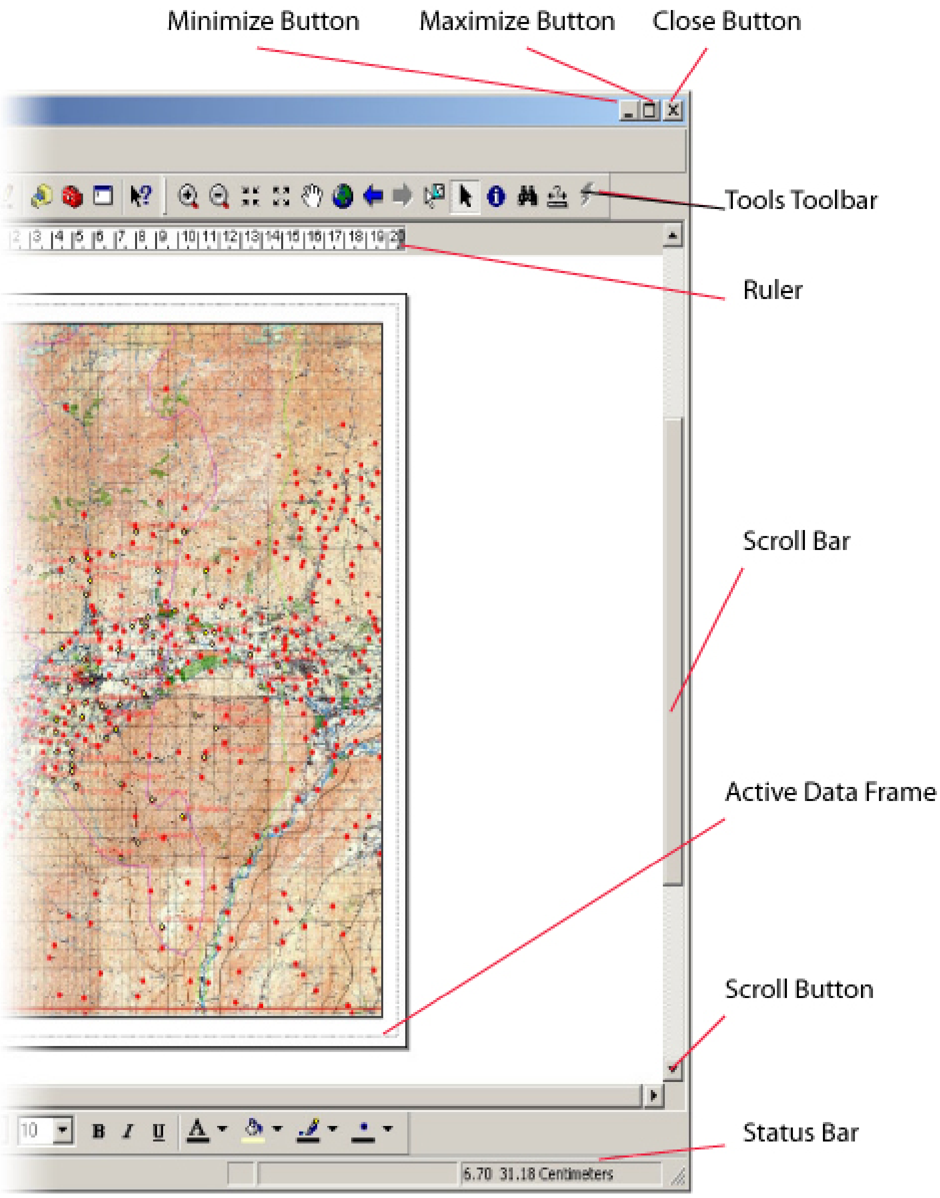

Figure A.5: *...and the right part of the ArcMap 9.2 GUI provides an intuitive interface for viewing, managing and modifying spatial datasets.*

A.1.5. Extensions

Apart from the three main modules, ArcGIS also relies on a series of extensions that provide specific activities. The ***Spatial Analyst*** extension, for example, allows carrying out analysis on raster data sets, while the ***Publisher*** Extension is used to package data into a format that can be read by the ArcReader standalone application. The ***3D Analyst*** extension provides tools for surface modelling and 3D visualisation. The ***ArcPress*** extension provides tools for the generation of high-quality vector cum raster printouts, while the ***Tracking Analyst*** extension provides tools for real-time visualisation of spatial elements and temporal analysis. Yet other extensions offer additional functionalities, depending on the users' requirements. Extensions are not delivered in the basic package of ArcGIS and have to be purchased separately.

A.2. The ArcGIS data concepts and formats

Basically both the vector and raster data models accomplish the same thing: they enable the representation of entities on the Earth's surface with a limited number of locations. The difference is only the methods used to create the representation. The vector approach is like creating a picture of a landscape with forms of various shapes and sizes. The raster approach, by contrast, is more like creating a mosaic with tiles of uniform size. There is no data model perfectly suited for all applications. Both result in two-dimensional representations that fail to capture the three-dimensional nature of real world objects.

ArcGIS supports several vector and raster data formats. These formats are described below.

A.2.1. Vector formats

The ***Shapefile*** format is used for storing vector data. It is the most commonly used format in ArcGIS, as well as in the ArcView 3.x software packages. This format is also supported by, or can be imported into most other GIS software packages.

Shapefiles are non-topological, which means that limited information is kept in the shapefile regarding the relationship of features to one another, such as what specific line shapes are used to define a specific polygon shape. The lack of topology means that shapefiles are less appropriate for sophisticated spatial analysis than other formats. However, it also provides some advantages, such as improved drawing time. The shapefile specification is openly published; therefore, shapefiles can be created by anyone. The shapefile format consists of at least three elements: shape, index, and attribute. Each of these elements is stored as a separate file on disk; therefore, a shapefile actually consists of three or more disk files (one for each element). Other, optional files can be included by a shapefile, such as the projection file (.prj) or the legend file (.avl).

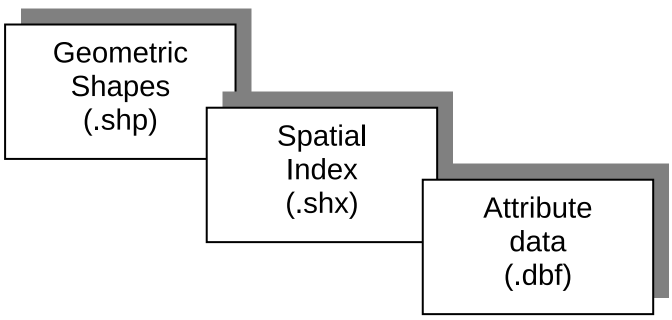

Figure A.5: *The three basic components of a Shapefile: Shape, Index and Attribute Data.*

The ***shape element*** is the portion of the shapefile describing the geometric shapes that represent the geographic features. These shapes are described by their X and Y coordinate locations. The disk file containing the shape element has a file name extension of SHP. The ***index element*** of the shapefile provides an optimized means of accessing the geometric shapes described in the shape element. The element contains a sequential index of offsets into the shape data. This spatial indexing, as it is called, provides for faster drawing times and faster queries of geographic features represented by geometric shapes. The disk file containing the index element has a file name extension of SHX. The ***attribute element*** contains tabular data associated with geographic features. For example a road may have associated information regarding its condition, the year it was constructed, and its width. This information can be stored in the attribute element of the shapefile and associated by the key value with the specific road shape to which it pertains. The attribute element of the shapefile is stored as a standard dBASE file with one record per shape. The disk file containing the attribute element has a file name extension of DBF. The basic elements of a shapefile are shown in Figure A.1 above.

Coverages are another format for storing vector data. This was the first vector data format used by ESRI on its PC ArcInfo and UNIX ArcInfo software packages. It seems that in its current development strategy ESRI intentionally reduces the support for the coverage format. Some functions like editing can not be performed on a default basis in ArcGIS.

There are several differences between coverages and shapefiles: In contrast to shapefiles, coverages have a topological data structure. This means that the format is much more sophisticated in its ability to track the relationship between features, such as what specific line shapes are used to define a specific polygon shape. Because of their more sophisticated data structure and the inclusion of topological information, coverages are better suited for larger data sets and for applications requiring complex spatial analysis. Coverages are represented by subdirectories existing within a Workspace. The workspace is a directory that serves as a work area and storage area for the coverages. The coverage subdirectories each represent a single coverage and are named with the coverage names. These subdirectories contain the geographic data stored in file names such as TIC, BND, and ARC. This data can be created and maintained using ArcInfo or the Arc Catalogue tool.

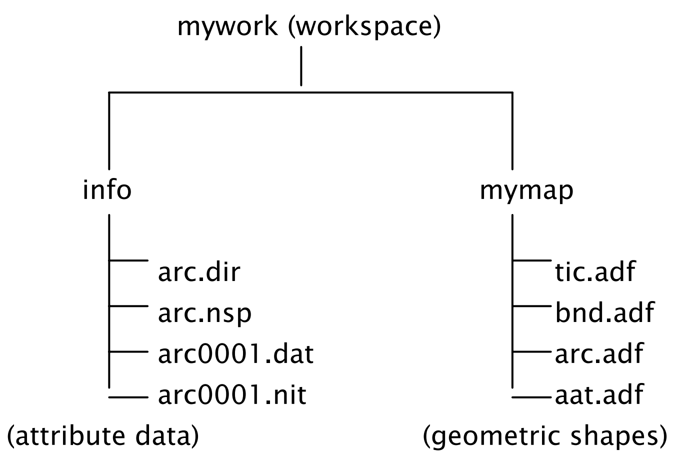

Figure A.6: *The ArcInfo data storage structure*

A separate subdirectory within the workspace contains the attribute data associated with the geographic features of all coverages stored in that workspace. This single subdirectory, named *info*, stores the attributes in database tables that can be accessed using the INFO module of ArcInfo. Figure A.2 shows an example of a coverage storage structure.

Important Note: In a workspace data storage structure you should never move, rename or delete themes with the windows explorer or another file operating tool. To operate with coverages or grids (see below) you should only use *ArcInfo* prompt commands, the *Arc Catalog* or the *Data Management* tool of ArcView.

Geodatabase: The Geodatabase data model supported by ArcGIS works in a different manner than the shapefile or coverage models, in that it tries to integrate the different layers of a database in order to allow for permanent relational and spatial analysis between these layers.

Geodatabases organize geographic data into a hierarchy of data *objects.* These data objects are stored in feature classes, object classes, and feature datasets. An *object class* is a table in the geodatabase that stores non-spatial data. A *feature class* is a collection of features with the same type of geometry and the same attributes. A feature dataset is a collection of feature classes that share the same spatial reference. Feature classes that store simple features can be organized either inside or outside a feature dataset. Simple feature classes that are outside a feature dataset are called standalone feature classes. Feature classes that store topological features must be contained within a feature dataset to ensure a common spatial reference. (ArcGIS desktop help)

CAD drawings are a format for storing vector data. They are produced by computer-aided design (CAD) applications and can be used in ArcGIS with use of the “Import CAD” geoprocessing tool found in the ToolBox. Basically all CAD formats can be converted to shapefile format.

A.2.2. Raster formats

ArcInfo Grids are a format for storing raster data. Grids are especially suited to representing geographic phenomena that vary continuously over space, and for performing spatial modelling and analysis of flows, trends, and surfaces such as hydrology. Grid themes use a matrix of cells to represent geographic features or phenomena. The size of the cells used is important to any analysis. The cell size is the smallest unit you are interested in mapping, and defines the limit of your spatial accuracy. The smaller the cell size the more accurate the representation. Higher accuracy will lead to larger data sets and to slower processing speed. Feature and grid themes have some similarities, but they are different in the way they model or represent spatial data. Grid themes are always stored in the ArcInfo data storage structure (see Figure A.2 above). That means grid themes are always stored in a workspace, in which you should never move, rename or delete files with the Windows Explorer.

Grids are stored either as *integer* or *floating-point* data. An integer grid has an associated value attribute table, short VAT. This table stores a single record for each unique value in the grid, as well as the number of cells taking that value, and one additional attribute you wish to attach. A floating-point grid has no VAT. Generally speaking, integer grids are smaller and faster to operate on than floating-point grids.

Every *image data* format is a format for storing raster data. Image data can be used as background for feature based themes. Features that appear on an image can be digitized to create a new vector database. Image data can be organized in a number of ways depending upon the particular image format. Typically, the image data file contains a header record that stores information about the image such as the number of rows and columns in the image, the number of bits per pixel, the colour requirements and the geo-referencing information. Following the image header is the actual pixel data for the image. The internal organization of the image data is dependent upon the image format. Some formats contain only a single band of data, while others contain multiple bands. ArcGIS can display and print black and white, greyscale, pseudo-colour and true colour images. The most important image formats that can be used in ArcGIS are *TIFF, ERDAS, JPEG.*

A.3. Projection and geo-reference in ArcGIS

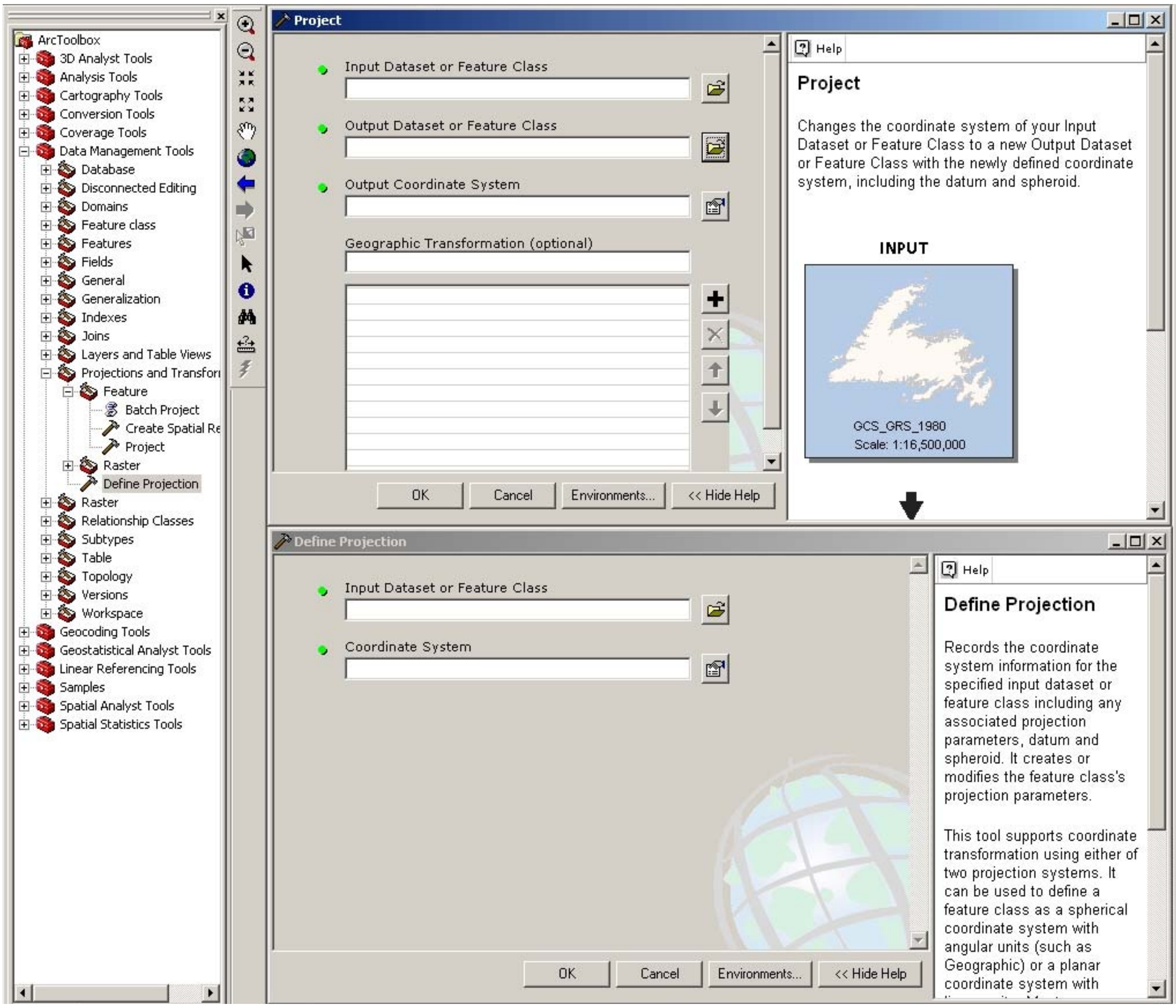

Figure A.7: *Screenshot of the ArcToolbox structure (left) leading to the projection tools; the projecting tool (top right) and the projection definition tool (lower right)*

ArcGIS is able to define the spatial reference and to project both vector and raster datasets. Projection definitions and changing projections are done with use of the ArcToolbox (see Figure A.3 above). The simple definition of a data layer's spatial reference can also be done in ArcCatalog, by selecting the data layer and selecting the "shape" field in the properties. The spatial reference is displayed in the field properties. If no reference was defined the table returns “unknown”.

Sources:

– Longley P.A., Goodchild M.F., Maguire D.J., Rhind D.W. 2005. *Geographic Information Systems and Science*, 2nd Edition. New York: John Wiley

– Jones C.B. 1997. *Geographical Information Systems and Computer Cartography,* Prentice Hal

– ESRI ArcGIS 9.1 2006 *Online Help*

Introducing GIS

Exercises

E.1. Exercises

E.1.1. Getting familiar with ArcGIS Desktop

Steps	Data	Remarks	Time
Loading extensions		- Use the Desktop Administrator to make sure the Spatial Analyst extension is installed and registered. - Start ArcMap and load the Spatial Analyst extension	10 min
Loading data	Keewlco1 Keewriv1 Keewtow1	- Find the layers in the data structure and load them into the active data frame (use data_naming.doc for orientation).	15 min
Getting familiar with the view		- Try out the zooming, panning, full extent and the zoom to layer tools (layer context menu!) to move around in the view. - Get additional information on the towns by using the identify tool.	15 min
Changing symbology of layers	Keewlco1 Keewriv1 Keewtow1 Land_code.doc	- Open the layer properties dialog from the layer context menu (right-click on the desired layer). On the symbology-tab of the layer properties dialog you can change the symbology in a way that suits you. For the landcover grid use the land_code.doc file for orientation.	20 min
Using transparency	Keewhil1	- Load the hillshade grid into the view (on top of the land cover layer). - Apply 50% transparency to the hillshade in the display tab of the layer properties. - Observe the colour shifts that may have appeared - Play around with different transparency levels and observe what happens.	20 min
Naming the data frame		- In the Data Frame – Properties menu change the name of the data frame to "Ewaso" - Observe the changes in the table of contents.	10 min
Saving the project	Exercise1-1.mxd	- Save the map in the student\mxd structure as "exercise1-1.mxd" - Close ArcGIS, look for the MXD file using the explorer, double click on the MXD file and observe what happens - Draw conclusions as to how data is saved in ArcView	20 min
		Approximate total time:	110 min

E.1.2. Using ArcCatalog and querying information from layers

Steps	Data	Remarks	Time
Managing data in ArcCatalog	Kenkedu1 kenkdtm1 kenkhil1 kenkrds1	- Open ArcCatalog and navigate to the “unsorted” folder in the data structure. This folder symbolises a CD-ROM that you may have received from a partner institution. - Copy all the layers needed for the exercise, as listed on the left, to their correct locations (NK stands for Nakuru). - Once it is done delete the same layers from the “unsorted” folder.	15 min
Loading data	Kenkedu1 kenkdtm1 kenkhil1	- Start ArcMap - Load the three data layers and display them - Change the legend of the DTM to be the beige to brown colour ramp and use the 50% transparent hillshade as a brightness theme - See what happens when you invert the colour ramp	10 min
Querying information on raster data	kenkdtm1 kenkhil1	- Using the raster calculator of the spatial analyst toolbar to find the areas which are above 2000 meters above sea level, then find the ones that are below 1800 meters above sea level. Finally make a request that will identify areas between 1800 and 2000 meters above sea level.	10 min
Querying information on vector data	Kenkedu1	- Change the legend of the school layer in a way that schools funded by the MCN appear in one colour and all other schools in another colour (use the “unique value” legend type to do this from the “layer properties” “Symbology” tab under “categories”, then click “add all values” from the bottom) - Query the layer to find primary schools funded by the MCN (disregard those which are mixed primary with other levels)	15 min
Viewing selected features in the attribute table	Kenkedu1	- Open the attribute table switch to the “Only show selected” view. - Find out how many schools match the query criteria entered in the previous step. - In the table launch a new query to find which ones among the selected schools have boarding facilities. - Switch back to the view to find out the locations of the two schools matching all the query criteria	10 min

E.1.3. Finding features, calculating distances and labelling

Steps	Data	Remarks	Time
Finding features	Kenkedu1	- Open the “find” tool and search for specific names on the displayed layers (for example: “Nakuru”, “Flamingo”, “Milimani”, etc.) - Try out various options (target layers and target fields	10 min
Measuring distance	Kenkedu1 Kenkrds1	- In the data frame – properties dialog set the map and display units to meters (–go to “Data frame properties”, “General” tab to do so!) - Find out the approximate distance in meters between the two selected schools (in a straight line) - Load the road layer and display it - Measure the approx. distance between both schools when following the shortest path along the roads	10 min
Labelling features	Kenkedu1	- Zoom in such that the two selected schools lie in opposite corners of the view - In the layer properties go to the labels tab and label the features by school names with an Arial 8 font. - Use a mask (halo with 1 pixel width) to make the labels more readable. Notice the difference in drawing performance. - Use label classes: only label the schools that are funded by MCN and that have boarding facilities. - Check which features have been labelled.	15 min
Saving project		- Save the map file in the student\mxd folder and call it exercise1-2.mxd. If the MXD folder does not exist create it in the Windows Explorer.	
		Approximate total time (parts I and II):	95 min

E.1.4. Transforming vector to raster

Steps	Data	Remarks	Time
Transforming vector to raster	Kenkblk1	- Load the town blocks layer, which is located in the administration folder of Nakuru, to the view - Using the Conversion Tools of the ArcToolbox, transform this layer into a raster data set (feature-to-raster transformation). Name the output layer kenkblk1_ras and choose an output cell size of 100 meters	10 min
Exporting raster layer to Grid format	Kenkblk1_ras	- The new raster layer is temporary. In order to make it permanent the result of the conversion needs to be exported to a raster data format. - Right-click on the layer's name in the table of contents and select "data" - "export data". - Convert the layer to a Grid. - Call the output grid kenkblk1_gr - save it under student\grid)	10 min
Observations	Kenkblk1 Kenkblk1_gr	- Draw relevant conclusions pertaining to the two data types. - Which type is more suitable for this particular type of information?	10 min
		Approximate total time:	30 min

E.1.5. Projecting shapefiles

Steps	Data	Remarks	Time
Loading data and browsing data frame extent	Keewwsh_geo Keewriv1	- Start ArcMap and load keewriv1. - Move the mouse on top of the map and observe the coordinate values displayed on the status bar - Load keewwsh_geo and zoom to the extent of this layer. Again, move the mouse and observe the coordinate values. What happens? - Check the coordinate system of the data frame (in the data frame properties). What system is it? - Terminate ArcMap and start it again. Load keewwsh_geo. - Check the coordinate system of the data frame. What is the coordinate system? - Load keewriv1– what happens? Explain.	20 min
Defining projection	Keewriv1	- The river layer lacks a geo-reference. This reference needs to be defined, which can be done either in the ArcToolbox, or in ArcCatalog. - Set the coordinate system of keewriv1 to: Projected Coordinate Systems- UTM - Other GCS - Arc 1960, Zone 37 south. - (You may use the search tab from the ArcToolbox bottom for finding the right tools)	20 min
Projecting in Arc Toolbox	Keewsh_geo Keewriv1	- The coordinate system of keewwsh_geo is a Geographic Coordinate System with Clarke 1880 spheroid and Arc 1960 datum. - In the Data Management Toolbox use the Project tool to change the coordinate system to UTM - Arc 1960 (same as keewriv1). - Save the new shapefile as keewwsh1 - Load the two shapefiles into a new Map Document in ArcMap and check whether they fit.	20 min
		Total time:	60 min

Eastern and Southern Africa Partnership Programme

Capacity Building in Geoprocessing

Module 2

Managing GIS

Centre for Development and Environment

centre for development and environment

Training Concept

This training module is part of a Geoprocessing Training Concept elaborated by the Centre for Development and Environment (CDE). Each module looks into GIS or RS methods and functions. A course in any of the two disciplines can be composed of a varying number of selected modules, depending on the participant's requirements and the duration of the course. Additional modules will be added to the Training Concept based on concrete requests, or on the basis of enhanced expertise of the CDE Geoprocessing unit. Each Training Module is divided into three main parts:

T	Theory	Theoretical background and concepts, as well as available references on the module's main topics
A	Applications	Specificities of selected GIS and RS software regarding the module's main topics. Currently the Training Modules are designed for use with ESRI's ArcGIS 9.x software family, but will be stepwise expanded, depending on the specific requirements of course participants.
E	Exercises	Concrete exercises on the module's main topics for implementation by the course participants with use of selected software

Module 2 of the GIS training kit is called "Managing GIS" and is a purely theoretical module without application and exercises sections. The module provides general information on important aspects related to the setting-up and the running of a GIS unit in a particular institution. Aspects like the identification of needs for GIS information and services, equipment and staffing, institutionalisation of GIS structures and activities, etc. are at the core of this module. It is important remembering that each specific case has its own particularities requiring a case-specific approach. The information and advices provided in this module have therefore to be considered as a general and non-exhaustive guidance for the setting-up of a GIS unit.

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Authors: A. Ehrensperger, T. Gurtner, C. Hergarten, C. Hösli
Based on various course manuals and guidelines prepared by CDE

Contents

Managing GIS
Theory

E.1. Preliminary considerations

T.1.1. Assessing the needs for GIS

GIS is a fashionable tool and has therefore sometimes been purchased in situations in which it was not really needed, or in which collaboration between institutions could have helped sharing resources, as well as reducing investments and maintenance costs. Many examples exist in which public institutions or NGOs have purchased a GIS, but lack expertise, mandates and data to fully take advantage of this technical tool.

An institution planning to setup a GIS unit needs to first make a realistic assessment of its own needs in relation to its overall mandate, specific activities, partnerships and means. Some of the questions that need to be asked during such an assessment are:

- Are our mandates and daily activities necessitating the use of spatial data and analysis on a regular basis, or do we need them once in a while?
- Are we relying mostly on baseline spatial information that is widely available and could be used after minor adaptations that do not require the availability of a GIS?
- What would be the concrete added value of having our own GIS unit and is this added value in balance with the necessary investment and additional running costs?
- Do we have partner institutions which already have a GIS, would have free capacity to process spatial data that we need to fulfil our mandates and would be ready to enter into partnership on the same?
- Can we combine a future GIS unit with other technical services (database management, hardware and software maintenance, web administration, etc.) in order to save costs?
- Could our GIS unit take over tasks for other institutions and do we need to discuss future collaboration with these institutions before planning and dimensioning the GIS unit?
- Are we realistically able to set aside a budget for the setting up and the running of a GIS unit, for the recruiting and training of staff, and for the acquiring and maintenance of necessary spatial data?

Each institution considering setting up a GIS unit should take the time to reflect on the above questions and to supplement them with additional ones that will provide adequate guidance in deciding about investing into GIS. It is worthwhile taking the time to assess the institutions' concrete requirements, financial options, the possible partnerships, before deciding on a particular option. It could also be advisable to send one member of staff (for example a technician, or a member of the cadre in charge of technical issues) to attend a GIS course in order to get an overview over the real possibilities offered by GIS and the degree of expertise they require.

Within public institutions, e.g. within a municipal council it is recommendable to involve all departments, which could potentially benefit from the introduction of a GIS unit into preliminary discussions and planning. Only in rare cases does it make sense for several departments to separately acquire and maintain their own GIS unit. Most of the time one department alone does not have a sufficiently high demand for spatial data and analysis to justify the setting up of its own GIS unit. For example an education department's only requirement for GIS outputs could be yearly updates of school statistics (enrolment, number of teachers and classrooms, infrastructure, etc.) displayed on maps and possibly linked to other indicators (e.g. demographic data). Such outputs can be produced by a centralised GIS unit in a very short time on the basis of spreadsheets prepared by the education department. Several departments combined are more likely to represent a big enough pool of activities for a centralised GIS unit. Such issues need to be discussed within the institution and discussions should also focus on the data to be produced, stored and disseminated by the GIS unit. Data ownership and access often are sensitive issues and some departments are reluctant to entrust others with the safekeeping of their data. Comprehensive institution-wide data accessibility, sharing and safety policy is therefore necessarily part of the debate that should be initiated prior to the setting up of a GIS unit.

T.1.2. Fitting into an existing GIS context

Institutions rarely operate in isolation from other institutions and from a regional, national and international context. Therefore, it is important gaining an overview over the GIS users' community in the local and national contexts and – at a global level – over the community of institutions dealing with similar tasks and making use of GIS. For public institutions it can be worthwhile contacting similar institutions abroad and enquire about their experiences with the setting up and running of a GIS unit. For example, sometimes municipalities have collaborative relationships with other municipalities in the world. Such linkages can be used to gather information on the implementation of GIS and the problems that this can cause. Some municipalities, state and national governments are displaying their GIS applications and available databases over the Internet (for example http://www.nysgis.state.ny.us/gisdata/), which can also be a good source of information and inspiration for the setting up of a GIS unit. NGOs can operate in a similar manner and contact partner institutions in view of gathering information and experiences on GIS implementation. Finally, some branches of the UN offer information material and even guidelines on the implementation of GIS units in different types of environments. It might therefore be advisable seeking advice from these branches.

In some countries, ***networks of GIS users*** try coordinating GIS related activities, sharing information and data, and organising common capacity development programmes. It is recommended trying to find out about the existence of such networks in the local and national context and becoming actively involved in them. The most frequent problem that such networks are facing is the reluctance of partner institutions to share their GIS data and expertise with others. This is understandable as meaningful data generation often requires massive investment in terms of manpower and/or the purchase of costly baseline data like satellite images and is therefore not easily disseminated without appropriate return favours or cash payment. Additionally, data is often perceived as being a source of power and potential generator of future mandates and income and is therefore often handled in a confidential manner.

However, GIS users' networks still can play an active role for data sharing and dissemination through the creation of a ***clearinghouse*** (usually web-based applications) by which GIS data available within the various partner institutions can be searched and explored. Such information can be presented as meta-data, i.e. previews of the spatial data or descriptions of the attribute information contained.
Examples: http://www.fs.fed.us/r5/rsl/clearinghouse/data.shtml, http://seamless.usgs.gov/, http://igskmncnwb015.cr.usgs.gov/adds/, http://geodata.grid.unep.ch/, http://eros.usgs.gov/, http://www.cartographic.com/, http://www.swisstopo.ch/en/products/digital/.

In view of the above considerations, a number of questions need to be answered pertaining to the GIS users' community in the regional and national context before setting up a GIS unit:

- Which institutions working on similar topics are using GIS and what are they using it for (type of outputs, intensity of use, etc.)?
- Are institutions organized in a GIS user network on a regional or national basis and in what fields is this network active (data sharing, fostering of bilateral collaboration, common capacity development, pooling of manpower and technical resources (e.g. GPS receivers, scanners), etc.)?
- Is there a consensus among GIS users on the sharing and dissemination of GIS data? Is there an existing data pricing policy?
- Is there a GIS data clearinghouse? Which institutions are involved in its management? How accessible is it and what use is being made of it by interested partners? What are the membership requirements and the advantages that one could gain from becoming a member?
- Which is the most frequently used software in the regional or national context? How are licenses purchased? Is there a regional software distributor? Are there options for special arrangements, like license sharing, software grant programmes, etc.?
- What data formats, scales and data projections are other institutions mostly working with? Are there national official or consensually agreed upon standards for data quality, attribute formats, symbology, etc.?

Awareness about the GIS users' community, available resources, capacities, data standards and exchange policies, networks and clearinghouses, etc. can be an important input for the designing and preparing of an institution's GIS unit. Therefore, examining the above questions should be, if possible, an integral part of the assessment and planning phase that is done prior to the setting up of a GIS unit.

T.1.3. Planning and setting up a GIS unit

The planning and setting up of a GIS unit requires a step-by-step identification and clearing of a number of issues and variables, some of which have been mentioned in the previous paragraphs. The following list is meant as a preliminary conclusion and a summary of the information provided in this first section:

Phase I

1. Identification of the institution's ***needs*** in terms of GIS-based outputs and products.
2. Identification of ***existing GIS*** **capacity** among partner institutions that could be tapped, or exchanged against other services, or financial remuneration.
3. Identification of the institution's ***financial ability*** to set up, staff and maintain a GIS unit with a long-term perspective. Parallel identification of possible sponsorships, software and hardware grant programmes, etc.
4. ***Decision*** about the necessity to set up a GIS unit within the institution on the basis of the three above listed points, and the assurance from the institutions' leaders that they will provide long-term support to the unit (important aspects of the institutionalisation of a GIS unit are provided in section T2).

Phase II

5. ***Dimensioning*** of the GIS unit on the basis of the above findings. Staff, equipment and needs depend on the institution's mandate, its financial ability and the availability of collaboration opportunities with partner institutions.
6. Establishing an overall ***mandate*** for the GIS unit and ***terms of reference*** for its team on the basis of the institution's needs for spatial data and analysis, its work processes, and development visions.
7. ***Recruiting*** personnel for the GIS unit on the basis of the above defined terms of reference and with consideration for the required profiles (see below paragraph T.2.4). It is advisable to recruit part of the team before purchasing the technical infrastructure in order to involve them in the selection of technical solutions, which can lead to a greater sense of ownership and commitment to the institution. Furthermore, unless an external consultant is hired to help in setting up the unit, the team can provide valuable input and help to avoid unnecessary or poorly planned technical investment.
8. ***Purchase*** of technical infrastructure including hardware, software and peripherals. It is advisable to first acquire a baseline infrastructure that allows to start with elementary tasks, like the structuring of a spatial database, designing of outputs (maps), generating of spatial data (digitising, GPS data collection and integration into a GIS environment), carrying out of elementary spatial analyses, etc. The most important part in this stage is the designing of a coherent and affordable software solution. Typically, this is a task the unit's leader should be entrusted with, as it is a strategic decision that affects both the technical possibilities and the types of outputs.

Phase III

9. Elaboration at a very early stage of the existence of the GIS unit of a ***data structuring*** and ***data safety*** concept. It is important to elaborate these concepts before large data generation and output production mandates demand the team's attention. Corrections and structuring at a later date often imply much higher effort and can lead to data loss. An easy to implement and reliable backup strategy needs to be put in place right from the start as well. There are too many examples known to the authors of this training module of institutions which have absolutely no backup strategy and no database administration. Data losses in such institutions are quite frequent and only tolerated as long as wages of technicians are kept low and their work load is not heavy.
10. A flexible ***capacity development*** concept needs to be designed in the early stages of the existence of a GIS unit. Such a concept can be modified at a later date, but it is important to start GIS activities while having such a concept in order to be able to factor capacity development costs and manpower into the unit's budget and scheduling. It is strongly advised, at least in the early stages of the unit, to focus capacity development onto the basic and most important skills and tasks like computer and database manipulation, maintenance and administration, networking through Internet user forums, software maintenance and updating, etc. Often teams of GIS units get stuck in their work because of not being able to solve basic technical problems, or not knowing how to find support to solve them. This is why baseline capacity development should not be neglected.
11. ***Networking*** with other GIS users and partner institutions. Exchange of information with other institutions is crucial for the survival of a GIS unit as it can help sharing resources, organising capacity development, getting access to existing data, being part of forums and taking part in conferences. Awareness about other institutions' activities can also lead to additional mandates and therefore additional income that can be reinvested in the unit for the purchase of consumables, the upgrading of infrastructure, or the implementation of data collection.
12. Elaboration of a ***corporate identity***. Outputs from the unit need to be recognisable through their format, quality and specific graphic elements. In most areas of the world and activity fields the production of GIS outputs is ever increasing and the chances of one's outputs being noticed is declining unless their quality is above average, in terms of presentation and data quality. It is a good idea designing a small "display window" for the unit's outputs (e.g. on the institution's web site, with demonstration material on CD-ROMs, or with fliers, demonstration maps, etc.).

The above listed stages concern only the planning, setup and early running of a GIS unit and are by far not exhaustive. Depending on the institution's specific requirements and conditions, and the ones of institutions it depends on or works with, other stages have to be defined. Furthermore, it can be necessary, depending on the existing GIS expertise within the institution to hire external expertise for all stages that have to be implemented prior to the recruitment of the GIS unit's staff (especially for the stages of Phase I).

E.2. Institutionalisation and sustainability

T.2.1. Institutional setup and local patronage

Often technical units and the management of institutions suffer from poor reciprocal communication. This is often the case when the management cadre is not aware about he technical implications of the services and outputs it requests from the GIS unit and when the unit's technicians only have scanty knowledge about the institution's main fields of activities. During transitions from non-computer based working procedures to computer based working procedures additional misunderstandings can lead to delicate situations. Therefore, once the necessity of a GIS unit has been established by a series of preliminary assessments (see above), the institutionalisation of that unit can still face serious difficulties. The process of institutionalisation of the GIS unit (and of the use of its outputs) can be greatly simplified if support can be obtained from individual members of the management cadre. Such internal patronage of the institutionalisation effort is particularly important to help formalising the existence of the GIS unit.

In some instances, GIS units are temporarily built up as part of a project that is implemented by the agency in collaboration with an external partner (e.g. a municipal council in collaboration with an international NGO). In such cases, the institution normally delegates members of its staff to work on that project with the intention to call them back to their former duties once the project is completed. The investment into upgrading existing GIS expertise is ultimately lost, if the institution does not formalise it beyond the existence of the externally funded project. Local patronage and support from the management cadre is crucial to help achieving this formalisation.

T.2.2. Financial matters

Expenses arise from the setting up and the running of a GIS unit. However, these expenses are sometimes overrated in the perception of institutions and development partners. Most public and private institutions are anyway undergoing gradual computerisation and thus – considering that most GIS products are nowadays available as desktop applications – the additional expenses brought about by a GIS unit are primarily linked to software, the acquisition of data and additional staff costs, or capacity development costs within existing staff positions. At equal proportions, a GIS unit is most of the time cheaper to maintain than other technical units as for example a water quality testing lab, or a unit requiring frequent travel by road. Even research units in the social sciences can prove to require higher financial investment for activities like socio-economic surveys, training of stakeholders, etc.

It has been estimated that the cost relation between hardware, software and data is 1 to 10 to 100 (i.e. *data costs* ten times more than software and a hundred times more than hardware). With decreasing costs of hardware and software, the relative weight of data cost could even be more overwhelming. This estimation is, of course, only valid for a GIS unit that is frequently solicited by the other departments of the institution and thus actively acquiring data on a regular basis. In other cases, witnessed by the authors of this module, GIS units have been set up with reasonable technical infrastructure (1 to 2 computers, a colour printer, GPS receivers, etc.) and personnel (1 to 2 technicians), but have at their disposition only one relevant data layer (e.g. a polygon layer of soil types at a national scale) and no funds for the acquisition of new data either through field work or purchase (e.g. of satellite images). Such situations are highly frustrating for the GIS team and represent a waste of human and technical resources. Therefore, it is crucial to factor in sufficient financial resources for the building up, maintaining and upgrading of a meaningful spatial database.

Another constraint many GIS units are often confronted with is the lack of budget for consumables (paper, printer cartridges, CD-ROM, etc.) and for hardware maintenance. Cases have been observed, in which GIS units were unable to produce outputs because of these hindrances (e.g. unable to write data on a CD because the CD drive of their computer was out of order). In order to avoid such bottlenecks – which have a negative impact on the unit's image –, funds need to be reserved for consumables and small maintenance and repair costs. If the GIS unit is generating some revenue through the selling of outputs (e.g. maps and digital data), or consultancies it can save this income for such kind of expenses. Revenue generated by the unit can also be invested in data acquisition, or the updating of a spatial layer (e.g. collecting the most recent data on school enrolment, or on the current incidence of malaria cases, etc.).

Finally, it must be noted that the fact that a GIS unit is sometimes able to generate its own revenue through the selling of outputs and consultancies can lead to tensions between this unit and other units of an institution, which might feel disadvantaged. Therefore, it is important to design a transparent plan for the re-investment of generated funds (hardware and software maintenance, purchase of consumables, acquisition of data, etc.), which does not provide space for personal gains of the GIS unit's staff.

T.2.3. GIS personnel

One of the common definitions of GIS says that it consists of hardware, software, data, methods and personnel. A GIS unit's team is, without doubt the most important and sensitive component of that unit. Therefore, team building, capacity development, career planning and the building up of an institutional memory in matters related to GIS is of crucial importance. These aspects are briefly examined hereafter:

Team building: In developing countries institutions interested in recruiting GIS technician face the problem that these professionals are highly marketable and can therefore afford to negotiate above average wages. For this reason, institutions often hire junior staff with only little experience into positions requiring strategic decision-making and conceptual development. Cases were observed by the authors of this module, in which inexperienced staff members were entrusted with the task of setting up a GIS unit for a relatively large governmental department. Such approaches are often bound to fail due to the lack of experience of the personnel in charge. Therefore, a coherent team strategy needs to be developed before positions are defined and advertised.

Within the GIS team, two important overall functions need to be fulfilled: Team management and technical implementation. Depending on the institutional setup and the size of the planned GIS unit, these two functions can be implemented by a varying number of staff members. Hereafter is a brief description of both functions and important aspects they entail:

- *Team management:* As was mentioned above (T.2.1) one can often observe lack of communication and understanding between an institution's GIS unit and management cadre. Misunderstandings happen when the former do not have sufficient insights and understanding about the topical concerns of the institution and focus too heavily on technical problem solving, or when the latter do not have insights into the technical implications of the services required from the GIS unit and are not informed about the tool's potentials and limitations. Therefore, it is important that a GIS unit has a leader who creates the link between both the technical and the topical sides. Such a person should be conversant with the overall topics and issues the institution is dealing with, while having gained relevant practical experience in GIS technology. For example, if the institution is dealing with environmental issues, it is usually preferable that the GIS unit leader is an environmentalist with a solid GIS background, rather than a GIS specialist with only limited knowledge about environmental issues. Communication, networking and flexibility are among the most important skills a GIS unit leader needs to possess. Furthermore, he or she needs to be able to develop a vision for the GIS unit in terms of working processes, acquisition of mandates, data and analysis presentation, information dissemination, etc.
- *Technical implementation:* Technical implementation should take place with proper guidance from the unit leader. The variety of technical skills that can be of use in a GIS unit is very wide and includes data digitizing, programming of applications and software extensions, cartographic and general graphical skills, GIS and remote sensing data analysis, database management, administration of a meta-database, capacity development, general computer maintenance skills, etc. Therefore, it is likely that a relatively small GIS unit (2 to 3 people) will not be in a position to acquire all these skills, and the unit's leader together with the institution's management need to choose the most important and commonly used skills required in the unit in accordance with the vision that was elaborated for that unit. Other skills that are needed on a more punctual basis need to be externalized and therefore, bilateral partnerships with other institutions or the participation in GIS user networks can prove to be very important.

Capacity development and career planning: GIS is a fast changing technology. New developments open up possibilities that can be important for an institution. For example the development of GPS has opened up new data acquisition and fieldwork possibilities that were not available before. Similarly, Internet-based GIS applications can be an important medium for advertising the institution's capacities and services, for exchanging data, or for multi-user data processing. Being up-to-date about technical developments can also be a means of avoiding unnecessary costs: *Open-source applications* offer an increasing number of functionalities that used to be available only with commercial software. For example, if an institution does not usually work with remote sensing tools, but requires from time to time simple satellite image classification functions, it might be able to get these functions with a simple application available on the Internet. Awareness about such possibilities can only be achieved and maintained with capacity development, active information-seeking behaviour and networking with other institutions.

Institutional memory: Especially when they deal with vast amounts of data, computer based procedures like GIS, can rapidly loose their transparency for anyone not directly involved in their implementation. For example, it can be impossible for a new GIS technician to understand a GIS database that is poorly documented without the help and additional information from the person who was in charge of maintaining this database. Therefore, an institution deciding to set up a GIS unit needs to be aware about the necessity of investing into data documentation and the building up of institutional memory. The terms of reference of the GIS unit leader and/or GIS database administrator need to be very clear on the documentation of data, working procedures, use of applications and tools, and networking activities. One way to enhance institutional memory is the setting up, on the institution's intranet, of an easily accessible meta-database that allows staff of other units and departments to gain an overview over the available spatial data and the technical services offered by the unit. Without appropriate investment into data documentation it can happen – and this has been witnessed by the authors of this module – that an institution conducts two times the digitalisation of a particular spatial layer, because of the lack of awareness of new GIS team members about the availability of that layer in the existing database.

T.2.4. Public-private sector solutions

As mentioned above, the range of possible tasks and expertise that can become necessary for the running of a GIS unit is very wide and includes fields like database management, application programming, GIS analysis, cartography, digitalisation and vectorisation of spatial data, scanning of source data, setting up and maintaining of Internet-based GIS applications, etc. Therefore, an institution having acquired its own GIS capacity needs to constantly identify and reassess its own unit's core tasks and the tasks that can not be performed by this unit due to lacking expertise and/or technical infrastructure. In the latter case, the question needs to be asked whether this expertise or infrastructure should be acquired, or externalised to a partner institution. In cases in which a particular expertise or infrastructure is needed on a punctual basis, capacity development, or infrastructure purchase can prove to be out of proportion and externalisation the better option (e.g. the occasional scanning of hardcopies, or lengthy digitalisation tasks that would absorb much of the time of a GIS unit's personnel). In other cases, the required skill or infrastructure might prove to become increasingly important and thus investment in it could be the better option. In other cases, the external expertise can also be hired on-site in order to provide capacity development opportunities to the GIS unit's technical team.

Managing GIS

Exercises

E.1. Exercises

E.1.1. Setting up a GIS Unit

Steps	Remarks	Time
Unit Setup	- By the water department, you get the task to set up a GIS unit for digitizing a large towns drinking water facilities. - What are the main points you have to think about in terms of: Organization Finances / Budgets Data Software	20 – 40
Project setup	- In a next step, you have to submit a project proposal. What do you think are the main points to clarify in terms of GIS data and GIS software (think about costs, copy rights etc.)? - GIS specialists are expensive and tend to overstrain the budget. What arguments do you have in order to justify the costs? Are there any alternatives? - Try to identify potential collaboration partners – what options do you have?	30 – 50
Total time		70 min

Eastern and Southern Africa Partnership Programme

Capacity Building in Geoprocessing

Module 3

GIS Data Preparation

Centre for Development and Environment

centre for development and environment

Training Concept

This training module is part of a Geoprocessing Training Concept elaborated by the Centre for Development and Environment (CDE). Each module looks into GIS or RS methods and functions. A course in any of the two disciplines can be composed of a varying number of selected modules, depending on the participant's requirements and the duration of the course. Additional modules will be added to the Training Concept based on concrete requests, or on the basis of enhanced expertise of the CDE Geoprocessing unit. Each Training Module is divided into three main parts:

T	Theory	Theoretical background and concepts, as well as available references on the module's main topics
A	Applications	Specificities of selected GIS and RS software regarding the module's main topics. Currently the Training Modules are designed for use with ESRI's ArcGIS 9.x software family, but will be stepwise expanded, depending on the specific requirements of course participants.
E	Exercises	Concrete exercises on the module's main topics for implementation by the course participants with use of selected software

Module 3 of the GIS training concept is called "GIS Data Preparation", which includes data acquisition, generation, editing, improvement and transformation. This module focuses on the creation of new spatial data, or the improvement, or adaptation of existing spatial data. Without appropriate and sufficient data on the spatial elements and phenomena under consideration, a GIS unit is of little use. Therefore, the process of acquiring data is of high importance, which gives this module a pivotal function in the entire training concept. Several ways of acquiring and generating spatial data exist and several tools can be used for that purpose. Each approach matches particular types of data and can not be used for others, reason for which it is important to have a good overview over these approaches. This module tries to show pragmatic approaches to data generation specifically adapted to the situation in Eastern Africa.

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Based on various course manuals and guidelines prepared by CDE

Contents

GIS Data Preparation Theory

T.1. Data preparation and input

Before using any GIS the first step is to feed it with data. The pre-processing and acquisition of spatial data is a laborious and time consuming process. However, much of the success of a GIS project depends on the quality of the data availed and used, and thus this phase of a GIS project is crucial and must be carried out cautiously and in a planned manner. The general consensus among the GIS community is that 60 to 80 % of the cost incurred during implementation of GIS technology lies in data acquisition, data compilation and database development. Therefore, financial concerns when setting up a GIS should not focus on equipment (hardware and software), which is comparatively cheap, but on the acquisition, preparation and maintenance of data.

A wide variety of sources exist for spatial data: Data can be obtained first-hand by using direct spatial data acquisition techniques like Global Positioning Systems (GPS). Data acquired in such a way is hereafter referred to as *"primary data"*. Data can also be obtained indirectly, by making use of spatial data collected earlier and/or by someone else. Data obtained in such a way is hereafter referred to as *"secondary data"*. Primary spatial data is usually obtained through direct observation of the relevant geographic objects and phenomena. This can be done through ground-based field surveys (field mapping, cadastral work, GPS measurements, etc.) or by using remote sensing (aerial photography, satellite imagery, etc.). A crucial aspect of ground-based surveying is that the data can be interpreted immediately by the surveyor. This is not the case for remotely sensed imagery, which requires pre-processing steps before use, as various sources of error may have been present at the time of sensing.

The indirect way of data capturing is very common and includes at least three basic procedures for inputting spatial data into a GIS. These are:

- Manual digitizing
- Automatic scanning and vectorization
- Conversion of existing digital data

These three modes of data capturing are described in the following paragraphs and will also provide for the bulk of the exercises in the third part of the module.

T.1.1. Manual digitizing

In its original form, digitizing is the technique aiming to transfer data from an analogue form to a digital format such that the data can be electronically processed and analyzed. This original form relied on the digitizing of paper maps with help of a digitizing tablet. In recent years, with the increasing availability of large format scanners, digitizing more often takes place on the screen, on the basis of scanned maps.

Due to the indirect process involved in digitizing, positional errors that may already exist in the analogue database (on the paper map, or on its scanned image that is being viewed on the computer screen) will be transferred to the digital version and possibly further accentuated due to digitizing inaccuracies. Such positional errors on the input dataset can be evaluated, either through comparison with other datasets, or through random verification in the field. The unsystematic positional errors emerging as a result of digitizing inaccuracies can also be evaluated. It is part of the data acquisition process to evaluate such errors and to decide whether the expected error magnitude is acceptable for the targeted output data.

In manual digitizing, a human operator follows the map's features with a mouse device, and thereby traces the lines, storing location coordinates relative to a number of previously defined ***control points***. The control point's function is somehow to 'lock' a coordinate system onto the digitized data: therefore they need to have known coordinates, and by digitizing them the system is told implicitly where all other digitized locations are. At least three control points are needed, but preferably more should be digitized to allow a check on the positional errors made. When entering the control points, most GIS software will calculate a so-called ***RMS*** (Root Mean Square) error, which provides information on the input data's internal spatial coherence. If a map was scanned in a way that spatial distortions occurred, the RMS error is likely to be high and the GIS technician will have to decide on the measures to be taken (adopt the error, if it is within the acceptable range, try to "rubber-sheet" the scanned image to improve the internal spatial coherence, or request for a new scan of the original paper map).

There are two forms of digitizing:

- ***on - tablet****:* the original map is fitted on a special tablet and the operator moves a special device over the map, defining points or interest by clicking the mouse at their location.
- ***on - screen****:* a scanned image, typically of a map, aerial photograph, or satellite image is displayed on the computer screen, and the operator moves the mouse cursor over the screen, again selecting points or lines of interest.

In both cases, the GIS works as a point recorder, and from this recorded data, line features are later constructed. There are usually two modes in which the GIS can record: in ***point mode***, the system only records a mouse location when the operator wants so; in ***stream mode***, the system continuously records locations. The first is usually the more useful technique because it is easier to control and is less affected by inaccurate hand movements.

T.1.2. The scanning process

The document to be scanned is illuminated by a digital scanner measuring the intensity of the reflected light with a sensor. The result of the scanning process is an image, i.e. a matrix of pixels, each of which holds a reflectance value. ***Note***: In order to understand the concept of pixels, i.e. the way an image is composed, one can load a photograph into an image viewing software (e.g. Microsoft Photo Editor) and zoom in until the image gets blurred and small squares become visible (see the extract from a satellite image on the right that shows the roof of a house and a swimming pool in Nakuru, Kenya). Each such square is a pixel, i.e. it contains one “colour”-value. Before scanning, one has to decide whether to scan the document in line art, grey-scale or colour mode. The first mode results in either white or black pixel values and the second mode in a range of 256 grey values, with white and black as the two extremes. For colour mode scanning, more storage space is required as a pixel value is represented in a red-scale value, a green-scale value and a blue-scale value. Each of these three scales, like in the grey-scale case, allows 256 different values.

Scanning devices have a fixed maximum ***resolution***, expressed as the highest number of pixels they can identify per inch; the unit is pixel-per-inch (ppi). For manual on-screen digitizing of a paper map, a resolution of 200-300 ppi is usually sufficient, depending on the thickness of the thinnest lines on the paper map (e.g. foot paths on a roads and communication map). For manual on-screen digitizing of aerial photographs, higher resolutions are recommended – typically, at least 800 ppi. (Semi-) automatic digitizing requires a resolution that results in scanned lines of at least three pixels width to enable the computer to trace the centre of the lines and thus avoid displacements. For paper maps, a resolution of 300-600 ppi should usually be sufficient. Automatic or semi-automatic tracing from aerial photographs can only be done in a limited number of cases. After scanning, the resulting image can be improved with various techniques of image processing. This can include corrections of colour, brightness and contrast, noise removal, the filling of holes, or the smoothing of lines.

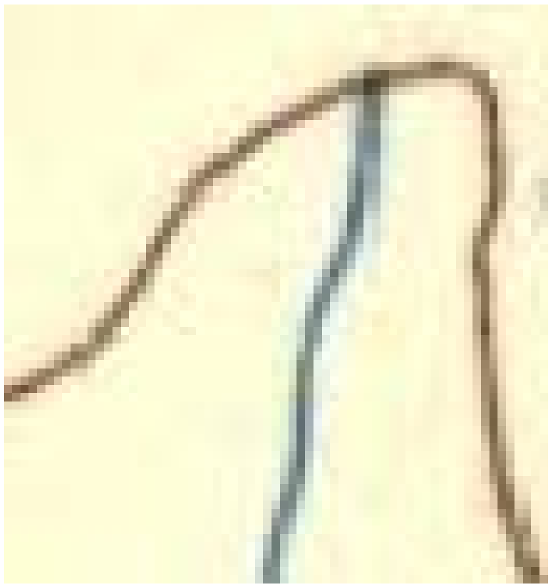


Figure T.1: *Extract from a topographic map sheet showing a river and a contour line*

T.1.3. The process of vectorization

Vectorization is the procedure that attempts to derive points, lines and polygons from a scanned image. As scanned lines may be several pixels wide (see Figure T.1 to the right), they are often first ‘thinned’, to retain only the centreline. This thinning process is also known as “skeletonizing”, as it removes all pixels that make the line wider than just one pixel. The remaining centreline pixels are converted to series of (x, y) coordinate pairs defining the line to be vectorized. Afterwards, features are formed and attributes are attached to them. Such process can be entirely automated or performed semi - automatically. Semi - automatic vectorization proceeds by placing the mouse pointer at the start of a line to be vectorized (e.g. at the beginning of the river shown in Figure T.1). The system automatically follows the line (e.g. a linear arrangement of pixels with the same value). At junctions, a default direction is followed, or the operator can indicate a preferred direction. In coloured pictures, the definition of the colour range that still depicts the objects of interest is a sometimes tricky issue. The brown elevation contour in Figure T.1 provides a good example. The “brown values” of the line are not identical in all parts of the feature and therefore a width of acceptable “brown values” has to be specified before starting vectorization. If that range is too wide, features other than elevation contours will be vectorized; if on the other hand the range is too narrow, the elevation contours might not be vectorized continuously. Gaps will appear in areas where the “brown values” are slightly different.

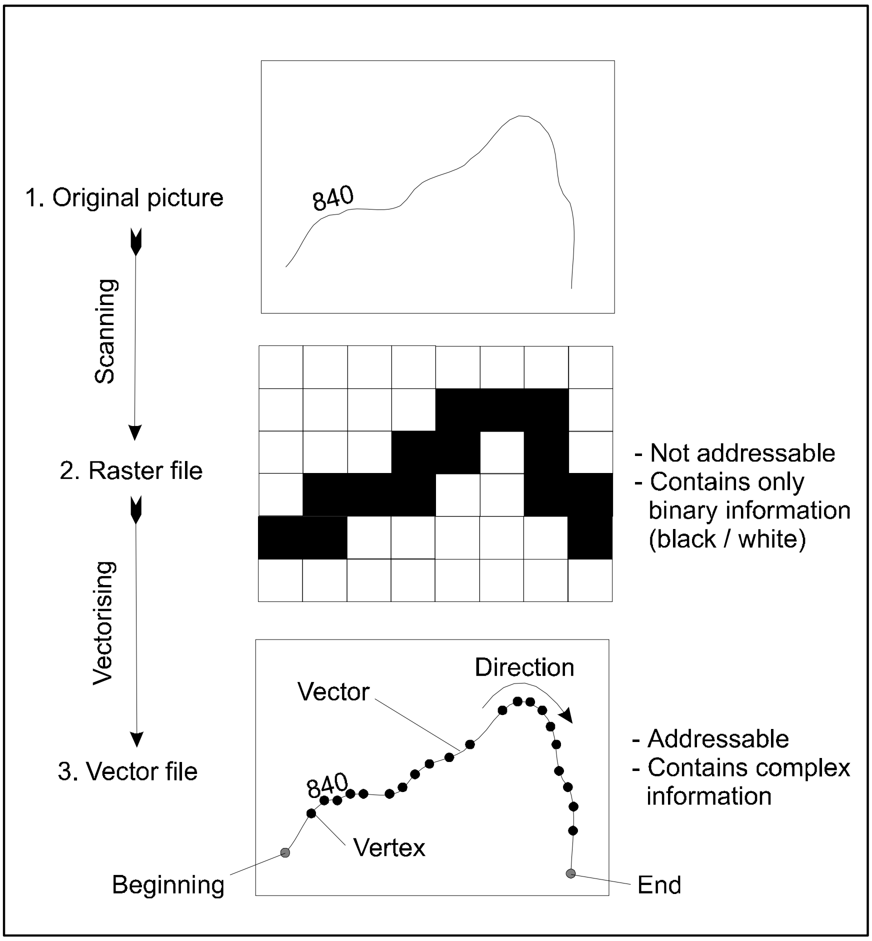


Figure T.2: *The phases of vectorization. The original picture (top) is first scanned (middle) and the resulting image is then vectorized (bottom).*

Pattern recognition methods – such as Optical Character Recognition (OCR) – may be used for the automatic detection of graphic symbols and text. Once symbols are recognized as image patterns, they may be replaced by symbols in vector format or by attribute data. For example, the numeric values placed on contour lines can be detected automatically to attach elevation values to these vectorized contour lines.

Vectorization usually causes errors such as small spikes along lines, rounded corners, errors in junctions, displaced lines or jagged curves. These errors are corrected in an automatic or interactive post-processing phase. The phases of the vectorization process are illustrated in Figure T.2 below.

T.2. Generating and importing GPS Data

An increasingly important source for geographic data is provided by satellite positioning technology. Especially land surveyors who have traditionally been depending on optical and electronic instruments are taking huge advantage of the global positioning system.
To date, the Global Positioning System (GPS) is still the only fully-functional satellite navigation system based on 24 satellites orbiting the Earth at altitudes of about 20,000 kilometers. GPS was developed by the US Department of Defense, primarily as a military locating and navigation utility. Since the end of the cold war however, GPS has proven to be a useful tool also for non-military applications.

Figure T.3: *A GPS satellite above the Earth*

This network of satellites transmits continuously coded information, which makes it possible to precisely identify locations on Earth by measuring distance from the satellites. The satellites transmit low power radio signals allowing anyone with a GPS receiver to determine his location on Earth.

T.2.1. Range of applications

The GPS system is useful for a variety of applications in the air, on land and at sea. GPS enables recording or creating locations from places on the Earth’s surface and helps to navigate to and from those locations. The use of GPS is virtually unlimited except where it is impossible to receive the signal such as inside buildings, subterranean locations and underwater.

Figure T.4: *GPS satellites orbiting the Earth*

Common airborne applications include navigation by aviation and commercial aircraft. At sea GPS is typically used for navigation by professional navigation and recreational boaters. The range of land applications is very broad. Surveyors use GPS for an increasing part of their work since it offers significant cost savings by reducing setup time at survey sites. The scientific community applies GPS for its high precision timing capability as well as other applications.

T.2.2. Segments of GPS

The NAVSTAR system (the official U.S. Department of Defense name for GPS: Navigation Satellite Timing and Ranging) is consisting of a space segment (satellites), a control segment (ground stations), and a user segment (GPS user community).

The main item of the system is the space segment, consisting of 24 satellites. The orbital arrangement of the satellites is optimized so a GPS receiver on earth always receives signal from at least four of them at any time. Powered by solar energy the satellites orbit the earth twice a day. The satellites are designed to reach a life expectancy of about 10 years.
Most civilian GPS receivers can only process the transmitted low-power radio signal designated L1, the other frequencies are reserved for military applications. Due to its low power, the signal will only penetrate clouds or glass, but will not pass through solid objects such as buildings. This is the reason why the use of GPS is restricted to clear-view-of-sky conditions.

The control segment is surveying the GPS satellites by tracking them and then providing them with corrected orbital and clock information (see Figure T.4). There are five control stations located around the world - four unmanned monitoring stations and one master control station. The four automatic receiving stations receive constantly data from the satellites and send that information to the master control station. The master control station is correcting the satellite data and together with two other antenna sites, sends or uplinks the information to the GPS satellites.

Figure T.5: *The control segment: GPS Control Stations around the Globe*

The user segment finally simply consists of the person with the GPS receiver on earth surface.

T.2.3. Calculating location

In order to provide correct location readings, the GPS receiver needs to know the exact position of the satellites (location) and how far away they are (distance). Let's first look at how the GPS receiver knows where the satellites are located in space. The GPS receiver picks up two kinds of coded information from the satellites. One type of information, called ***almanac*** data, contains the approximate positions (locations) of the satellites. This data is continuously transmitted and stored in the memory of the GPS receivers so they know the orbits of the satellites and where each satellite is supposed to be. The almanac data is periodically updated with new information as the satellites move around. Any satellite can travel slightly out of orbit, so the ground monitor stations keep track of the satellite orbits, altitude, location, and speed. The ground stations send the orbital data to the master control station, which in turn sends corrected data up to the satellites. This corrected and exact position data is called the ***ephemeris*** data, which is valid for about four to six hours, and is transmitted in the coded information to the GPS receiver. So, having received the almanac and ephemeris data, the GPS receiver knows the position (location) of the satellites at all times.

Even though the GPS receiver knows the precise location of the satellites in space, it still needs to know how far away the satellites are (the distance) so it can determine its position on Earth. There is a simple formula that tells the receiver how far it is from each satellite:

Your distance from a given satellite object equals the velocity of the transmitted signal multiplied by the time it takes the signal to reach you (Velocity x Travel Time = Distance). Using the same basic formula to determine distance, the receiver already knows the velocity. It's the speed of a radio wave — 186,000 miles per second (the speed of light), less any delay as the signal travels through the Earth's atmosphere. Now the GPS receiver needs to determine the time part of the formula. The answer lies in the coded signals the satellites transmit. The transmitted code is called ***pseudo-random code*** because it looks like a noise signal. When a satellite is generating the pseudo-random code, the GPS receiver is generating the same code and tries to match it up to the satellite's code. The receiver then compares the two codes to determine how much it needs to delay (or shift) its code to match the satellite code. This delay time (shift) is multiplied by the speed of light to get the distance. Your GPS receiver clock does not keep the time as precisely as the satellite clocks. Putting an atomic clock in your GPS receiver would make it much larger and far too expensive! So each distance measurement needs to be corrected to account for the GPS receiver's internal clock error. For this reason, the range measurement is referred to as a "pseudo-range". To determine position using pseudo-range data, a minimum of four satellites must be tracked and the four fixes must be recomputed until the clock error disappears.

Now that we have both satellite location and distance, the receiver can determine a position. Let's say we are 11,000 kilometers from one satellite. Our location would be somewhere on an imaginary sphere that has the satellite in the center with a radius of 11,000 kilometers. Then let's say we are 12,000 kilometers s from another satellite. The second sphere would intersect the first sphere to create a common circle. If we add a third satellite, at a distance of 13,000 kilometers, we now have two common points where the three spheres intersect.

Even though there are two possible positions, they differ greatly in latitude/longitude position AND altitude. To determine which of the two common points your actual position is, you'll need to enter your approximate altitude into the GPS receiver. This will allow the receiver to calculate a two-dimensional position (latitude, longitude). However, by adding a fourth satellite, the receiver can determine your three-dimensional position (latitude, longitude, altitude). Let's say our distance from a fourth satellite is 10,000 miles. We now have a fourth sphere intersecting the first three spheres at one common point.

The unit stores data about where the satellites are located at any given time. This data is called the ***almanac***. Sometimes when the GPS unit is not turned on for a length of time, the almanac can get outdated or "cold". When the GPS receiver is "cold", it could take longer to acquire satellites. A receiver is considered "warm" when the data has been collected from the satellites within the last four to six hours. When you're looking for a GPS unit to buy, you may see "cold" and "warm" acquisition time specifications. If the time it takes the GPS unit to lock on to the signals and calculate a position is important to you, be sure to check the acquisition times. Once the GPS has locked onto enough satellites to calculate a position, you are ready to begin navigating! Most units will display a position page or a page showing your position on a map (map screen) that will assist you in your navigation.

T.2.4. GPS Receiver Technology

Most modern GPS receivers are a parallel multi-channel design. Older single-channel designs were once popular, but were limited in their ability to continuously receive signals in the toughest environments – such as under heavy tree cover. Parallel receivers typically have from between five and 12 receiver circuits, each devoted to one particular satellite signal, so strong locks can be maintained on all the satellites at all times. Parallel – channel receivers are quick to lock onto satellites when first turned on and they are unequaled in their ability to receive the satellite signals even in difficult conditions such as dense foliage or urban settings with tall buildings.

Civilian GPS receivers have potential position errors due to the result of the accumulated errors due primarily to some of the following sources:

- Ionosphere and troposphere delays – The satellite signal slows as it passes through the atmosphere. The system uses a built-in “model” that calculates an average, but not an exact, amount of delay.
- Signal multi-path – Occurs when the GPS signal is reflected off objects such as tall buildings or large rock surfaces before it reaches the receiver. This increases the travel time of the signal, thereby causing errors.
- Receiver clock errors – Since it is not practical to have an atomic clock in your GPS receiver, the built-in clock can have very slight timing errors.
- Orbital errors – Also known as “ephemeris errors”, these are inaccuracies of the satellite’s reported location.
- Number of satellites visible – The more satellites the receiver can “see”, the better the accuracy. Buildings, terrain, electronic interference, or sometimes even dense foliage can block signal reception, causing position errors or possibly no position reading at all. The clearer the view, the better the reception. GPS units will not work indoors (typically), underwater, or underground
- Satellite geometry/shading – This refers to the relative position of the satellites at any given time. Ideal satellite geometry exists when the satellites are located at wide angles relative to each other. Poor geometry results when the satellites are located in a line or in a tight grouping
- Intentional degradation of the satellite signal – The U.S. military’s intentional degradation of the signal is known as “Selective Availability” (SA) and is intended to prevent military adversaries from using the highly accurate GPS signals. SA accounts for the majority of the error in the range. SA was turned off May 2, 2000, and is currently not active. This means you can expect typical GPS accuracies in the range of 6-12 meters (about 20-40 feet). However, accuracy can be improved by combining the GPS receiver with a Differential GPS (or DGPS) receiver, which can operate from several possible sources to help reduce some of the sources of errors described above.

T.2.5. Differential GPS

Differential GPS works by placing a GPS receiver (called a reference station) at a known location. Since the reference station knows its exact location, it can determine the errors in the satellite signals. It does this by measuring the ranges to each satellite using the signals received and comparing these measured ranges to the actual ranges calculated from its known position. The difference between the measured and calculated range for each satellite in view becomes a "differential correction". The differential corrections for each tracked satellite are formatted into a correction message and transmitted to DGPS receivers. These differential corrections are then applied to the GPS receiver's calculations, removing many of the common errors and improving accuracy. The level of accuracy obtained is a function of the GPS receiver and the similarity of its "environment" to that of the reference station, especially its proximity to the station. The reference station receiver determines the error components and provides corrections to the GPS receiver in real time. Corrections can be transmitted over FM radio frequencies, by satellite, or by beacon transmitters maintained by the U.S. Coast Guard. Typical DGPS accuracy is 1-5 meters (about 3-16 feet).[1]

T.3. Tabular Information

Information commonly stored, or manipulated, using a GIS usually has two main components – the spatial and the descriptive attributes. These two data types may appear to be a seamless unit for many users and within many software products. However, there are some data management issues which are peculiar to whether you are working with spatial or attribute data, and certain general issues which are common to either form of information.

Attributes are data that describe the properties of a point, line, or polygon record in a GIS. For example, imagine a GIS coverage in which points represent sites on a landscape. The attribute data that accompanied this coverage would record more detailed information about each site. Attribute information might include an indication of the time period in which the site was covered with forest; full descriptions of land cover types etc. Provided there is an existing dataset with geographic features, attribute data can be joined after the process of spatial data capturing, making use of one common item. Typically, a table of data attributes will be joined to a layer based on the value of a field that can be found in both attribute tables. Generally, the name of the field does not have to be the same, but the data type has to be the same; numbers are joined to numbers, strings to strings, and so on. In terms of data acquisition and integration into a GIS environment, the possibility to join tabular data to spatial data opens up interesting possibilities. For example a water supply authority of a particular municipality can keep a database on water users, including their water subscription number, the number of the plot on which the water meter is located, and other useful data in a conventional spreadsheet database (e.g. Microsoft Excel), if the personnel in charge is more acquainted to that format and later join that information to a GIS using, for example, the plot number as a join-item. This link can then be used to localise areas with numerous payment arrears and therewith to enhance the efficiency of revenue collection.

Sometimes tabular information is provided with locational information, i.e. with a column indicating a spatial feature's X coordinate (longitude), another column showing its Y coordinate (latitude) and possibly a third column storing its Z coordinate (elevation). Such information can be

1 Section T.2 on GPS takes over large shares of the "GARMIN GPS Guide for Beginners" (GARMIN, 2000), which can be downloaded from GARMIN's hopmepage (http://www.garmin.com/support/userManual.jsp).

imported into a GIS in a quite straightforward manner, simply by informing the software about which column contains which type of coordinate.

For more details on working with tables and on other data basics see Section T.2 of Module 1.

T.4. Other data sources

Apart from digitizing, scanning, vectorizing, GPS measurements and the import of tabular data, which are all data acquisition techniques that have been described in the sections T.1 to T.3, some GIS data can be accessed through other means. Various spatial data sources exist, though sometimes only commercially. The price of a spatial dataset, or the possibility of accessing this data set for free (and legally!) mainly depends on the nature, scale, and date of production of the dataset.

Topographic base data is easier to obtain than elevation data, which is in turn easier to get than natural resource or census data. Of course obtaining large-scale and more precise data is more problematic than small-scale, highly aggregated, or re-sampled data, while recent data is more difficult to obtain than older data. Some of this data is only available at a price.

Often national mapping organizations are the most important spatial data providers, though their role in many parts of the world is changing. Many governments seem to be less willing to maintain large mapping institutes, and are looking for alternatives to the nation's spatial data production. Private companies are probably going to enter this field, and for the GIS data customers this means they no longer have a single provider. Statistical and thematic data always was the domain of national census or statistics bureaus, but they too are affected by changing policies. Various commercial research institutes also are starting to function as provider for this type of information.

T.4.1. Clearinghouses and online data sources

Digital data provision is an expertise by itself, many of the above – mentioned organizations provide their data via centralized places, often creating online marketplaces where potential data users can buy them. They are sometimes called spatial data clearinghouses. An important added value that they provide is metadata: searchable descriptions of the data sets that are available.

T.5. Data editing

Editing includes all manipulations altering the geometry of a spatial data set, i.e. adding shapes (e.g. adding a newly built road to an older road dataset), deleting shapes (e.g. removing a mine field from a mine field coverage after that particular area was cleared from unexploded ordinance) and reshaping shapes (e.g. refining a river coverage after more precise base data like aerial photographs, or high resolution satellite data became available). Furthermore, attribute modification, i.e. data manipulation in the attribute tables of a layer, is also part of the editing possibilities of a GIS.

The most common task when editing an existing spatial data set is to correct, refine and complete existing information on the basis of new indications or data. The completing and to some extent the refining tasks can be assimilated to digitizing tasks and have been described earlier in this chapter. The correcting of existing information mainly consists in reshaping lines and polygons and in moving features. Reshaping becomes necessary when the original digitising operation did not fulfil the precision standards required, or when the digitised features have changed in reality (e.g. increases of built-up areas, new train tracks, etc.).

The above described reshaping manipulations are conducted with vertex editing tools. Vertices are points along a line which divide this line into a number of straight line segments. On a straight line few vertices are required to draw the shape adequately. However in curves, smaller spacing between individual vertices is necessary in order to smoothly conduct the line (see figures below).

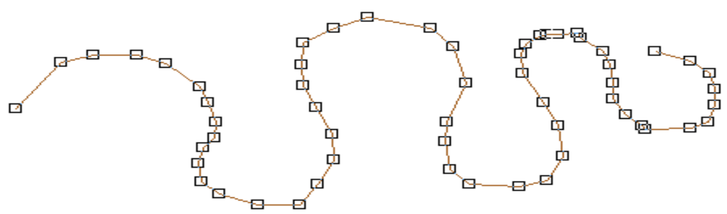


Figure T.6: *Distribution of vertices on a curvy line*

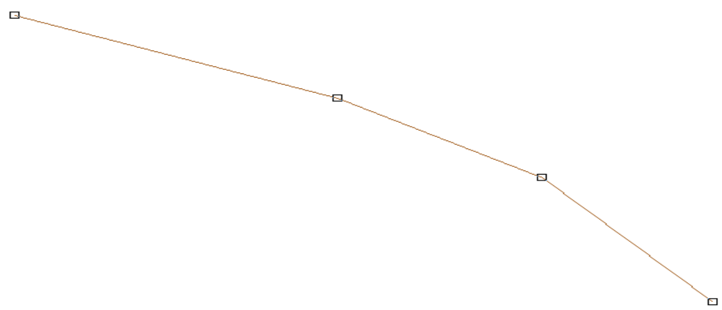


Figure T.6: *Distribution of vertices on straight lines*

The edit tools allow moving single vertices in order to reshape the line. In the example below, the second vertex from the left of the above line is moved downwards using a vertex editing tool. The line follows a new route.

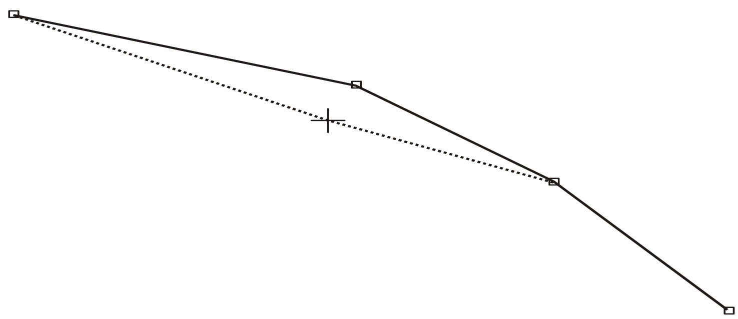


Figure T.7: Moving vertices with a vertex edit tool

T.5.1. Data correction and preparation

Spatial data preparation aims to make the acquired spatial data ready for use. Images may require enhancements and corrections of the classification scheme of the data. Vector data also may require editing, such as the trimming of overshoots of lines at intersections, deleting duplicate lines, closing gaps in lines, and generating polygons. Data may need to be converted to either vector format or raster format to match other data sets. Additionally, the process includes associating attribute data with the spatial data through either manual input or reading digital attribute files into the GIS.

The intended use of the acquired spatial data, furthermore, may require thinning the data set and retaining only the features needed. The reason may be that not all features are relevant for subsequent analysis or subsequent map production. In these cases, data and/or cartographic generalization must be performed to restrict the original data set.

Often acquired data sets must be checked for consistency and completeness. This requirement applies to the geometric and topological quality as well as the semantic quality of the data.

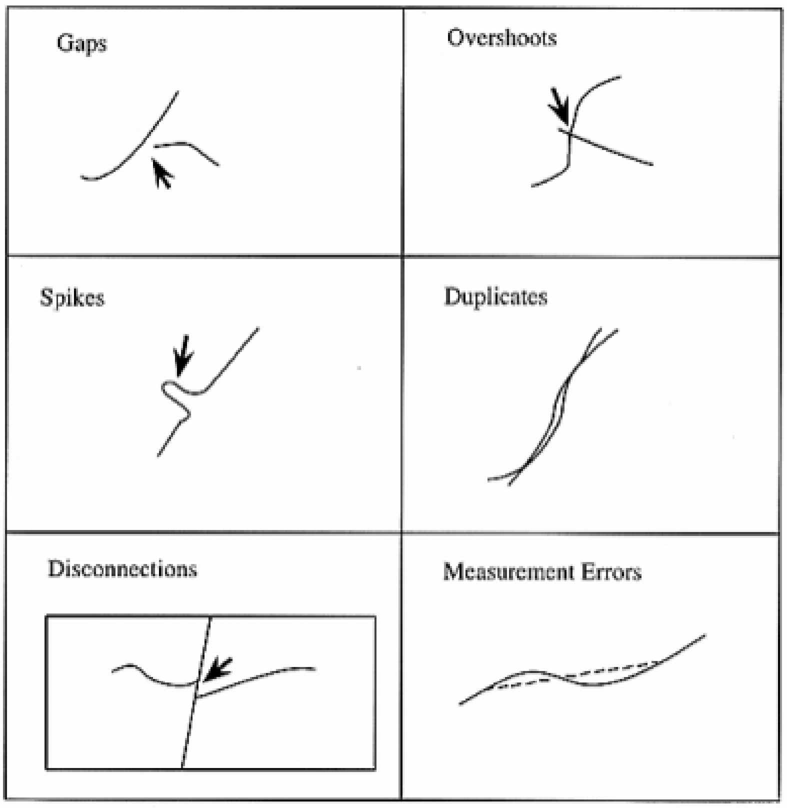


Figure T.8: Typical errors that can appear on vector data sets.

There are different approaches to clean up data. Errors can be identified automatically, after which manual editing methods can be applied to correct the errors. Alternatively, a system may identify and automatically correct many errors. Clean-up operations are often performed in a standard course. For example, crossing lines are split before dangling lines are erased, and nodes are created at intersections before polygons are generated. A number of typical errors are shown in Figure T.8.

T.5.2. Topology

From a historical perspective topology has been apprehended as a spatial data structure used to ensure that the associated datasets form a consistent topological structure. In some respect this view still holds true, but with advances in object-oriented GIS development an exiting alternative view of topology has emerged. Considered from feature behaviour perspective topology enables a more flexible set of geometric relationships to be modelled than the data structure perspective has done. From such alternative view, topology can still be applied to make sure the dataset form clean and consistent topological construct; but it is also used to ensure that the features obey the specific geometric rules settled for their role in any database structure.
When it comes to digitising and editing one of the main problems is the inability to create a real-world representing topology. It is important to note that ***shapefiles do not inherently have a topology*** (see box below) like Arc/Info coverages had one.

The lack of topology sometimes leads to ***unexact results***, especially when splitting an arc, or when snapping a new arc to an existing one. Furthermore, polygons are not “adjacent” in the normal sense. Two polygons within a shape file can actually overlap each other. And, if two polygons are side by side and appear to have a common arc they actually do not. Each polygon has it's own boundary which is not automatically “shared” with any other feature.

Albeit these shortcomings are inherent to the shapefile format ArcGIS offers some “on-the-fly topology” solution called map topology discussed in the next section.

T.5.3. Moving features

Sometimes the shapes of the various features of a spatial data set are precise enough, but the location of these features in space does not satisfy requirements. Such cases happen frequently when using data sets based on different referencing parameters, or originating from different projections. Projection and precise referencing of spatial data are complex issues. Furthermore, in various areas of the world, no, or not enough precise benchmarks with which such spatial data can be referenced have been defined. Because of these reasons, shifts from one data set to the other can often be observed, as it is the case in the example below. In this example from Eritrea, the river beds shown on the satellite image are shifted by approximately 180 meters to the north when compared to the vector lines representing the rivers. The shift is constant over the entire extent displayed.

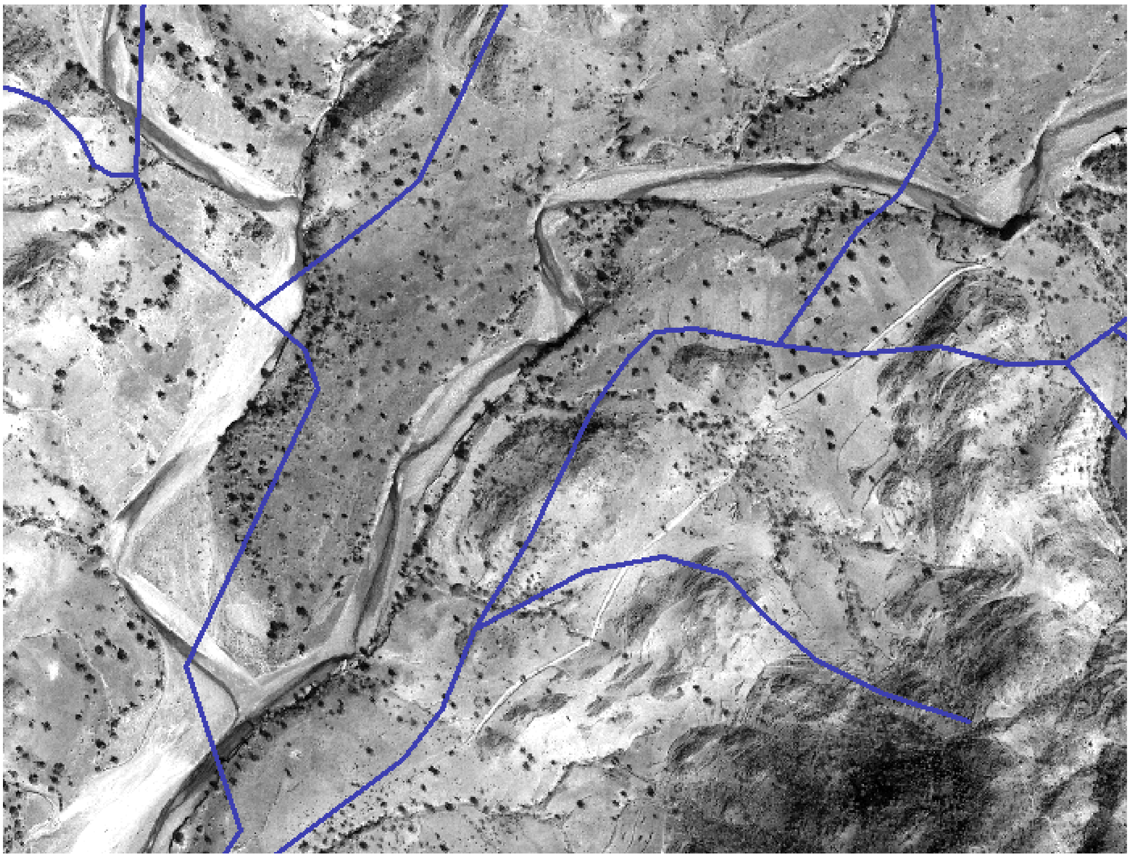


Figure T.9: *Shift between an Ikonos satellite image and corresponding linear features of a shapefile.*

In such cases, presenting a constant shift over the entire data set, one possibility to correct the incoherence is to move all the features of the concerned shapefile an approximate 180 meters to the north. If the georeference is incorrect, the satellite imagery can be shifted so that it matches the features of the shapefile. In the event of such manipulations it is very important to always keep a clear track of the shifts and warps undertaken on the various data sets. Furthermore, it is primordial to ***choose one and only one set of references*** which will then be considered to be "correct" and which will serve as a basis for the correction / adaptation of the other data sets.

In other cases, the shift might not be uniform and thus the differences between two or more data sets might rather be related to varying projection parameters. Sometimes, one or several parameters defining the exact projection of a spatial data set, as for example the datum, or the spheroid are not precisely defined, or the benchmarks used for the definition of these parameters are not accessible anymore because of a war, a conflict, or other reasons.

T.5.4. Flipping lines

Another editing manipulation which is used especially for the preparation for further manipulation of hydrologic features (rivers, streams, canals, etc.) and themes to be used in the frame of a network analysis is the line flipping operation. As it is shown in the figure below, a line always has a beginning node, and end node, vertices and a direction – vectors are oriented.

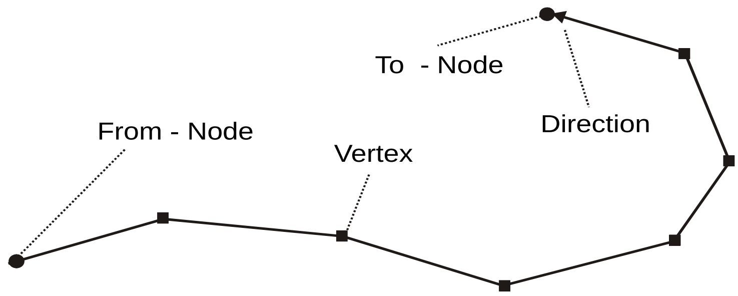


Figure T.10: *Anatomy of a vector*

Some calculations (some DTM algorithms, some steps in hydrologic modelling, some traffic modelling, or networking tasks, etc.) require a correct orientation of all the lines (rivers, or roads – when they are one-way roads) of the spatial data used for the calculation. The problems that can arise, when a DTM is calculated with an incorrect hydrologic entry are shown in Figure T.11 below. The algorithm interprets the rivers as being the lowest point of a valley and the direction of the vector indicates the direction of the slope. In the case below, calculated with an option which gives priority to the indications provided by the hydrologic dataset, the algorithm tries to make the river flow by all means through the valley, only in the wrong way!

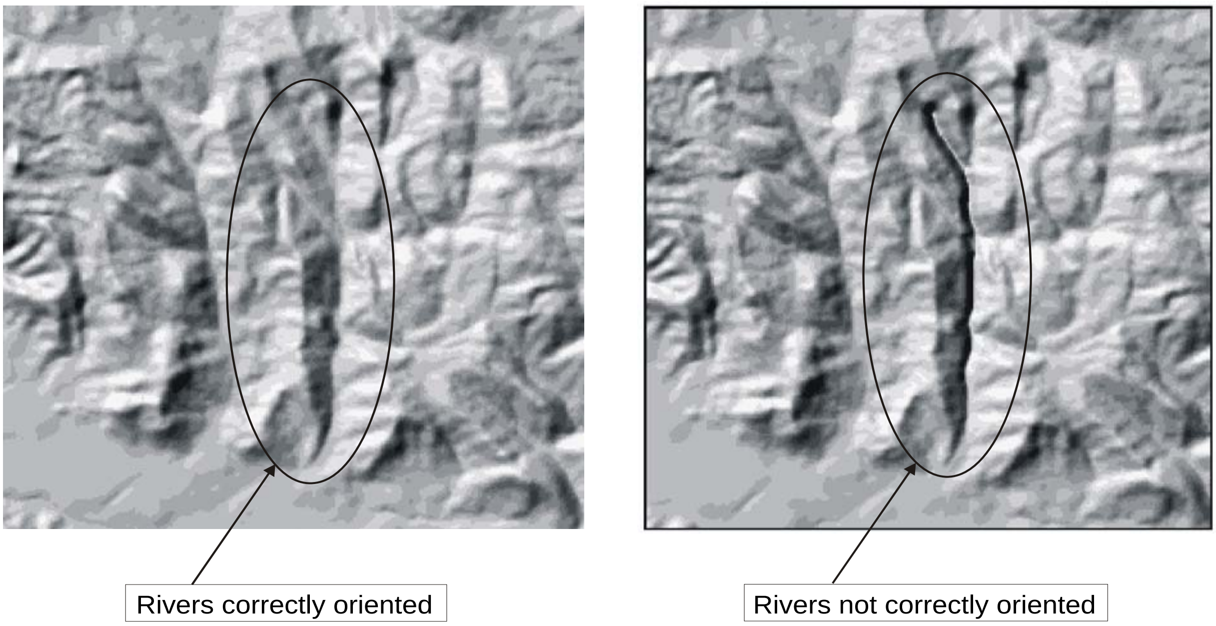


Figure T.11: *The effect of wrongly oriented river lines on the calculation of a DTM using the Topogrid Algorithm of ArcInfo.*

Sources:

– Longley P.A., Goodchild M.F., Maguire D.J., Rhind D.W. 2005. *Geographic Information Systems and Science*, 2nd Edition. New York: John Wiley

– Jones C.B. 1997. *Geographical Information Systems and Computer Cartography,* Prentice Hal

GIS Data Generation and Editing Applications

A.1. Data preparation in ArcMap

As discussed in the theory section, data input is a very crucial issue to any GIS project. The choice of the input method is mainly governed by the application, the budget available as well as the type and the complexity of the data being used. In most cases the user will have to decide whether to get the necessary data through manual digitizing, automatic scanning or the conversion of existing digital data. Within the scope of this section, emphasise will be given to technical and methodological aspects of data generation related to software packages such as ESRI's ArcGIS.

A.1.1. Capturing and editing features in ArcMap

Prior to editing a new feature layer (point, line or polygon shapefile) has to be generated. The procedure depends on whether the user wants to start from scratch or with parts existing datasets. Creating a new blank shapefile is done in ArcCatalog.

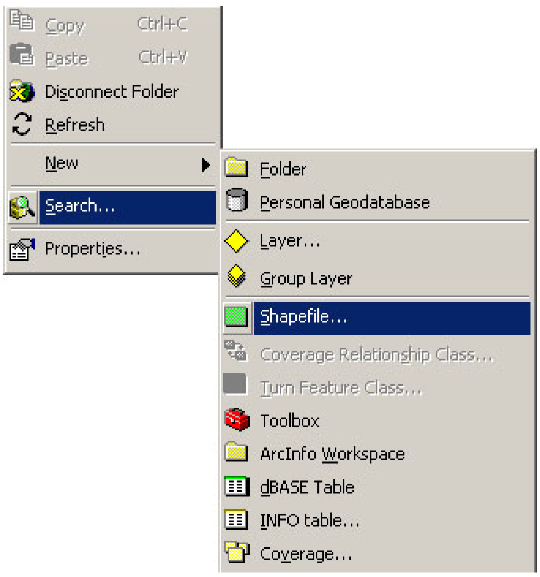


Figure A.1: *Creating a new shapefile from ArcCatalog*

Procedure 1:

After starting ArcCatalog, the user has to navigate to the appropriate directory, right click in the right panel and to choose "New" – "Shapefile". From the following dialog the user has to choose the feature (point, line, polygon) to be digitized as well as the name. The "Spatial Reference" can be left empty or filled in using another existing dataset as a master. As a next step, the newly created shapefile can be loaded into an ArcMap view and digitizing can start.

Procedure 2:

The user can select the features being copied to a new shapefile with the “Select Feature” tool. In the table of contents one has to right click the existing dataset and to choose “Data” – “Export Data”. From the resulting dialog one can choose “Selected features” or “All features”, leaving the coordinate system as it was in the input layer. Before confirming, the output file can be named.

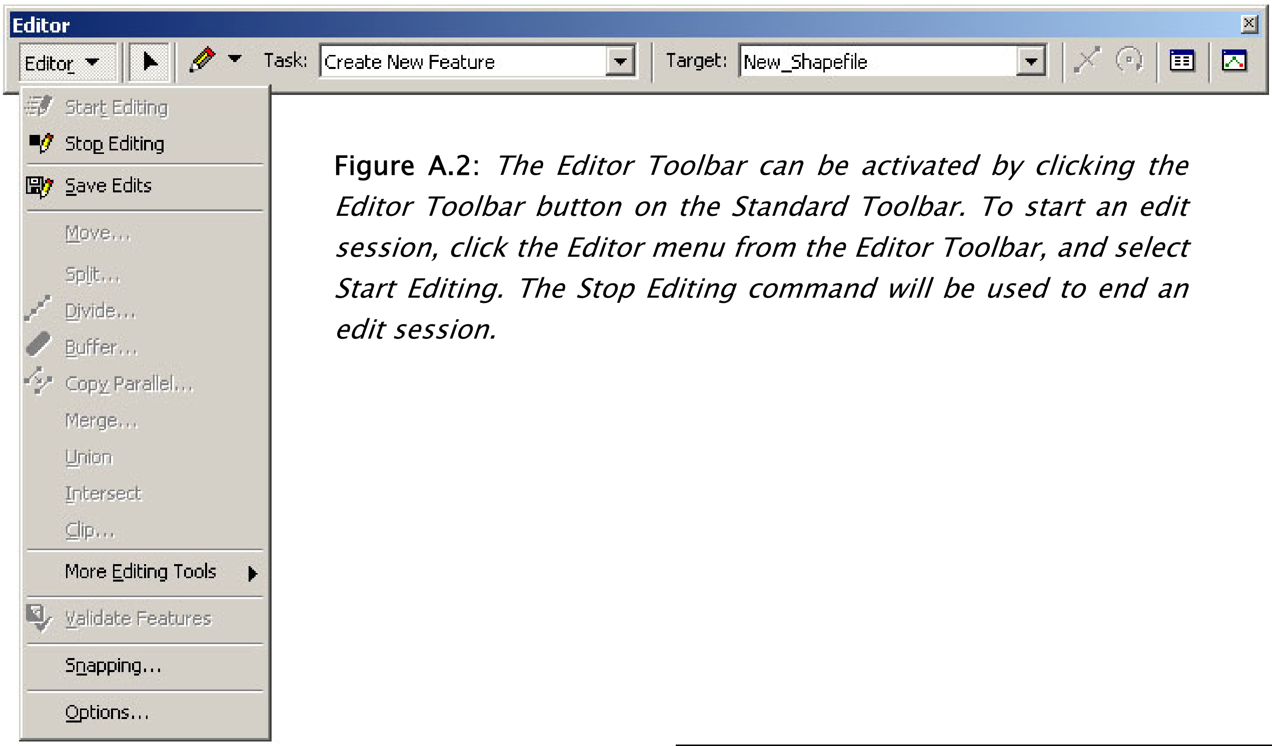


Figure A.2: *The Editor Toolbar can be activated by clicking the Editor Toolbar button on the Standard Toolbar. To start an edit session, click the Editor menu from the Editor Toolbar, and select Start Editing. The Stop Editing command will be used to end an edit session.*

Feature editing in ArcGIS begins with employing ArcMap. Using the Editor Toolbar, users are able to edit new or existing shapefiles, personal geodatabases or tabular data. With the “Editor Toolbar” several tasks can be carried out to edit features. The geometry of a feature can be manipulated in various ways (merged, reshaped, divided...). Editing in ArcMap begins by starting an ***edit session***, making changes to map features using sketches, adapting attributes, save the changes and finally end the edit session.

However, prior to start digitizing it is highly recommended to check what is called the ***editing environment*** and to make some adaptations to the settings. Without doing so, the user is running the risk of generating a “dirty” dataset afflicted with errors such as sliver polygons, over-

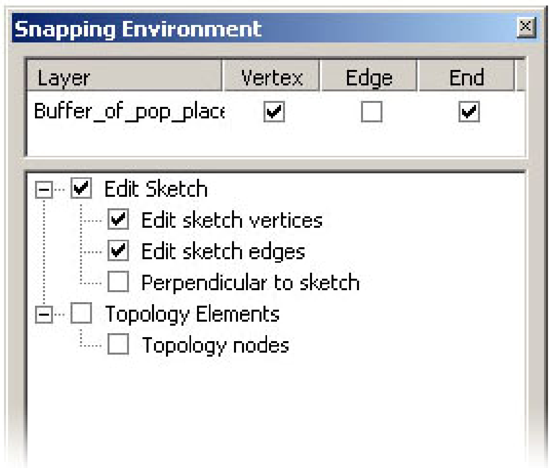


Figure A.3: *The Snapping Environment corresponds to settings in the ArcGIS Snapping Environment dialog and Editing Options dialog box (both from Editor’s menu) that define the conditions when snapping will take place. These settings include snapping tolerance, snapping properties, and snapping priority.*

laps and gaps. First of all, the ***snapping environment*** has to be set. This is done by selecting "Snapping" from the Editor menu.

The setting of the "Sticky move tolerance" within "Editing options" allows the user to set a minimum number of pixels the pointer must move on the screen before the selected feature is moved. This is a ***very useful*** way to avoid features from being accidentally moved only small distances when they are activated using the edit tool.

From these dialogs the snapping rules can be defined according to the respective needs; e.g. when digitizing a district boundary following a river the snapping layers will be the boundary layer as well as the river layer.

More detailed information about Snapping Environment is available from the ArcGIS online help or from page 104 "ArcGIS 9 – Editing in ArcMap".

Very often the user has to digitize features The problem of missing ***topological structures*** when editing shapefiles is addressed in ArcMap with the topological editing tools enabling the user to build temporary ***map topology.*** It is a temporary simple topology that can be imposed upon simple features during an edit session. Map topology enables to simultaneously edit simple features that overlap or touch each other. With the use of the Topology Edit tool from the Topology toolbar and the Modify Edge and Reshape Edge edit tasks the features in a map topology can be edited. The features can have different geometries and may represent one or more feature classes such as polygons and lines. Outlines of polygons and Line features become topological edges as soon as map topology is being created. The endpoints of lines, point features and edge intersections become nodes.

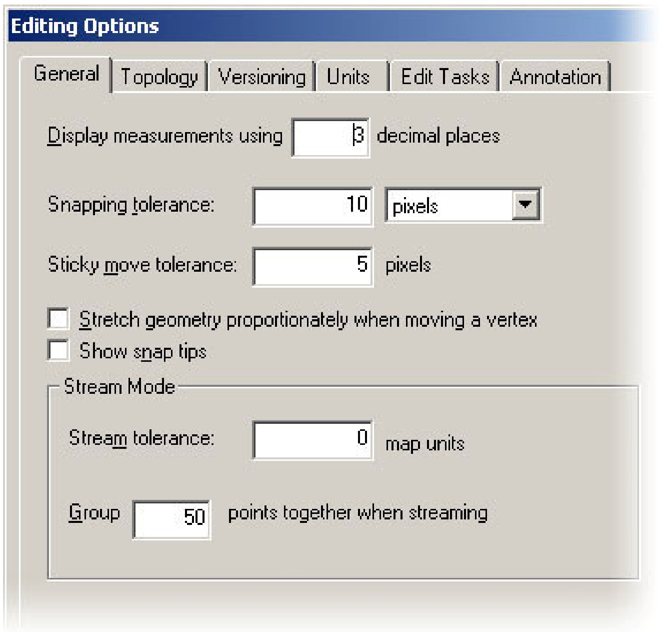


Figure A.4: *The Snapping Distance setting will control which points will have to collapse.*

Figure A.5: *The Topology toolbar has to be added from the View menu – Toolbars*

After starting an edit session when clicking the Map topology button, the associating layers can be selected. The cluster tolerance can be changed as well, however the default value will do for most cases. In a next step using the Topology Edit tool the area to be edited can be selected and turns magenta. Now using the Modify and Reshape Edge task tools any necessary editing steps can be executed – in a topologically correct manner.

In order to show unselected nodes which are located at the intersection of line segments or arcs, check “Unselected Nodes” from Editor menu – Options – Topology Tab.
More detailed information about Topology is available from the ArcGIS online help or from page 142 in “ArcGIS 9 – Editing in ArcMap”.

A.1.2. Editing in ArcMap

Once the setup is done, the user can start the main task. ArcMap offers an incredible number of different options and tools for digitizing – some of them are only useful for very specific tasks. In the context of this module only the most important options will be discussed.

Start editing

- Select “Start Editing” from the Editor Toolbar
- Define selectable layers from the Selection tab in the Table of Contents
- Its is advisable only to turn on the layers one really needs to edit, this will prevent a mess with selected features
- !!! Edits are not saved until the user selects “Save Edits” or “Stop Editing” from the Editor Toolbar!!!

Modify Edge (node-2-node editing)

- Set edit task to “Modify Edge” on the Editor Toolbar
- Click the line to be edited using the “Topology Edit” tool from the Topology Toolbar
- The line will turn magenta when selected and vertexes will appear as green points

Moving a single vertex

- Remain with cursor (Edit Tool) over the vertex, cursor symbol will change from arrow to diamond shape, left click mouse and drag the vertex to desired location
- Keep in mind – the new vertex position is just a sketch necessary to fulfil the task
- To make permanent, either double left click or press F2 button on the keyboard

Deleting a vertex

- Remain with cursor over the vertex to be deleted, the cursor symbol will change from an arrow to a diamond shape, right click mouse, select “Delete Vertex”
- Keep in mind – the new vertex position is just a sketch necessary to fulfil the task
- To make permanent, either double left click or press F2 button on the keyboard

Inserting a vertex

- Remain with cursor over the line where you want to insert the vertex, the cursor symbol will change from an arrow to a cross, right click mouse, select “Insert Vertex”
- Keep in mind – the new vertex position is just a sketch necessary to fulfil the task
- To make permanent, either double left click or press F2 button on the keyboard

Moving all vertices on a line simultaneously

- Choose “Editor” menu, “Options”, “General Tab”, turn on “Stretch geometry proportionately when moving a vertex”
- Remain with cursor over a vertex, left click mouse, move all vertices to the desired location
- Keep in mind – the new vertex position is just a sketch necessary to fulfil the task
- To make permanent, either double left click or press F2 button on the keyboard

To sketch in stream mode

- Adapt stream tolerance under “Editor” menu, “Options”, “General tab”, “Stream tolerance” → try 30 map units (meters)
- Select the “Sketch Tool”
- Press F8 to turn on stream mode
- Click left with mouse to start sketch
- Drag mouse to sketch new line
- Keep in mind – the new vertex position is just a sketch necessary to fulfil the task
- To make permanent, either double left click or press F2 button on the keyboard
- Make sure to press F8 again in order to turn off stream mode

Cut Polygon Features / Merge

- From the Editor Toolbar select edit task “Cut Polygon Features”
- Select polygons to be cut with the “Select Features” tool
- The selected polygons are outlined in cyan
- Select the “sketch Tool”
- Draw the cut line with the Sketch Tool” crossing polygon lines at the beginning and end of the sketch
- Left double click to finish the sketch
- Multi-part polygons may be resulting, depending on how the cut was done
- While all of the polygons involved in the cut are still selected, select the Explode button from the “Advanced Editing Toolbar” to bring them back to a single part polygons
- After the cut it may be necessary to merge polygons together
- Select polygons to merge with the “Select Features” tool
- Choose the “Merge” command from the “Editor” menu, highlight the polygon number to maintain after the merge and confirm

Flipping lines (change direction)

- Any vector file has a direction – normally assigned during digitizing
- To change the direction, from the “Editor Toolbar”, choose “Modify feature” task
- With the “Edit Tool”, select the line whose direction has to be changed
- Right click and choose “Flip” command from the context menu

The many other options available for data editing in ArcMap can be explored using ArcGIS online help “Editing and data compilation” or from page 14ff in “ArcGIS 9 – Editing in ArcMap”.

A.1.3. Spatial Adjustment

As a matter of fact GIS users are very often confronted with any kind of vector data without any spatial reference. Supposed this data is needed for analysis purposes, there is now way to avoid imposing spatial reference to it.
This is only possible if there is one dataset having a defined coordinate system. Any assignment of proper coordinates to an existing vector dataset requires spatial adjustment. The method applied is also used to correct geometric distortions in datasets. Using ArcMap this is done using the functionality of the Spatial Adjustment toolbar.

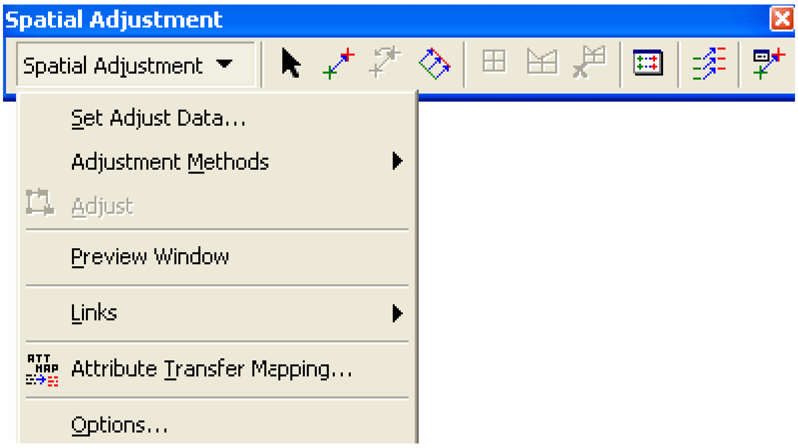


Figure A.6: *ArcMap's Spatial Adjustment toolbar loaded from the View menu – Toolbars*

Adjustments using the Spatial Adjustment toolbar

- Add the control layer to ArcMap. The control layer is the dataset with the known coordinates
- Add the dataset to be adjusted to ArcMap
- Activate the "Editor Toolbar" by choosing "View" – "Toolbars" – "Editor". Start an edit session
- Activate the "Spatial Adjustment toolbar" by choosing "View" – "Toolbars" – "Editor" – "Spatial Adjustment"
- Ensure the projection of the data frame is the same as the control layer. Right-click "Layers" – "Properties" – "Coordinate System" and select the appropriate projection information
- Click the "New Displacement Link" button in order to start adding links between the two datasets
- Zoom in to the dataset to be referenced and select a location by clicking left. Zoom in to the control layer and select the same location. This will create a first link between the two datasets Hint: Use the magnification tool Window – Magnifier in order to achieve a more accurate link
- Repeat the collection of links until enough have been created (the necessary number of links will depend on the size and type of features present in the dataset)
- Take notice of the Root Mean Square error in the Spatial Adjustment – Links – View Link

Table dialogue, providing an estimation of accuracy. Typically an RMS error of less than or equal to half the pixel size of the control layer is acceptable, however, this indication is somewhat subjective.

- Once all the links have been created and the RMS error is at an acceptable level, the adjustment can be started. Choose Spatial Adjustment – Set Adjust Data and specify the dataset to be referenced
- Click on Adjustment Methods and select the method that best fits the type of transformation required. Typically, the Affine transformation is most often used and will handle shifting, scaling, skewing, and rotations
- Choose “Set Adjust Data” from Spatial Adjustment to start the transformation
- If the adjustment is not satisfactory you will have to collect more or other links, otherwise click Editor – Save Edits followed by Editor – Stop Editing. The formerly unreferenced dataset will now have the coordinates as the reference dataset
- A final step would be to export this data using the projection of the data frame. Right click on the newly transformed dataset and select Data – Export Data. Ensure that the Export field is set to All features and the Output path and filename are defined correctly
- Click OK and the data will be saved using the proper projection and coordinates

The degree to which the transformation can accurately map all control points can be measured mathematically by comparing the actual location of the map coordinate to the transformed position in the dataset. The distance between these two points is known as the residual error. The total error is computed by taking the root mean square (RMS) sum of all the residuals to compute the RMS error. This value describes how consistent the transformation is between the different control points (links). Links can be removed if the error is particularly large, and more points can be added. While the RMS error is a good assessment of the accuracy of the transformation, don’t confuse a low RMS error with an accurate registration. For example, the transformation may still contain significant errors due to a poorly entered control point.

Adapted from ArcGIS online Help

More detailed information about spatial adjustment is available from the ArcGIS online help or from page 245 in “ArcGIS 9 – Editing in ArcMap”.

A.1.4. Adding Tabular Data

ArcMap provides not only access to GIS files such as shapefiles, the user can also add tabular data containing geographic locations stored as simple X,Y coordinates.
The only crucial point is the table has to contain two fields holding the x- and y- coordinates. However, only numeric fields are supported, otherwise they will not be available for selection. Therefore coordinate values stored in degrees, minutes, and seconds in a field will not be listed. The conversion from degrees, minutes, and seconds to decimal degrees is mandatory. Fortunately, in order to add a table of X, Y coordinates to a map, the values in the fields may represent projected and unprojected coordinate system and units such as latitude and longitude or kilometers. The layer behaves almost like normal point feature layers once the tabular data is added to the map. However, the table on which this layer is defined has some limitations. Since the table does not have an ObjectID, such as tables from OLE DB connections or delimited text files, it is impossible to make selections. In terms of editing interactively moving points on the map is not possible, since the location depends only on the coordinates in the table.

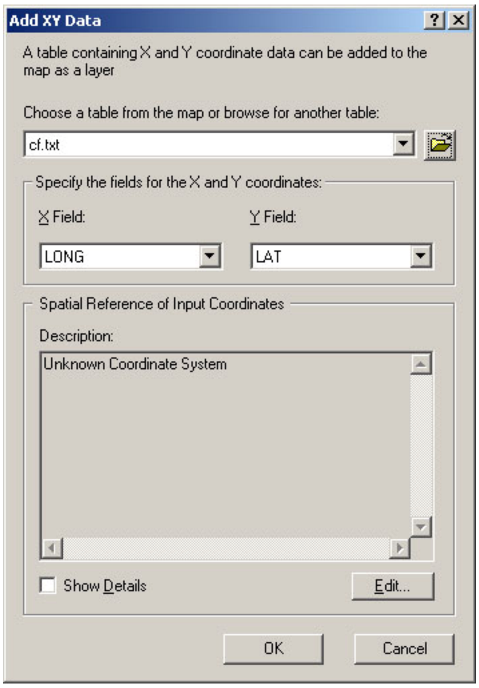


Figure A.7: *ArcMap's Add X,Y Data dialogue*

Step-by-step procedure for adding X,Y Data

- Click "Add XY Data" from the "Tools" menu
- Press the table dropdown button and choose the file containing x,y coordinate data
- Click the X Field dropdown button and choose the field that contains the x-coordinates
- Click the Y Field dropdown button and choose the field that contains the y-coordinates
- Press the Edit button on the bottom of the dialog to define the coordinate system and units represented in the x and y fields
- In order to match the coordinate system of the data frame, the x,y coordinates will automatically be transformed
- Confirm by clicking OK

A.1.5. Getting GPS Data into ArcGIS

With the availability of fairly accurate GPS signals satellite based positioning systems have become a very important data source for Geographic Information Systems. Therefore, GIS software packages such as ArcGIS provide well defined interfaces for GPS data input. However, in some

cases it might be beneficial to use open source 3d party software in order to download and safe data collected by GPS.
DNR Garmin developed and provided by the Minnesota Department of Natural Resources is a quite nice tool for interacting with a GPS receiver. The tool is available from
http://www.dnr.state.mn.us/mis/gis/tools/arcview/extensions/DNRGarmin/DNRGarmin.html

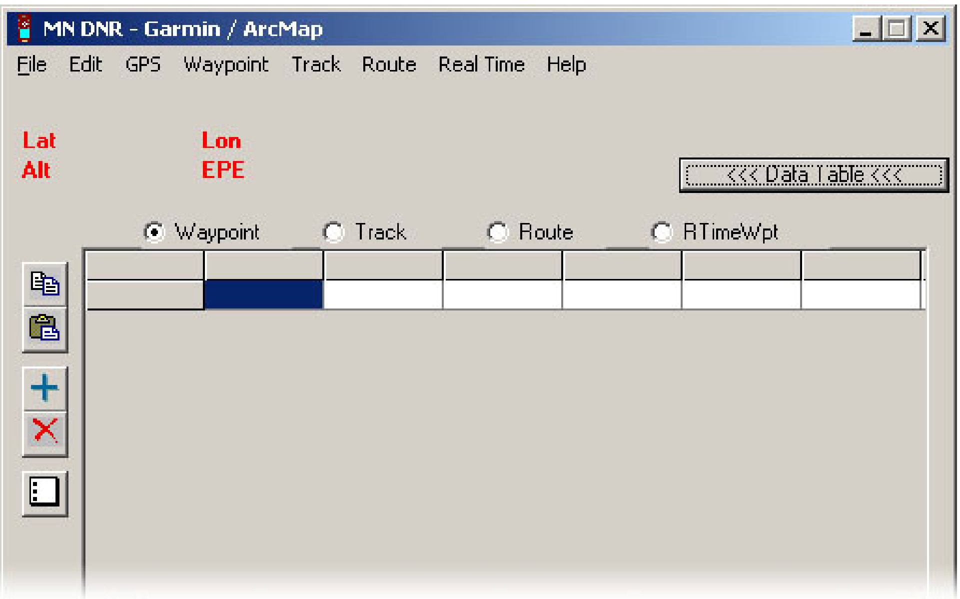


Figure A.8: *The clearly arranged DNR Garmin user interface*

The data exchange between the PC based software tool and the GPS receiver is very simple and runs smoothly once the user has specified the necessary settings from the menu "GPS" – "Set Port" and "Set Baud Rate". There might be some experimentation necessary with these settings, depending on the type of GPS receiver. Once this is done, waypoints, tracks and routes can be downloaded and will display in the main panel of DNR Garmin. In a next step the data can be saved from menu "File" – "Save To" directly to a shapefile or to a text file. Using the first option, the GPS data can directly be loaded into ArcMap.
Natively GPS receivers handle all coordinates as latitude / longitude readings based on the WGS84 datum and spheroid. Albeit GPS have some limited reprojection capabilities built in, it is wise to reproject the data only with well defined reprojection parameters as they are implemented in ArcGIS.

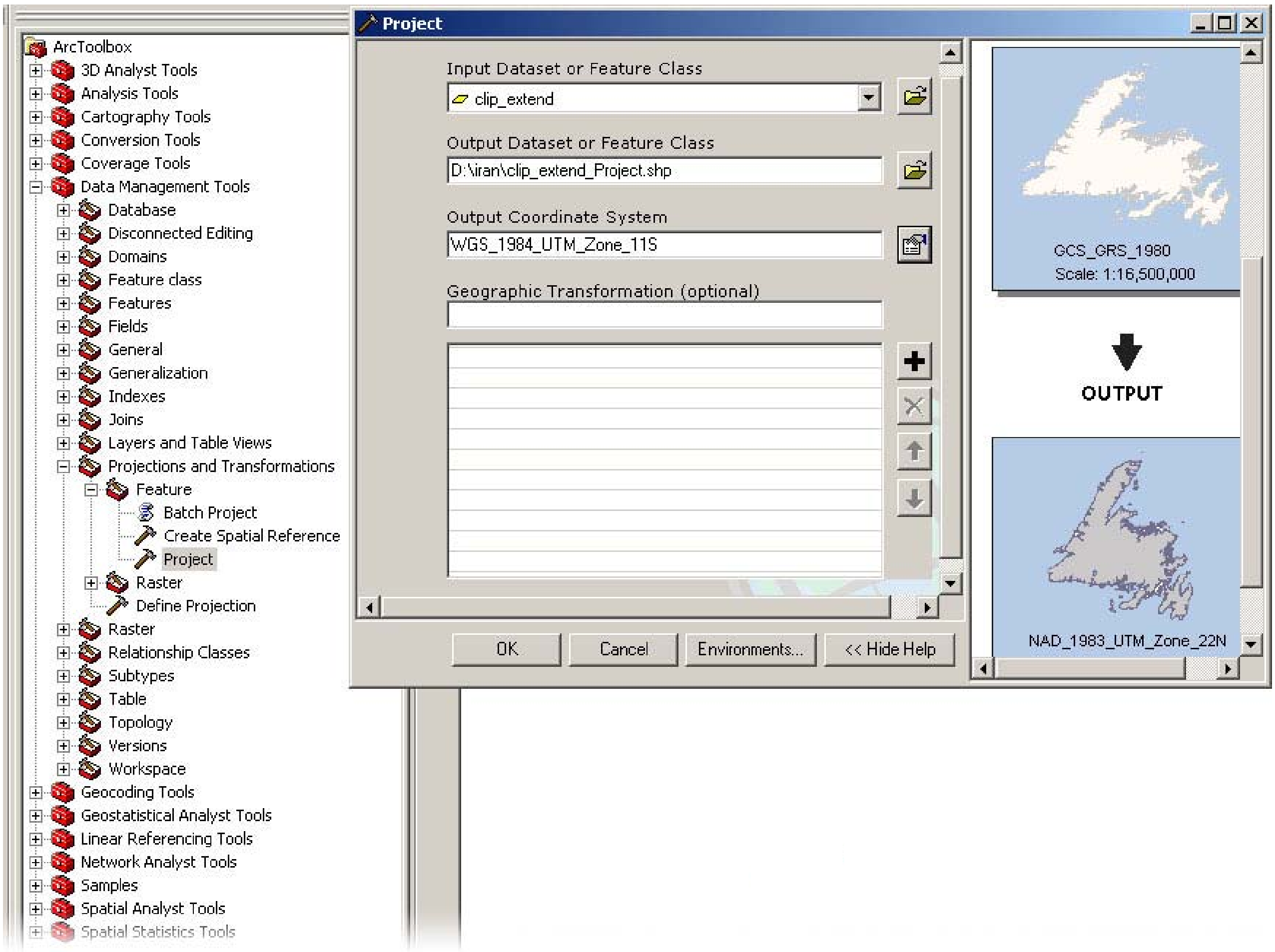


Figure A.9: *The user-friendly reprojection tool from ESRI's ArcToolbox*

The reprojection tool can be accessed from the "ArcToolbox" – "Data Management Tools" – "Projections and Transformations" – "Feature" – "Project". The parameters to be defined are input and output file and the Output Coordinate System which can be selected either by copying from another dataset or by defining it through selection from a list.

DNR Garmin provides also support for real time applications as well as upload capabilities (PC to GPS). Users who prefer to work in one software environment can make use of ArcMap "GPS Toolbar" offering similar functionality.

Sources:

– Longley P.A., Goodchild M.F., Maguire D.J., Rhind D.W. 2005. *Geographic Information Systems and Science*, 2nd Edition. New York: John Wiley

– Jones C.B. 1997. *Geographical Information Systems and Computer Cartography,* Prentice Hal

– ESRI ArcGIS 9.1 2006 *Online Help*

GIS Data Generation and Editing Exercises

E.1. Exercises

E.3.1. Digitising on screen

Steps	Data	Remarks	Time
Digitising River Njoro	kenk_qb120.tif kenk_njoro.shp	- Njoro River can be distinguished on the Quickbird satellite image (resampled to 1,2 m pixel size) - Create a new line shapefile in ArcCatalog, name it kenk_njoro.shp; set its projection to UTM, its spheroid & datum to WGS84 and its zone to 37S. - Make sure the editing tool is present in the tool bar, otherwise load it by right-clicking on the tool bar and selecting it from the list that appears. - Load the image and the newly created shapefile - Digitise Njoro river - Save the edits, add a “Name” field in the theme’s table and label the field accordingly - Name the theme correctly and save it in the correct folder (create a folder if none exists)	35 min
Digitising roads of block 12	kenk_qb120.tif kenkblk1.shp	- The town is divided into town-planning blocks. Load and display the layer to located block 12 - Create a new line shapefile in ArcCatalog, name it kenkrds12.shp, give it the same projection as above and digitise the roads in block 12, including those running along its borders and pay attention to have correctly networked roads (snap). - Save the edits, name the new theme correctly and save it in the correct folder.	40 min
Digitising plantation forest blocks on Menengai	kenk_qb120.tif kenkfor1.shp	- Various blocks of Eucalyptus plantations can be identified on Menengai. The blocks are usually separated by roads or paths. - Create a new polygon shapefile in ArcCatalog, name it kenkfor1.shp and give it the same projection as above. - Digitize the forest plantation blocks - Use the auto-complete, or the cut-polygon tool to digitize polygons adjacent to others and make sure that the logic of the geometry is intact - Save the edits	45 min
		Total time:	120 min

E.3.2. Calculating polygon areas

Calculating the areas of the digitized polygons	Kenkfor1.shp	- Open the attribute table; add a field (type "double", there is no need to change the "field properties") and call it "Area". Select the field and right-click on its header. Select "Calculate Values". Tick the "Advanced" button and enter the following VBA statement **Dim Output as double** **Dim pArea as Iarea** **Set pArea = [shape]** **Output = pArea.area** - In the text box directly underneath type **Output** - Check the values returned. What units are they in? Try to calculate the area in hectares – either by adapt the above VBA statement or by calculating the values in a new field based on the previous calculated area.	45 min
Calculating the x – and y – coordinates of the digitized polygons	Kenkfor1.shp	- Apply the same procedure as above. Add a new field (type "double"). For the X-coordinate, replace the expression: **pArea.area** from above by: **pArea.Centroid.X** - Try to find the expression for calculating the y-coordinate (Hint: it's a matter of one letter…) - If you can't figure out, check the help from the field calculator interface.	30 min

E.3.3. Scanning and Vectorizing in ArcScan

Steps	Data	Remarks	Time
Scanning a paper copy	Paper copy of sub-catchment boundaries of Ewaso Ngiro Basin	- The participants will scan the paper copy in groups. Alternatively, the scanning process is demonstrated. Particular attention is paid to correct resolution and colour format. - Name the scanned image keewcat.tif and save it in an adequate folder	30 min
Geo-reference scanned image	Keewcat.tif	- Load the scanned image into ArcMap. Make sure the Map Units are set to meters and the coordinate system of the data frame is set to UTM, Arc 1960, Zone 37 South - Load the Georeferencing Tool and enter the four control points provided on the scanned image with the “add control points” tool (first left-click and then right-click on the point to enter the coordinates). - Once the four points have been entered, open the control points table and check on the RMS error. What can you conclude? If the RMS error is too big, remove the worst points and re-enter them - Save the reference and save the image file as keewcat_ref.tif	30 min
Tracing the image with ArcScan	Scanned image	- Prepare the scanned image for automated tracing in ArcScan: Reclass the image in order to have only 2 values (1 and 0). Run the vectorizing tool. - Save the vector data as a shapefile and name it keewcat1.shp. - Observe the result. What can you see? How is the vector data’s quality? Is there need for post-editing?	30 min
Preparing a coloured image for vectorization		- Demonstration of the vectorizing of complex images (coloured images), through interactive reclassification using various customized tools. The output of this part of the exercise will be saved as top_vect1.shp and saved in student\shp. This output will be used again in Exercise 3.5 on vector data editing.	30 min
		Total time:	120 min

E.3.4. Creating a new point feature class with coordinate points

Steps	Data	Remarks	Time
Reformating table as a DBase file	Kenkbor1_ coord_geo.xls	- The co-ordinates of 38 boreholes are stored in an Excel table in the Nakuru database structure. This table needs to be saved as a DBF table (DBase format) in order to be imported into ArcGIS (Alternatively you can also set up an ODBC connection for this Excel sheet and thus directly work on the Excel file). - Store the DBF table in student\tables with the same name.	30 min
Adding tabular data as event theme	Kenkbor1_ coord_geo.dbf	- Open the DBF table in ArcGIS. In case the file cannot be opened, open the DBF table in Excel again and make sure there are no column headers without data. - Go to Add X/Y Data on the Tools menu to create a new layer based on the tabular information of the DBF file. Pay attention to select the correct columns for the X and Y co-ordinate information - In the layer context menu go to Data - Export Data to save the layer as shapefile in student\shp. Name the layer kenkbor1_geo.shp	30 min
Project the theme into UTM-37	Kenkbor1_geo.shp	- Open the Arc Toolbox - Project the point theme from its current geographic coordinate system to a UTM projection with WGS84 spheroid and datum and zone 37 south. - Control the position of the boreholes by use of the satellite image. - Save the projected shapefile in the student\shp folder and name it kenkbor1_utm.shp	30 min.
Total time			90 min.

E.3.5. Joining tabular information

Steps	Data	Remarks	Time
Preparing the tabular data	Kenkbor1_ attributes.dbf	- Open the DBF table in Excel and control the entries and the correct disposition of the data in the table. Also control that none of the field headers exceeds 8 characters in length - Save the table as a DBF file again. While doing so, make sure that you have either selected none or all of the fields that need to be included in the final DBF document.	10 min.
Opening the DBF in ArcView	DBF table created in step 1 and output from exercise 3.3	- Open the DBF table in ArcGIS - Open the attribute table of the borehole shapefile (output from exercise 3.4) - Compare both tables and check if a join could be carried out (there needs to be a common item)	10 min.
Joining the tables	id.	- Join both tables. Pay attention to selecting the correct join items.	10 min.
Make join permanent	attribute table of borehole shapefile	- Joins are non permanent links between tables. The "Remove all joins" option in the layer context menu allows you to remove the joined data from the table. - To keep the data permanently in the table either add new fields and copy the information from the joined fields into these new fields, or carry out an "Export Data" command on your shapefile.	10 min.
Total time			**40 min.**

E.3.6. Correcting shapefile topology in ArcGIS

Steps	Data	Remarks	Time
Loading sub-catchment layer	Output of exercise 3.3	- The shapefile generated in exercise 3.3 presents an important number of geometric inaccuracies which occurred during the transformation of the information into a DXF layer. In the present exercise, the participants will try eliminating some of these inaccuracies using ArcMap's topological editing tools together with the Line Editing Tools. - Start ArcMap, load and display the sub-catchment shapefile generated in exercise 3.3.	10 min
Setting of data frame properties and loading extension	---	- Set the map and distance units in the data frame – properties menu to the correct values. - Make sure the Line Editing Tools extension has been installed and loaded in ArcMap.	10 min
Starting Extension and cleaning dangling nodes	Output of exercise 3.3	- Start editing and specify the layer to be edited - Start editing the layer and delete the lines that were created while vectorising the GCPs and the coordinate numbers. - From the Editor menu on the Editor Tool Bar move the mouse arrow to More Editing Tools and choose Topology and Advanced Editing toolbars. - From the Topology toolbar, click Map Topology button and adapt Cluster Tolerance. - Select all features and from Topology toolbar, click Construct Features and adapt Cluster Tolerance. Then push okay to generate map topology for the dataset. Repeat with Planarize Lines from Topology toolbar. - Using the Line Editing Tools show veritices, end-points and dangles - Use functions from the Line Editing Tools and the Advanced Editing Toolbar to correct undershoots, overshoots and dangling nodes. For generalization use the function from the Advanced Editing Toolbar. - You might have to run these operations repeatedly with different tolerance values in case the initial trials do not give satisfactory results.	20 min

Transforming lines into polygons	Cleaned Shapefile	- Once you are satisfied with the result save the edits and stop editing. - Transform the lines into polygons with the "Feature to Polygon" tool in Arc Toolbox (Data Management Tools – Features – Feature to Polygon). - Enter a folder and a name for the polygon layer to be generated. - The new polygon shapefile is automatically displayed in the data frame. Change the symbology to unique value in order to check whether polygons are actually delimited from each other or not.	20 min
Eliminating polygons	Polygon shapefile	- Unless manual editing was conducted in exercise 3.1 it is probable that some sliver polygons remain between some of the "real" catchment polygons. In order to remove them start editing the catchment polygon layer. - Remove sliver polygons by selecting them using the area criterion and applying Eliminate (Data Management Tools – Generalization – Eliminate)	20 min
		Total time:	80 min.

E.3.7. Improving shapefiles in ArcGIS without EditTools Extension

Steps	Data	Remarks	Time
Loading Shape-files generated from GPS field work	Output of GPS field work	- The shapefile generated during the GPSfield work present an important number of geometric inaccu-racies. In the present exercise, the participants will try eliminating some of these inaccuracies using ArcMap's topological editing tools together with the Line Editing Tools. - Start ArcMap, load and display the shapefiles gen-erated during GPS field work - Make sure the shapefiles are in the correct projec-tion. If this not the case project the shapefiles.	10 min
Setting data frame proper-ties. Loading extension	---	- Set the map and distance units in the data frame - properties menu to the correct values. - Make sure the Line Editing Tools extension has been installed and loaded in ArcMap.	10 min
Starting Exten-sion and clean-ing dangling nodes	Output of GPS field work	- Start editing and specify the layer to be edited - Start editing the layer and delete all features that are erroneous. - From the Editor menu on the Editor Tool Bar move the mouse arrow to More Editing Tools and choose Topology and Advanced Editing toolbars. - From the Topology toolbar, click Map Topology button and adapt Cluster Tolerance. - Select all features and from Topology toolbar, click Construct Features and adapt Cluster Tolerance. Then push okay to generate map topology for the dataset. Repeat with "Planarize Lines" from Topol-ogy toolbar. - Using the Line Editing Tools show veritices, end-points and dangles - Use functions from the Line Editing Tools and the Advanced Editing Toolbar to correct undershoots, overshoots and dangling nodes. For generalization use the function from the Advanced Editing Tool-bar. - You might have to run these operations repeatedly with different tolerance values in case the initial trials do not give satisfactory results.	20 min
		Total time:	80 min.

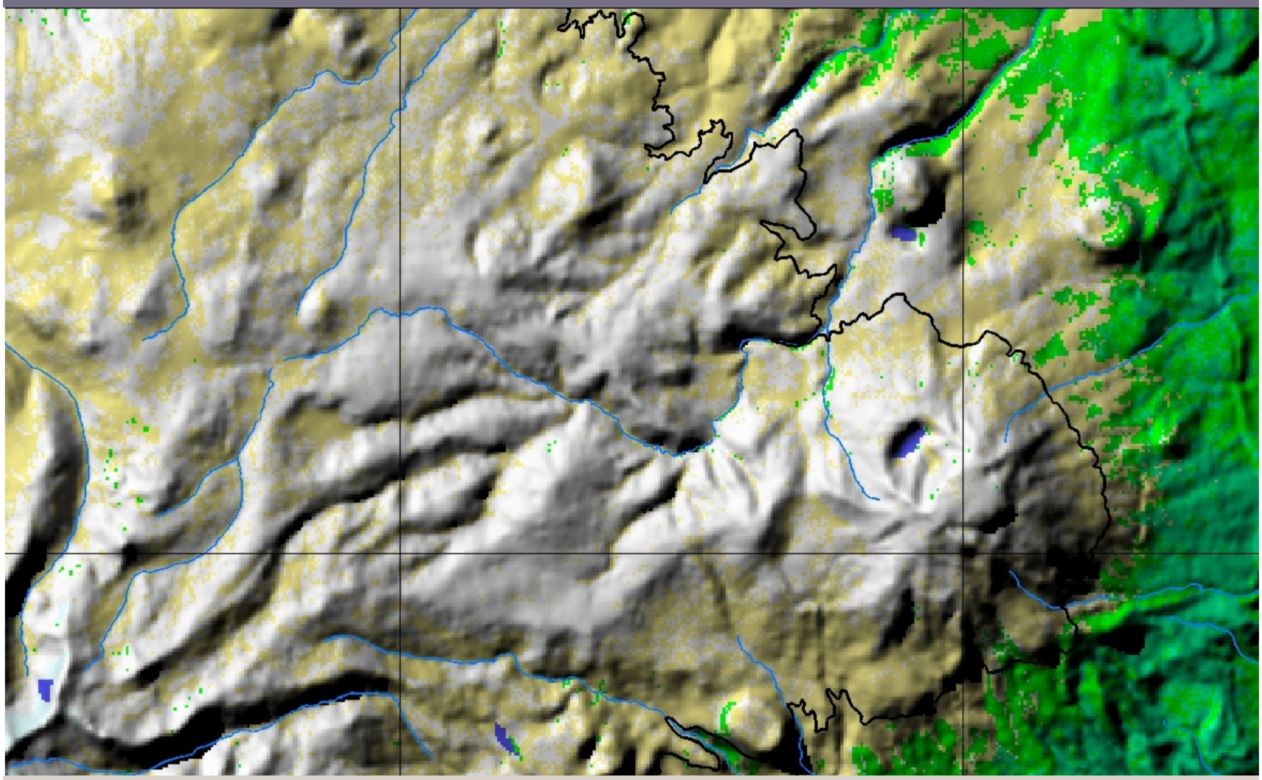
Eastern and Southern Africa Partnership Programme

Capacity Building in Geoprocessing

Module 4

GIS Data Presentation

Centre for Development and Environment



Training Concept

This training module is part of a Geoprocessing Training Concept elaborated by the Centre for Development and Environment (CDE). Each module looks into GIS or RS methods and functions. A course in any of the two disciplines can be composed of a varying number of selected modules, depending on the participant's requirements and the duration of the course. Additional modules will be added to the Training Concept based on concrete requests, or on the basis of enhanced expertise of the CDE Geoprocessing unit. Each Training Module is divided into three main parts:

T	Theory	Theoretical background and concepts, as well as available references on the module's main topics
A	Applications	Specificities of selected GIS and RS software regarding the module's main topics. Currently the Training Modules are designed for use with ESRI's ArcGIS 9.x software family, but will be stepwise expanded, depending on the specific requirements of course participants.
E	Exercises	Concrete exercises on the module's main topics for implementation by the course participants with use of selected software

Module 4 of the GIS training concept deals with the part of GIS work that is often considered the most rewarding, as it is the part where one can see the results of the previous hours spent on data preparation and analysis. In GIS, data presentation often has to do with map design and map production. In most cases, maps still are the GIS output that the non-GIS community perceives and is aware about. However, maps are but one possibility to present spatial data. The electronic media and the Internet have opened a new path of spatial data distribution that does not rely on printed maps. Internet Map Servers are such a product that users can view and query through the Internet. The CDE homepage features such a tool for the Pamir region in Central Asia (http://cdegis.unibe.ch/pamir/). Customized applications make spatial data accessible to people with no GIS expertise are another possibility to disseminate information and knowledge gained through GIS. The present module focuses primarily on the mapping aspect. While doing so, aspects of cartographic rigor and quality are particularly stressed.

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Based on various course manuals and guidelines prepared by CDE

Contents

GIS Data Presentation Theory

T.1. Mapping the world

Mapping the world in which one dwells has of all times been an occupation, which human societies have been relying on for various purposes. One can realistically imagine cave people drawing sketches in the mud to explain to their tribesmen the location of a good hunting ground. Later maps have been used to get orientation in unknown areas, to plan activities and support decision making, and even to elaborate military strategies. Maps have also been and still are used to claim authority over a certain area and to promote the identification of a civil society with a national territory.

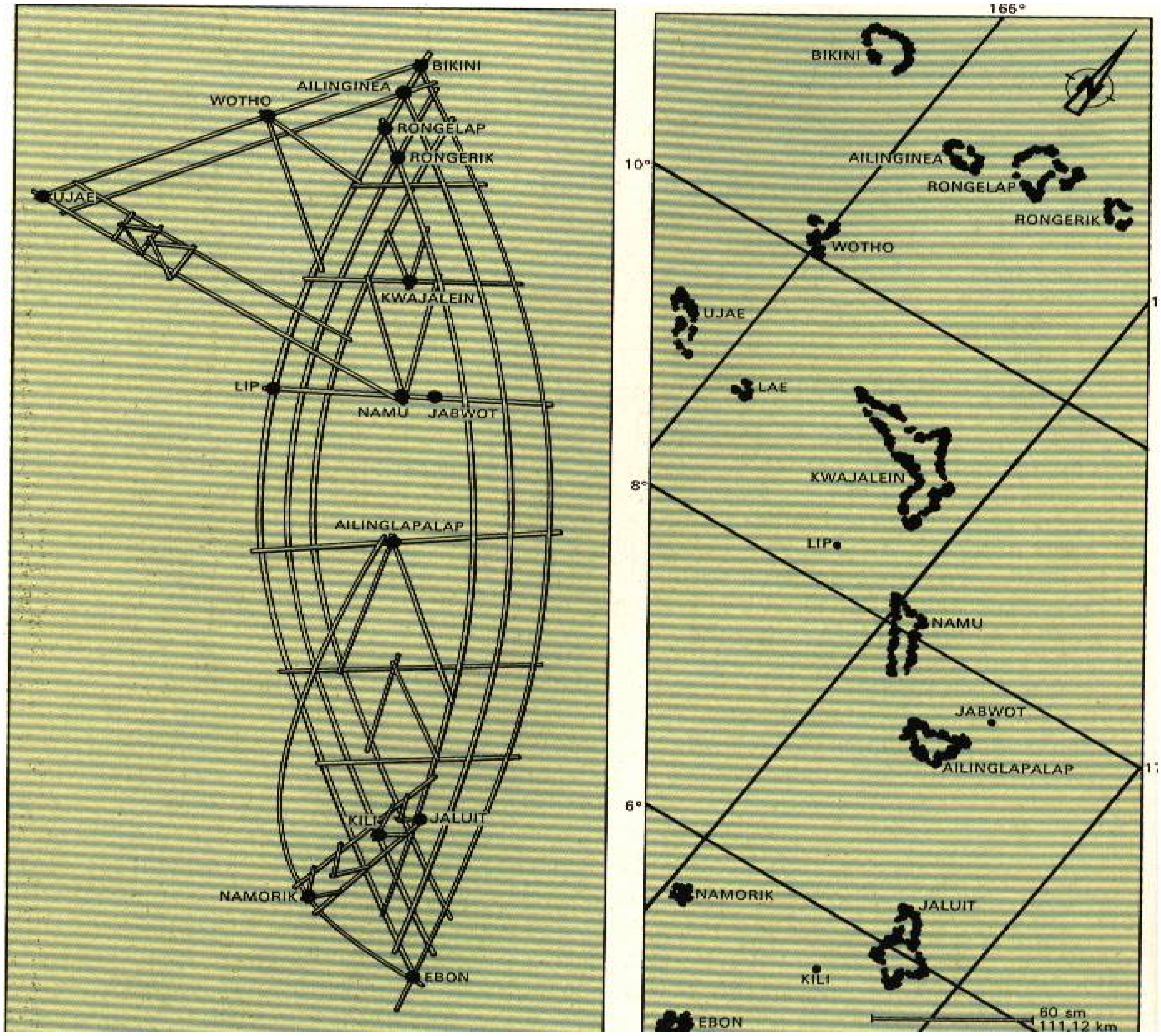

Figure T.1: *Traditional stick charts of the Marshall Islands (left) and map of the same area (right). The stick charts were constructed as instructional aids for teaching to preserve knowledge. They were not taken on voyages, for all knowledge was memorised. The charts depict natural phenomena and interpret the wave and current patterns that strike the islands. Long before modern day navigational instruments were brought to the Marshallese, they travelled the ocean, maintained courses and determined positions of islands by the use of wave patterns that are depicted in the stick charts.* <u>http://marshall.csu.edu.au/Marshalls/html/essays/es-tmc-2.html</u>

Figure T.2: Map of Switzerland produced around 1730. Although the map shows spatial distortions, the precision and degree of detail is astonishing for that time. The inclusion of graphic elements like small angels on three corners on the map tends to stress the "divine" acknowledgement of the territorial claim. Maps are therefore not only practical tools, but also political or military statements at the intention of neighbours, or any other power that were to challenge the claimed territorial sovereignty. Source: Preview of the map available at the Bern University Homepage: http://www.stub.unibe.ch/stub/ryhiner/ch/rec00001/r0000049.htm

In the frame of the Modular Training Module in Geo-Processing, the realisation of maps mainly is perceived as a means of communication at a professional level, or between technical services and representatives of a given community. Maps are tools that help decision makers to get a better idea of a particular aspect of reality in a particular geographical setting and through that should enable them to arrive at better decisions. Maps also are of importance to conduct participatory processes in view of sustainable local and regional development. In such a context, maps can be used to gain consensus over proposed development plans, or to integrate internal views into the development of these plans. Maps are also perceived as logistical support that can help to enhance the efficiency of service delivery in various public and parastatal institutions, like water supply and sanitation companies, or services, telecommunication institutions and local authorities.

T.2. GIS and maps

There is a close relation between maps and GIS: Maps can be used as input for a GIS; they can be used to communicate results of GIS operations; and maps are tools that help to execute and support spatial analysis operations. However, maps can do more than just providing information on location. They can also inform about the thematic attributes of the geographic objects located in the map.

T.2.1. Short introduction on maps

Basically, maps have three attributes: Scale, projection and symbolisation. (MONMONIER, 1996).

Scale: provides indication about the ratio between a distance on the paper and the same distance in reality. A scale of 1:50,000 indicates that 1 unit on the map is equal to 50,000 units in reality, e.g. one centimetre on the map is equal to 50,000 centimetres, or 500 metres in reality.

Projection transforms the curved, three-dimensional surface of our planet into a flat, two-dimensional plane. The appearance of a large scale map (e.g. 1:10,000 or 1:50,000), which covers a very small portion of the globe, as for example a small catchment, a district, or a village area, will not be heavily affected by the type of projection chosen to map it. Visible differences arise on small scale maps (e.g. 1:1,000,000) representing larger areas, as for example countries, continent, or the world. Refer to Module 1 of this training concept to learn more about map projections, how to define and how to transform them.

Symbolisation finally complements the map scale and projection by making visible the features, places, and other locational information represented on the map (MONMONIER, 1996). Mostly the symbolisation underlies national or international convention. One of the conventions used in cartography is for example to set the azimuth of the sun to 315 degrees, i.e. to north-western direction. The azimuth determines which slopes will be exposed to the light of the virtual sun and which ones will be lying in the shadow of topographic features like hills and mountains. With an azimuth of 315 degrees, all slopes oriented into north-western direction will be exposed to the sun light and all slopes facing south-east will be in the shadow. The visual effect of relief is created, in a hillshade map, by shading the surface of the map according to the exposure to direct sun light. Our eyes have become so much used to this convention, that when a map is held upside-down, one has a tendency to perceive valleys as being mountains and vice-versa.

T.2.2. Functions of maps

Maps are used for various purposes. "The most important function of maps is probably the function of orientation or navigation. In any case, most of the maps the general public comes across, with the exception of weather charts, are produced as an aid to orientation and navigation. (...) Physical planning maps are maps that inventory the present situation, maps that define development processes, and maps that contain propositions for a future situation, e.g. future land use. Maps used for management tasks or monitoring purposes are generally large-scale maps that are manufactured bearing in mind the management and maintenance of objects, e.g. roads, railways, forests, dikes, canals and airports. (...) For educational objectives, special purpose map material has been produced since around 1750; school atlases, wall maps and work books provide the pupils with a spatial frame of reference in order to be able to understand national and world-wide developments. Another map function is codification, e.g. showing the legal situation as regards property rights." (KRAAK, M.J. and F.J. ORMELING, 1998*, 53).*

T.2.3. Some mapping rules

Disregarding the function of the map you are producing, whether it is orientation, planning, education, or codification, some map elements should not be absent from your map layout. Hereafter is a (non-exhaustive) list of these elements:

Map field: This is the area of your map layout, in which the actual map is positioned. Depending on the theme and on the function of the map, different elements will be included in the map field. Pay attention to choose clearly readable symbols, colours, etc. for the different elements. Some conventions are widely used and it is advisable utilising them as well (see paragraph on map symbolisation above).

Map frame: The frame around the map field is commonly used to indicate at regular intervals the co-ordinates of the portion of space represented in the map field. The interval between displayed co-ordinates should be chosen depending on the scale of the map.

Map margin: The map margin contains all additional and relevant information concerning the map. Among this additional information the following should not be left out ("compulsory elements"):

- **Map title** clearly summarising the contents and the intention of the map
- **Map legend** giving unequivocal information on all punctual, linear and spatial map elements. It is advisable to separate the key for linear and punctual information from the key for spatial information showing hatches or shades.
- **Scale bar and map scale** in numbers. The scale of the map could actually be derived from the co-ordinate grid, but the indications provided with the scale bar can be considered as compulsory. If you intend to photocopy, or scan your map to use it at a different scale, there is no point in indicating a scale (e.g. 1:50,000) as this one will not be correct any longer, the indications provided by the scale bar, however, will still be valid.
- **North arrow.** Though the overwhelming majority of maps are north oriented, the indication of the cardinal points is still a required element of the map layout.
- **Projection information**: All parameters of the map projection used to display the spatial data layers should be clearly indicated, including the type of projection, the spheroid, the datum, the units and shifts in X and Y directions.
- **Map source**: The map elements portrayed on your map layout may originate from your own database (e.g. GPS measurements in the field), or from external sources (e.g. satellite imagery purchased from an official provider, vector information bought from a topographic institute, etc.). Wherever your data comes from, the source(s) of this data have to be indicated on the map. The map source information should also contain indication about the age of the primary information used.

Next to the above listed compulsory elements, some other elements may be added to the map margin:

- **Project information**: The map you are producing is maybe prepared for a specific project. In a text frame, you can give some summarised information on this project (e.g. implementing agency, donor agency, runtime of the project, main aims of the project, etc.).
- **Second map field**: A second, smaller map field can be used to locate the geographic extract shown in the main map field, a second map field can also be used to show the same area as in the first map field, but at a different period in time (e.g. land use in a district in 2005 in the first map field and in 2000 in the second map field).
- **Charts**: Some of the thematic contents of the map could be worth being portrayed as a statistical chart (e.g. statistical distribution of slope classes in a catchment, statistical distribution of soil types in a village territory, etc.)
- **Pictures**: Some graphs or photographs portraying the area displayed in the map field can help designing an attractive map layout. The use of such graphic elements is left up to the map author. It is advisable, not to overload the map layout with too many elements.

T.3. Thematic mapping

T.3.1. Choropleth maps

Choropleth is a Greek word and is composed of choros (= region) and pleth (= value). Basically choropleth maps are generated by colouring geographic units (mostly polygons) with colourshading varying proportionally to the attribute data being mapped. In Figure T.3, districts with low population numbers are displayed in yellow, districts with high population numbers are displayed in red. When using choropleth maps a major limitation is the fact they do not show the variation within the boundaries of the polygons. Thus, in Figure T.3, one may believe that population is spread evenly across each province; while actually a great amount of within-province variation is hidden.

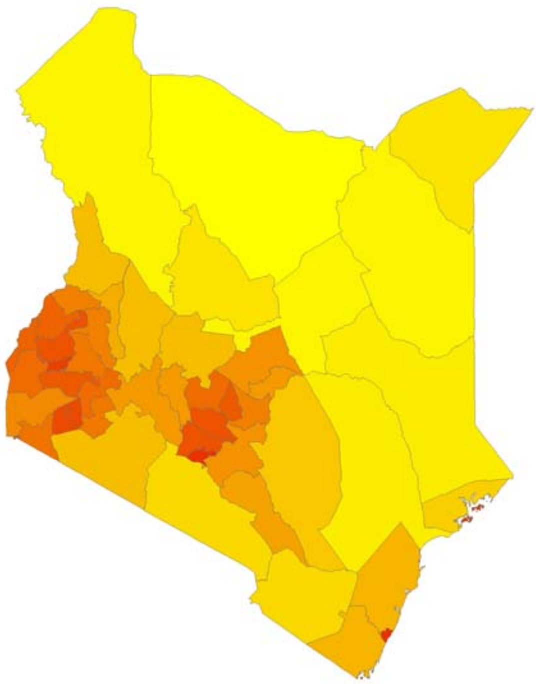

Figure T.3: *A choropleth map reflecting the Kenyan population (census 1989)*

T.3.2. Proportional symbol maps

Usually proportional symbol maps are generated by scaling symbols in proportion to data attributes associated with point locations. Proportional symbol maps depict data values found at an actual location, e.g. in *Figure T.4*. But they can also be used to show values associated with area features. In such cases the symbols are placed at the geographic center of the polygon features, as in Figure T.4. Symbols can be geometric (circles or squares), or any other bitmaps like houses in *Figure T.4.*

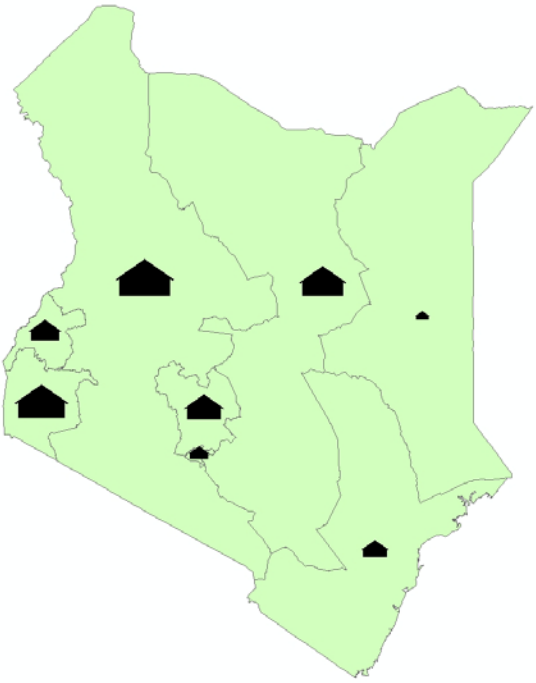

Figure T.4: *A proportional symbol map reflecting the number of households on province level in Kenya (census 1989)*

T.3.3. Dot density maps

Dot density maps are generated by setting a dot equal to a certain amount of the appearance of a phenomenon. Thus dot density maps are used to communicate density of occurrences of a feature in addition to the quantity. Ideally, dots are placed in a way that reflects the true distribution of the phenomenon. This requires a certain level of additional knowledge about the distribution and it involves a large amount of manual work in placing the dots. In addition, dot density maps can be misleading – the human eye infers patterns even if there are none.

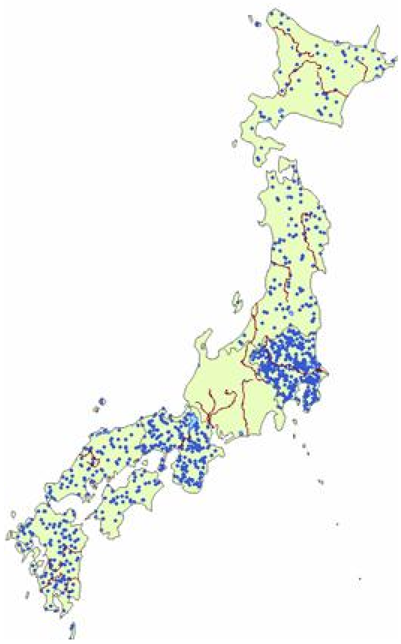

Figure T.5: *Dot density map of Japanese population (Teknomo)*

T.3.4. Multivariate mapping

Multivariate maps are applied to display more than one variable on a single map layout. Pie and bar chart maps are two of the most commonly used multivariate map designs. These types of maps are very helpful for presenting categorical data, like ethnicity, religious affiliation, or land use. ***Figure T.6*** shows an example of a pie chart map of ethnic composition in the United States.

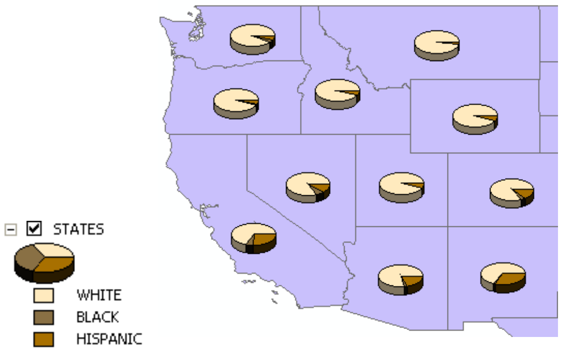

Figure T.6: *A multivariate map using 3D pie chart symbols symbol reflecting ethnicity*

However, there are other types of multivariate maps that can convey enormous amounts of additional information. The most widely known are the ***Chernoff faces*** as well as the ***polygonal glyph*** representing more options of symbolisation in cartography. Since the production of such maps is quite complex and its applicability is limited the production of these types of multivariate maps is not supported in standard GIS software.

T.3.5. Normalisation

The most common applied of the map types discussed above is doubtlessly the choropleth map, since its application is easily done in any GIS software package. Many datasets available for use contain information regarding counts of individuals for specific geographic areas, such as "Population per census tract" or "Unemployment per census tract." It is probably the most common mistakes made by a beginning cartographer to create a choropleth map that shades each area according to the value of the raw count statistic. The point is that choropleth maps “mislead” the viewer to compare tabulation areas; however the areas are often arbitrary in size and population (districts, provinces, census tracts). Characterizing these areas by counts means to compare them on unequal terms. So in a statistical sense normalizing means to transform measurements in a way they can be compared in a more meaningful way. From a technical perspective, normalisation (also standardization) means to factor out the size of the domain when comparing counts sampled over unequal population or area. Normalization transforms “measurements of magnitude” into “measurements of intensity”.

A look at **Figure T.7** to the left suggests almost equal distribution of population over the country. But the figure to the right shows the huge differences between lowland and highland areas (subblocs) in Kenya.

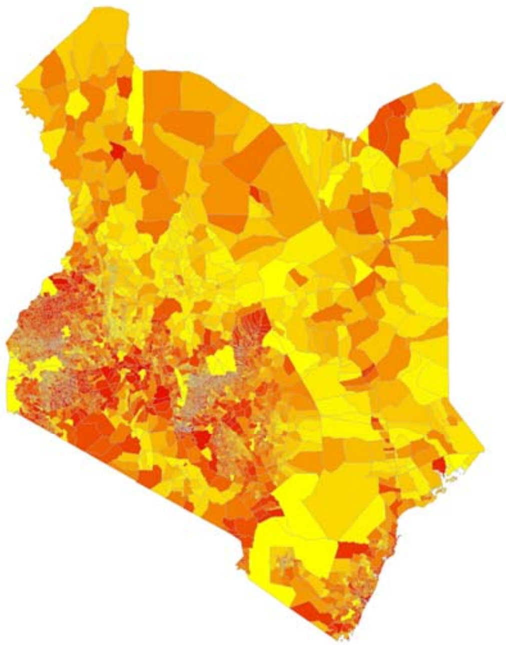

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Figure T.7: *To the left, raw population counts have been mapped; to the right, the counts were normalized by division by the area prior to mapping.*

Given this simple example this point may not seem very important, but when mapping statistics like HIV/AIDS cases or crop production it is critical that the data be normalized, though dividing by area may not be very plausible in these cases. For the HIV/AIDS case, it makes definitely more sense to calculate the number of occurrences per 100,000 people. In the case of crop production, it is more intuitive to divide the number of harvested hectares by the number of planted hectares.

T.4. GIS and other media

Maps are but one possibility to present spatial data, though the most popular. However, other media are increasingly being used by various user segments:

- For office-based activities, for which the availability of spatial information is relevant, accessing this data digitally and being able to select from a range of topics and features is an undeniable advantage. Customised applications featuring spatial data viewing and analysis functionalities are a tool that is increasingly used in different departments of public services.

- In GPS navigation, spatial databases can be kept digitally and viewed, together with the actual location of the vehicle in which the receiver is installed, through a screen. The combination of the actual position with a spatial database in the form of scanned topographic map sheets, or more complex GIS databases offers the advantage of immediate localisation and comparison with other features.
- Some municipalities offer Internet based mapping tools for potential tourists to view places of interest before starting their journeys. Online enquiries in several countries feature a mapping tool that shows the location of the address that was searched by the user. These tools are available as CD-ROMs that can be purchased, or online.
- Some public participation tools for neighbourhood planning make use of the presentation potentials of Information and Communication Technology (ICT) to reach a wider audience.

Although the present module focuses on the generation of maps, these other means of data dissemination are also addressed and examples availed to the participants for trial. Publishing functions are integrated into the training when they are available.

Sources:

- ESRI ArcGIS 9.2 *Online Help*

- Teknomo, Kardi. Introduction to GIS. http:\\people.revoledu.com\kardi\tutorial\GIS\

- Slokum, Terry *Thematic Cartography and Visualization*. NJ: Prentice-Hall, Inc.

GIS Data Presentation Applications

A.1. Map layouts in ArcGIS

In ArcGIS maps are designed in the Layout View (as opposed to the Data View in which the data is prepared, assembled, or analysed before map making). Various tools assist you in constructing legends, measured grids (co-ordinates), etc.

Legends, scale bars, north arrows, and graticules are adapted when the map extent or the map content is changed in the Layout View. These elements can be converted to graphics in order to change them to the user's needs. However, the resulting graphics are not associated with the map extent any more and do not change / scale appropriately when changing the mapped extent. Some of the restrictions of ArcView 3.x have been dealt with, however, printing maps with transparent rasters has still some restrictions in ArcGIS 9, especially when containing white elements in the symbology. Layout templates in ArcGIS are stored in map template files (*.mxt). There is a number of pre-defined templates to chose from, or custom-made layouts can also be stored as template files and reused at a later occasion. There is a limitation that one map file can only contain one layout, which is planned to be solved at higher versions.

A.1.1. Compilation of map layouts

If only simple map layouts are needed, the map production workflow in ArcMap is quite a straightforward process. However, for the compilation of a more complex map, the process becomes more complicated. Below the steps for the process of generating a more complex map layout are summarized.

Generally spoken, ArcMap does make quite easy to produce a nice looking map that combines maps, tables and charts, but anyway one has to evaluate carefully all the components and steps required to produce a more complex layout.

The ***Layout View*** is the environment where publishable maps are created. The map layout is actually a direct representation of the ***Data View*** environment – any processing steps that can be run in the Data View will also raun in the layout view – both windows are hot-linked.

The first step will be to create the ***Data View*** with the themes displayed in a meaningful order, and the themes (data layers) titled appropriately. Removing all unnecessary layers before creating the layout will save time later. The ***Data Frame Properties*** window in the ***View*** menu allows changing the name of the data frame. The layer names also can be changed – by right-clicking when over the layer name and selecting ***Properties/General.*** The symbol used to represent the layer can be changed by left-clicking on the current symbol, or by selecting ***Symbology*** in the ***Data Frame Properties*** window. The view's scale can be adapted by explicitly setting the scale to an amount like 1:100,000 by typing in the value directly in the scale window.

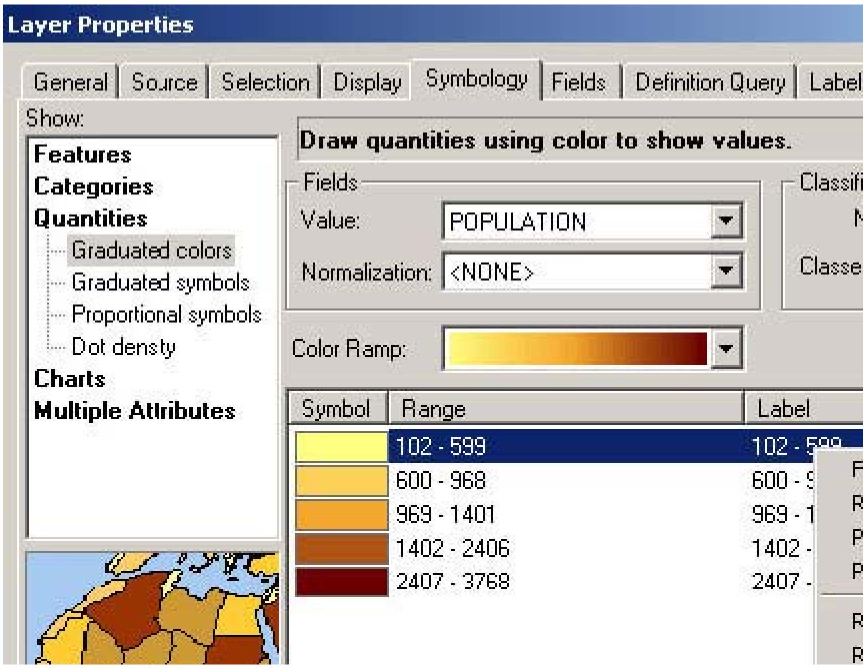


Figure A.1: ArcMaps' elaborated and powerful Layer Properties dialog, where also map labelling options are available

The ***Data Frame Properties Size and Position*** tab of the data frame's properties can be used to control the behaviour of the map elements. All elements like scale bar, legend and north arrow can be found under the ***Insert*** menu when the Layout View is active, add any explanatory text to each layout, and fill in the empty layout frame with the attribution text. You should also title the map appropriately, and fix the legend presentations.

Once you have fine-tuned the layout to your satisfaction, save the ArcMap Document (File, Save or Save As), and then print out your map.

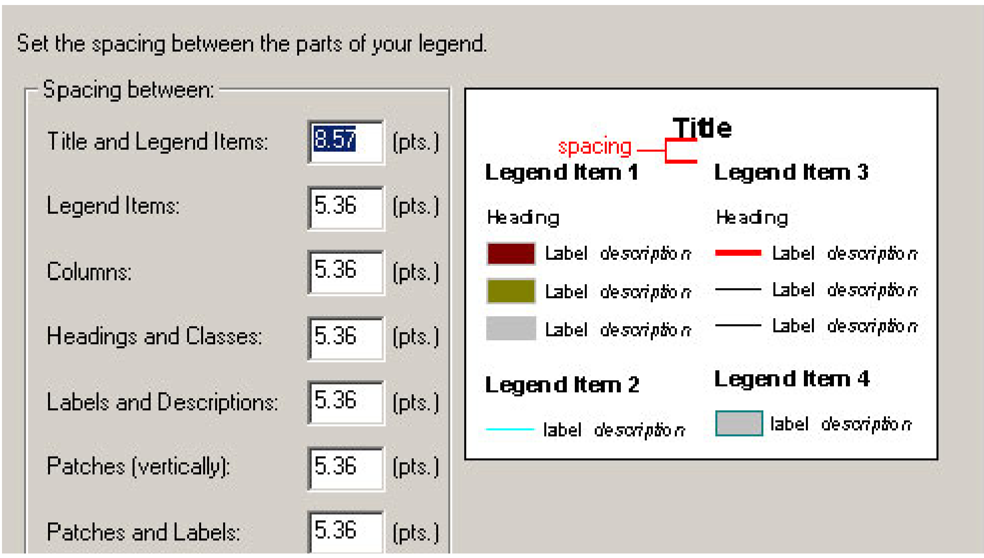


Figure A.2: ArcMaps' legend creator

Once the map layout is finished, it may be exported from ArcMap (from menu File – Export map), where the user may choose an appropriate file format and quality (resolution and colour).

A.2. Data Display

ArcGIS offers the user a great wealth of data display options, started with easy on the fly classification up to topographic shading effects. All this features are available from the layer properties dialog of any layer.

A.1.2. Thematic data display

- Choropleth map designs are created In ArcGIS using the ***Graduated Color*** legend type found on the Symbology tab of the Layer property dialog window.
- Proportional symbol maps can be generated in ArcGIS using the Graduated Symbol legend type found on the Symbology tab of the Layer property dialog window.
- Dot density maps are created in ArcGIS using the Dot density legend type (Symbology tab on the Layer property dialog window). Dots are placed randomly within features, and hence do not represent the real distribution of the phenomenon.

A.1.3. Data Classification

Most of the discussed cases mentioned above relied on data that have been divided into classes or categories. Basically, there are different methods for classifying statistical data and ArcGIS offers some very useful methods.

Natural Breaks
The natural break method creates classes by minimizing a measure of classification error that occurs when unequal values are grouped together in the same class. This classification method identifies breaks between groups to form groups that are homogeneous – while respecting heterogeneity among classes. The natural break method is usually a good choice also for discovering patterns in data and works well with data that is not equally distributed. However, it is not always easy to understand the legends describing the data.

Quantiles
For quantile classification, breakpoints between classes are identified so that each class contains the same number of features. If a theme has 20 features, quantile classification will place 4 features into each of 5 classes (if 5 classes were selected). If the number of classes is 5, then the

data is broken into 5 (quantiles), if the number of classes is 4, it results in 4 classes (quartiles). Generally, this classification method works best with data that is equally distributed.

Equal Interval

The equal interval classification method makes sure that each class occupies an equal interval. The class interval is identified by computing the range of data and dividing it by the number of desired classes. The map created using this method is easy to interpret. A major drawback of the classification method is that it does not take into account the distribution of the data. Therefore the method works well with continuously distributed data.

Mean Standard Deviation

In the Standard Deviation classification method, ArcGIS calculates categories by placing data values into classes based on their numeric distance from the mean. A map of this type usually has four categories: -2 SD to -1 SD, -1 SD to Mean, Mean to +1 SD, and +1 SD to +2 SD. A major advantage of this method is that a statistically trained viewer knows that about 68% of the data falls between +/- 1SD of the mean, and that about 95% falls between +/- 2SD of the mean. Before this method is being applied, it is important to make sure the data is normally distributed.

A.3. Maps and PowerPoint Presentations

One of the purposes of map making is presentation and communication. Maps are used to inform stakeholders, decision makers, project partners, etc. about a specific topic, or characteristic of the portrayed area. In such cases, maps are included to publications, brochures and fliers, or are presented during exhibitions.

Sometimes, however, cartographic products need to be presented during conferences and workshops with use of PowerPoint, or other presentation media. In such cases, maps are usually exported into an image format and copied into the presentation. While doing this there are a few things to consider:

1. *Size*
2. *Resolution*
3. *Format*

The combination of these three dimensions will define the ideal map output that can be deployed in PowerPoint. Normally, a resolution of 150dpi is sufficient for PowerPoint presentations. The format to choose is probably PDF or Jpeg , which are acceptable compromises between quality and size.

GIS Data Presentation

Exercises

E.1. Exercises

E.4.1. Basic topographic mapping

Steps	Data	Remarks	Time
Open a new map document and choose appropriate settings	- kemkhls1.tif	– - In ArcMap, open a new mapfile and load ...\kenya\mt_kenya\GIS\topo\kemkhls1.tif. – - Select Data frame properties from View menu - and make sure the coordinate system is WGS_1984_UTM_Zone_37S. – Create a folder in the student directory in path ...\student_db\kenya\mt_kenya\"mapfiles" and save the mapfile there as Mt_Kenya.mxd – Go to File menu and select Page and print setup. Select any available printer, paper size A3, and check the Portrait radio button. – To switch from data view to layout view, go to View menu and select Layout View. – In View - Data frame properties, select tab Size and position and set the position to: X=0.85cm, Y=8cm, and Size Width=28cm, Height=33cm. – Again in Data frame properties, select tab Data frame and set the Extend to Fixed scale 1:300'000. Now you are finally ready!	
Designing a topographic map layout	- kemkcen1.shp - kemkrds1.shp - kemkriv1.shp - kemkcnt2.shp - kemkele1.tif	– Add the layers listed to the left to the new layout; don't worry about the strange colours. – Change the layer symbology for the shapefiles by right-clicking the theme in the TOC and choosing Properties. Next go to the tab Symbology and click Single symbol - Symbol. You may choose predefined colours and symbology or create your own style. – For the raster layer kemkele1.tif select Unique values - Value and choose any appealing colour scheme before you click Apply. Then switch to Display tab (still Layer properties) and set transparency to 40% and click Ok. If you want you may save your symbol style by right-clicking kemkele1.tif	

		and choose Save as layer file. This way your styles will be available for other layers or other people. – Now you will apply a prepared Symbology style incl. adapted labels. Go to the Symbology tab, click Import and navigate to mt_kenya\auxil and select the file kemkele1.lyr and click Ok. – Now you may increase Brightness of the hillshade theme to 20% and play around with the other layers Display settings. – For panning and zooming in your layout go to View menu, select Toolbars and choose Layout toolbar. Don't forget to save from time to time!	
Apply labelling	- kemkriv1.shp - kemkcen1.shp	– Now right-click the theme kemkriv1.shp in the TOC, select Properties and the go to the Labels tab. Check Label features in this layer and select the Label field NAME. Change font size and colour to match the rivers symbology style. Check the created labels in the layout. If you don't like it, go back to Labels tab and click Placements properties in the lower left. Play around with the settings and check the result. – Once you accept the result, apply labelling to the town layer kemkcen1.shp. – Don't forget to save from time to time!	
Add map legends		– Next we will add a legend to the layout. Go to View menu - Zoom layout and choose Zoom to whole page. – Now go to Insert menu, and choose legend. In the new dialog, make sure to put all layers except for ekmkhls1.tif to the legend items. Accept the next few dialogs in order to see the result - you may apply changes later on. – You will see the legend is one huge pile of items, so we have to find a work-around to get a solution. Double-click the legend items, go to Items tab and remove kemkele1.tif - accept and you have a legend block only for vector features. Now add a new legend block and remove all layers	

		except the kemkele1.tif. Accept all dialogs and check the result – still not okay? Double click the new legend block, go to Items tab, and set the Columns to 2. – Change the legend title to Elevation classes (masl) and Feature layers and set the title fonts to 14 bold. – From the legend tab change the Patch size to Width=20 and Height=10. – To change the feature layer description, go back to the TOC and double-click the layer name and change it to meaningful things like Roads, Rivers, and Towns. Since it is linked, the changes will apply automatically to the legend. – If you are still not happy with the legend, you may customize it further by converting the legend features to graphics (right-clicking on the legend block, choose Convert to graphic and Ungroup). Keep in mind this step is detaching the legend from the TOC and can not be undone easily. – Don't forget to save from time to time!	
Add map elements		– Go to the Insert menu and add additional map elements like north arrow, scale bar and title and a neatline that can be placed around all elements. – Arrange these elements above, below or behind the map and change the scale bar settings according to your needs (double-click on the scale bar itself).	
Export map layouts		– Finally you may export or print your map. While printing is done from the File menu – Print, exporting the layout is done via File menu, Export map. Export to jpg format with 300dpi, quality 75%. – Compare and discuss the printed and the exported versions.	
Total time			90 min

E.4.2. Thematic mapping (choropleth mapping)

Steps	Data	Remarks	Time
Load & explore datasets	Kenapop79 Popdens.mxd	– Load the layer kenapop79 and produce a map depicting the population numbers. The attribute to be used for mapping is called “Total”. Save the mapfile as Popdens.mxd in the mapfile directory.	
Preparation of thematic map layouts	Kenapop79	– From the table of contents, right-click Kenapop79, choose properties and go to symbology tab. Choose categories - unique values and select the attribute Total as Value Field. – Click Add all values and click Yes when being asked to map more then 500 items. – Apply the green-to-red flow colour ramp and click apply and okay.	
Preparation of thematic map layouts	Kenapop79	– Repeat the same procedure but use the attribute “Density” instead of Total. – Compare the two layers and try to explain the different appearance. Which layout is more “correct” or has more explanatory power?	
Create map layout	Kenapop79	– Create an appealing map layout from both layers (create a layout with two data frames)	
Export map layouts		– Instead of printing, export the layout (File menu, Export map). Export to jpg format using once 100dpi and once 300dpi, quality 75%. – Compare the outputs in terms of quality.	
Total time			60 min

Optional:
Try to create a map reflecting the sex ratio for selected areas of Kenya using the population numbers in kenapop89 and/or kenapop79. Use proportional symbols (layer properties - Symbology - Charts - Pie). Next select males and females and draw the map. Try to explain the differences.

E.4.3. Customized mapping (freestyle)

Steps	Data	Remarks	Time
Loading data to view	Various layers of Nakuru	– In this exercise, participants use various spatial layers of Nakuru Municipality to design a map and print it out. – Decide on a theme and purpose for your map – Load the required data into the view – Adapt the symbology of each layer; add labels if needed; select a background; decide on a relevant map extend	
Defining page setup		– Define the page setup for the map to be A3 in Landscape format	
Adapting the data frame in the layout		– In the layout view adapt the data frame: decide on the scale and size of the data frame and add coordinate grids in UTM – Zone 37S – WGS 84 to the data frame	
Adding compulsory map elements		– Add the following elements and design them to your liking: Legend, scale bar, scale information, projection information, map title and sub-title, data source(s), copyright information, north arrow. Explore the different map layout elements provided such as the connection between the layer properties and the powerful legend builder. Most of these elements can be added from ArcMap's Insert menu.	
Final design of the map layout		– Re-arrange the map elements until you are satisfied with your map layout. Add additional map elements (photos, graphs, etc.) if available and if deemed necessary.	
Print map layout		– Print the map layout. – The printouts of each group are hung side by side on a wall and discussed in a plenary session. Mapping rules and aesthetic issues are discussed among the participants	
Revise layout		– Depending on time, the remarks made during the plenary session are taken up and layouts are adapted and printed again	
Total time			60 min

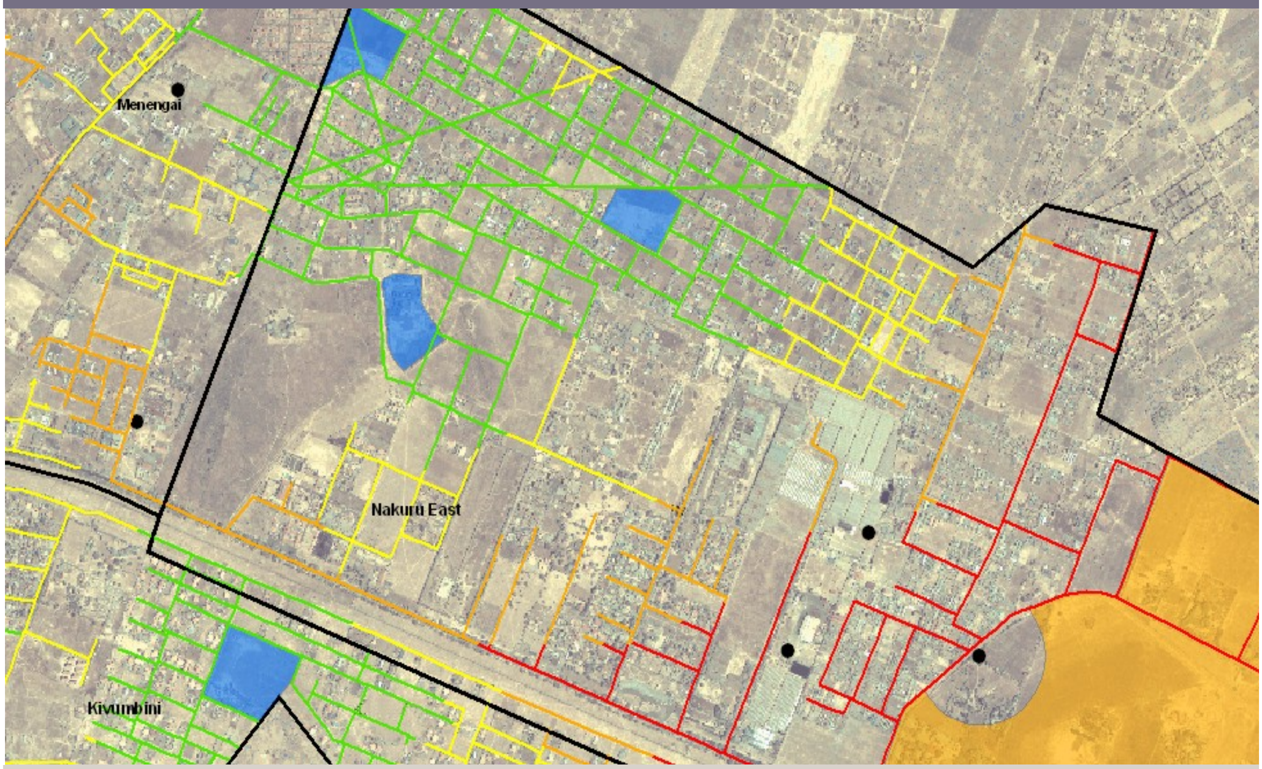
Eastern and Southern Africa Partnership Programme

Capacity Building in Geoprocessing

Module 5

GIS Vector Data Analysis

Centre for Development and Environment



centre for development and environment

Training Concept

This training module is part of a Geoprocessing Training Concept elaborated by the Centre for Development and Environment (CDE). Each module looks into GIS or RS methods and functions. A course in any of the two disciplines can be composed of a varying number of selected modules, depending on the participant's requirements and the duration of the course. Additional modules will be added to the Training Concept based on concrete requests, or on the basis of enhanced expertise of the CDE Geoprocessing unit. Each Training Module is divided into three main parts:

T	Theory	Theoretical background and concepts, as well as available references on the module's main topics
A	Applications	Specificities of selected GIS and RS software regarding the module's main topics. Currently the Training Modules are designed for use with ESRI's ArcGIS 9.x software family, but will be stepwise expanded, depending on the specific requirements of course participants.
E	Exercises	Concrete exercises on the module's main topics for implementation by the course participants with use of selected software

Module 5 leads from the preparation and presentation of GIS data towards its analysis. Together with module 6 on the analysis of raster data, this module exemplifies the potential of GIS as a tool that helps to understand the surroundings in a better way. The analysis of elements and processes that take place in space provides an important basis for many decision-making and consensus finding processes, but also for scientific research, early warning systems and modelling activities. The analysis of vector data takes place principally through overlaying different layers of information and identifying correlations between them. However, vector data analysis also includes the definition of proximity within one, or across several data layers. Along linear networks, GIS also provides tools for the analysis of routes, transportation costs and the definition of delivery areas. All these activities have a definite advantage for logistic purposes, but also for the identification of spatial correlations in the frame of development activities and scientific research.

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Authors: A. Ehrensperger, T. Gurtner, C. Hergarten, C. Hösli
Based on various course manuals and guidelines prepared by CDE

Contents

GIS Vector Data Analysis Theory

T.1. Definitions and scope

GIS distinguishes itself from other data processing systems by its spatial-analytic capabilities. These capabilities use the spatial and non-spatial data in the spatial database to answer questions and solve problems. The principal objective of spatial data analysis is to transform and combine data from diverse sources/disciplines into useful information, to improve one's understanding or to satisfy the requirements or objectives of decision-makers. A GIS application deals with only some delineated, relevant slices of reality, termed as the universe of discourse of the application. Typical problems may be in planning (e.g., what are the most suitable locations for a new dam?) or in prediction (e.g., what will be the size of the lake behind the dam?). The universe of discourse here is construction of the dam, and its environmental, societal, and economic impacts. The solution to a problem always depends on a (large) number of parameters. Since these parameters are often interrelated, their interaction is made more precise in an application model. Such a model, in one way or other, describes as faithfully as possible how the application's universe of discourse behaves, and it does so in terms of the parameters. It is fair to say that an application model tries to simulate an application's universe of discourse. Application models used for planning and site selection are usually prescriptive.

T.2. Overlay functions

In this section, we look at techniques of combining two spatial data layers and producing a third one from them. The binary operators that we discuss are known as spatial overlay operators. We will first discuss vector forms, and then raster overlay operators (Module 6). Standard overlay operators take two input data layers, and assume they are geo-referenced in the same system, and overlap in study area. If either condition is not met, the use of an overlay operator is senseless. The principle of spatial overlay is to compare the characteristics of the same location in both data layers, and to produce a new characteristic for each location in the output data layer. Which characteristic to produce is determined by a rule that the user can choose. In raster data, as we shall see, these comparisons are carried out between pairs of cells, one from each input raster. In vector data, the same principle of comparing locations in pairs applies, but the underlying computations rely on determining the spatial intersections of features, one from each input vector layer, in pairs.

T.2.1. Vector overlay operators

In the vector domain, the overlaying of data layers is computationally more demanding than in the raster domain. We will discuss here only overlays from polygon data layers, but remark that most of the ideas carry over to overlaying with point or line data layers.

The standard overlay operator for two layers of polygons is the ***polygon intersection*** operator. It is fundamental, as many other overlay operators proposed in the literature or implemented in systems can be defined in terms of it. The result of this operator is the collection of all possible polygon intersections; the attribute table result is a join of the two input attribute tables.

There are two more polygon overlay operators: The first is known as the ***polygon clipping*** operator. It takes a polygon data layer and restricts its spatial extent to the generalized outer boundary obtained from all polygons in a second input layer. Besides this generalized outer boundary, no other polygon boundaries from the second layer play a role in the result. A second overlay operator is ***polygon overwrite.*** The result of this binary operator is defined as a polygon layer with the polygons of the first layer, except where polygons existed in the second layer, as these take priority.

Figure T.1 on the left provides an overview of the possible vector data overlay analyses. The ***first*** example from the top shows the ***clip*** function, that cuts one data layer with use of the outer boundary of the feature(s) of another layer. The ***second*** example shows the ***intersect*** function, which combines the features of two layers and restricts the output to the area that is common to both layers. The ***third*** example shows the ***union*** function, which does the same as the intersect function, but keeps the entire extent of the data (not only the extent common to both layers). The fourth example shows the dissolve function, which reduces the number of polygons in a layer, depending on a particular attribute. If the values of the selected attribute are identical and the polygons share a common boundary, then that boundary is removed. The fifth example shows the merge function, which brings together layers that are depicting neighbouring areas. The output is one layer that contains the features of all input layers (which can be more than two.)

Most GISs do not force the user to apply overlay operators to the full polygon data set. One is allowed to first select relevant polygons in the data layer, and then use the selected set of polygons as operator argument.

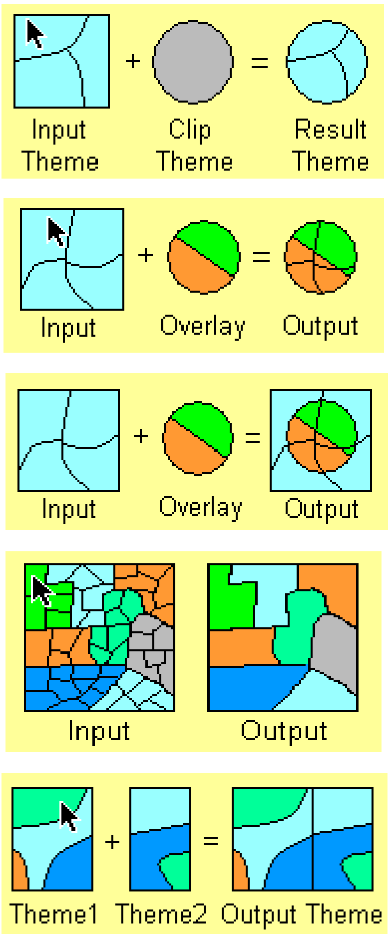


Figure T.1: Different types of vector overlay analyses

The really fundamental operator of all these is ***polygon intersection***. The others can be defined in terms of it, usually in combination with polygon selection and/or classification. For instance, the polygon overwrite of A by B can be defined as polygon intersection between A and B, followed by a (well-chosen) classification that prioritizes polygons in B, followed by a merge. The reader is asked to verify this. Vector overlays are also defined usually for point or line data layers. Their definition parallels the definitions of operators discussed above. Different GISs use different names for these operators, and one is advised to carefully check the documentation before applying any of these operators

T.3. Proximity analysis

T.3.1. Neighbourhood functions

The guiding principle in the section on overlay functions was to combine the values from two different data layers at the same location. Another crucial principle in spatial analysis is dealing with surrounding area. This principle is to find out the characteristics of the vicinity, often called neighbourhood, of a location. It's a fact that many spatially relevant questions depend not only on what is exactly at the location, but also on what is next to that location.

The crucial o perform neighbourhood analysis, we must

1. state which target locations are of interest to us, and what is their spatial extent,

2. define how to determine the neighbourhood for each target,

3. define which characteristic(s) must be computed for each neighbourhood. For instance, our target can be a medical clinic. Its neighbourhood can be defined as:

- an area within 2 km distance, as the crow flies, or
- an area within 2 km travel distance, or
- all roads within 500 m travel distance, or
- all other clinics within 10 minutes travel time, or
- all residential areas, for which the clinic is the closest clinic.

Then, in the third step we indicate what characteristics to find out about the neighbourhood. This could simply be its spatial extent, but it might also be statistical information like:

- how many people live in the area,
- what is their average household income, or
- are any high – risk industries located in the neighbourhood.

The above are typical questions in an ***urban setting.*** When our interest is more in natural phenomena, different examples of locations, neighbourhoods and neighbourhood characteristics arise. In proximity computations, we use geometric distance to define the neighbourhood of one or more target locations. The most common technique applied is the generation of buffer zones, another technique deals with Thiessen Polygons.

T.3.2. Buffer zone generation

The principle of buffer zone generation is simple: we select one or more target locations, and then determine the area around them, within a certain distance. In ***Figure T.2***, a number of main and minor roads were selected as targets and a buffer with a fixed distance was computed from them. In ***Figure T.3*** the same features are buffered with a distance that is contained in one of the attribute fields of the data layer. This field could for example represent the road class and the road width is directly correlated to it. In some case studies, zonated buffers must be determined, for instance in assessments of traffic noise effects. Most GIS support this type of zonated buffer computations. In vector-based buffer generation, the buffers themselves become polygon features, usually in a separate data layer, that can be used in further spatial analysis.

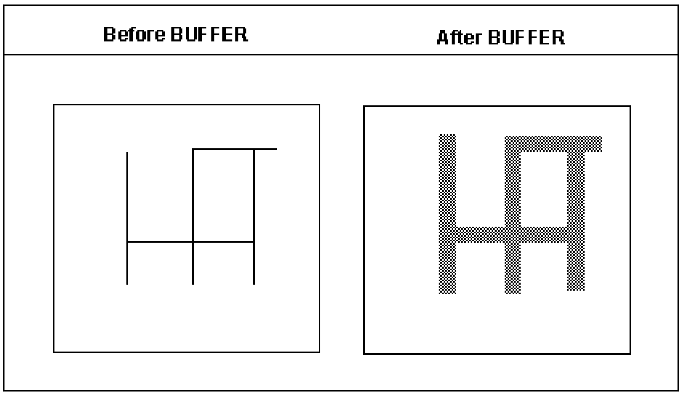


Figure T.2: *Buffering with a fixed distance*

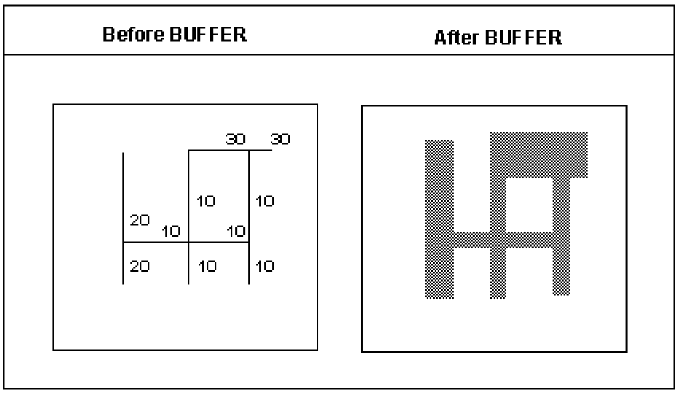


Figure T.3: *Buffering with a distance defined from an attribute field*

T.3.3. Thiessen polygon generation

Another technique that makes use of geometric distance for determining neighbourhoods s useful if we have a spatially distributed set of points as target locations, and we want to know for each location in the study to which target it is closest. This technique will generate a polygon around each target location that identifies all those locations that ‘belong to’ that target.

A partitioning of the plane into polygons that have this characteristic—containing all the locations that are closer to the polygon's 'midpoint' than to any other 'midpoint'—is called a Thiessen polygon partition. Given an input point set that will be the polygon's midpoints, it is not difficult to construct such a partition. It is even much easier to construct if we already have a Delaunay triangulation for the same input point set (see Section 2.2.3 on TINs). Figure 4.18(a) repeats the Delaunay triangulation of Figure 2.8(b). The Thiessen polygon partition constructed from it is in part (b). The construction first creates the perpendiculars of all the triangle sides; observe that a perpendicular of a triangle side that connect point A with point B is the divide between the area closer to A and the area closer to B. The perpendiculars become part of the boundary of each Thiessen polygon.

T.4. Network analysis

A completely different set of analytic functions in GIS consists of computations on networks. A network is a connected set of lines, representing some geographic phenomenon, typically of the transportation type. The 'goods' transported can be almost anything: people, cars and other vehicles along a road network, commercial goods along a logistic network, phone calls along a telephone network, or water pollution along a stream/river network. Network analysis can be done using either raster or vector data layers, but they are more commonly done in the latter, as line features can be associated with a network naturally, and can be given typical transportation characteristics like capacity and cost per unit. One crucial characteristic of any network is whether the network lines are considered directed or not. Directed networks associate with each line a direction of transportation; undirected networks do not. In the latter, the 'goods' can be transported along a line in both directions. We discuss here vector network analysis, and assume that the network is a set of connected line features that intersect only at the lines' nodes, not at internal vertices.

For many applications of network analysis, a planar network, i.e., one that is embeddable in a two – dimensional plane will do the job. Many networks are naturally planar, like stream/river networks. A large-scale traffic network, on the other end, is not planar: motorways have multi-level crossings and are constructed with underpasses and overpasses. Planar networks are easier to deal with computationally, as they have simpler topological rules. Not all GISs accommodate non-planar networks, or can do so only using trickery. Such trickery may involve splitting overpassing lines at the intersection vertex and creating four out of the two original lines. Without further attention, the network will then allow to make a turn onto another line at this new intersection node, which in reality would be impossible. Some GIS allow associating a cost with turning at a node and that cost, in the case of the overpass trick, can be made infinite to ensure it is prohibited.

T.4.1. Optimal path finding

Optimal path finding techniques are used when a least-cost path between two nodes in a network must be found. The two nodes are called origin and destination, respectively. The aim is to find a sequence of connected lines to traverse from the origin to the destination at the lowest possible cost.

The cost function can be simple: for instance, it can be defined as the total length of all lines on the path. The cost function can also be more elaborate and take into account not only length of the lines, but also their capacity, maximum transmission (travel) rate and other line characteristics, for instance to obtain a reasonable approximation of travel time. There can even be cases in which the nodes visited add to the cost of the path as well. These may be called turning costs, which are defined in a separate turning cost table for each node, indicating the cost of turning at the node when entering from one line and continuing on another.

GIS Vector Data Analysis Applications

A.1. Vector Analysis using ArcGIS

A.1.1. Topological Overlay

The topological overlay processes lie at the core of the original ArcInfo toolbox. In fact, topological overlay is what ArcInfo and its predecessors, such as Odyssey, were originally designed to do. Topological overlay allows us to ask questions like "Where are locations that are on unstable soils, with a slope in the range of 25-40%, that were harvested within the last 15 years, on low productivity sites, and ***what is their percentage of area with respect to the entire watershed***?"

Topological overlay is a process whereby separate layers sharing the same spatial extent are merged in different ways. The landscape architect Ian McHarg developed an analog method, a precursor to the digital implementation within GIS. His approach was to take maps traced on sheets of acetate or mylar, and place one on top of the other, and tape the stack to a window or atop a light table. Areas of overlap will be darker than areas that do not overlap. The GIS performs in a similar manner, except that the input and output is more accurate and precise, and easier to manage.

The reason these operations are known as "topological" overlay is because the overlay process includes the rebuilding of the topological relationships that make layers function. In the GIS, where lines intersect between one layer and another, vertices are created. Where lines or points share the same space as polygons, the lines and points inherit the attributes of the spatially corresponding polygons. New layers are formed which can take on the attributes or coordinate properties of input datasets. Some or all features from the input datasets are passed on to the output. Attribute values from both input datasets are passed on to the output dataset.

Topological overlay is different from the ***Select By Layer*** operations described in the last lesson. In the Select By Layer operations, ArcGIS only looks at the spatial overlap of the features of two layers, and creates a new selected set in one of those layers; no new datasets are produced; no attribute updates are made. In Topological overlay, new layers are created whose geometry and/or attribute structure are altered. Topological overlay allows us to find overlapping features, as well as to quantify the area or length of overlap.

Buffering is a separate topic from topological overlay, but is frequently bundled with overlay because more often than not the results of buffering are used in subsequent overlay analyses to quantify the properties of the landscape within a buffer area.

In ArcGIS, geoprocessing operations, including topological overlay operations, are accessible through ArcToolbox.

ArcToolbox exists as a dockable window within any of the other ArcGIS Desktop applications (ArcMap, ArcCatalog, ArcGlobe, ArcScene). The overlay and proximity methods for feature classes (shapefiles and geodatabases) are arranged within the ***Analysis Tools*** tree within ArcToolbox:

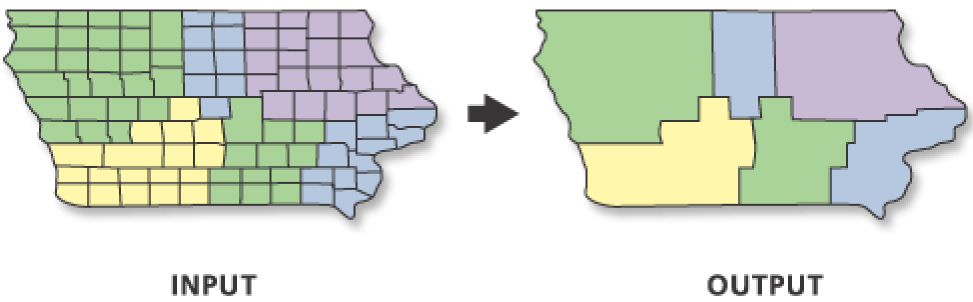


Figure A.1: *The Dissolve function is found in the ArcToolbox in: Data Management Tools > Generalization > Dissolve*

Appending is used to merge together multiple data sets that represent the same thematic data, but are contiguous. It appends multiple input point, line or polygon feature classes, tables, rasters or raster catalogs to a target feature class.

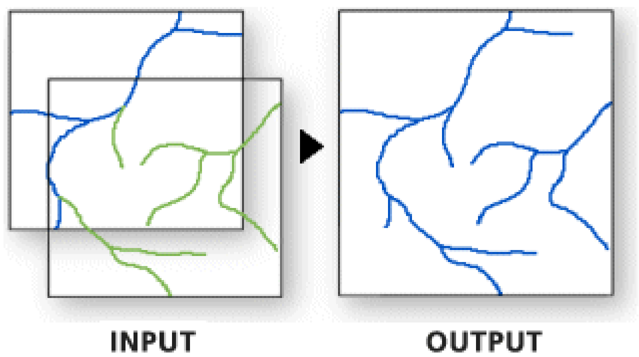


Figure A.2: *The Merge / Append function is found in the ArcToolbox in: Data Management Tools > General > Append tool*

Use Clip when you want to cut out a piece of one feature class using one or more of the features in another feature class as a "cookie cutter". This is particularly useful for creating a new feature class that contains a geographic subset of the features in another, larger feature class.

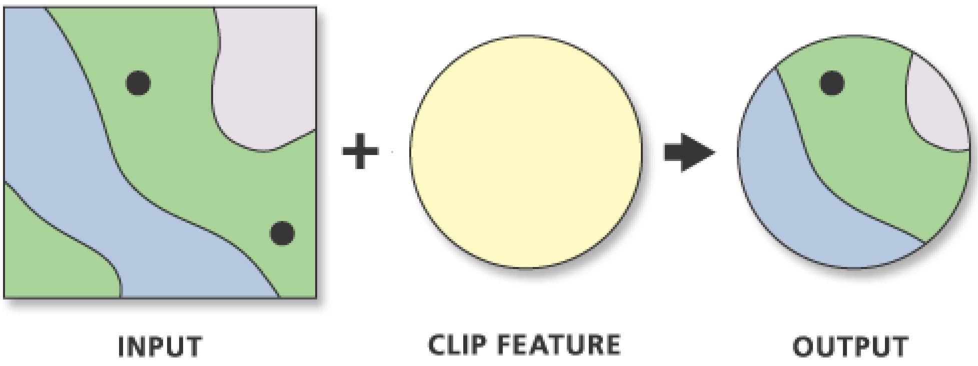


Figure A.3: The Clip function is found in the ArcToolbox following Analysis toolbox > Extract > Clip tool

The Intersect tool calculates the geometric intersection of any number of ***feature classes*** and ***feature layers***. The features or portion of features that are common to (intersect) all inputs will be written to the output feature class.

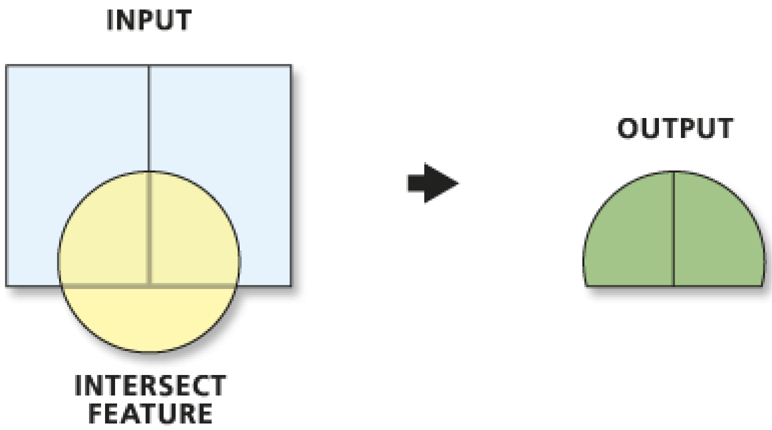


Figure A.4: The Intersect function is found in the ArcToolbox in: Analysis toolbox > Overlay > Intersect tool (Source: ArcMap Online Help)

Union calculates the geometric intersection of any number of ***feature classes*** and ***feature layers***. All inputs must be of a common geometry type and the output will be of that same geometry type. This means that a number of polygon feature classes and feature layers can be unioned together. The output features will have the attributes of all the input features that they overlap.

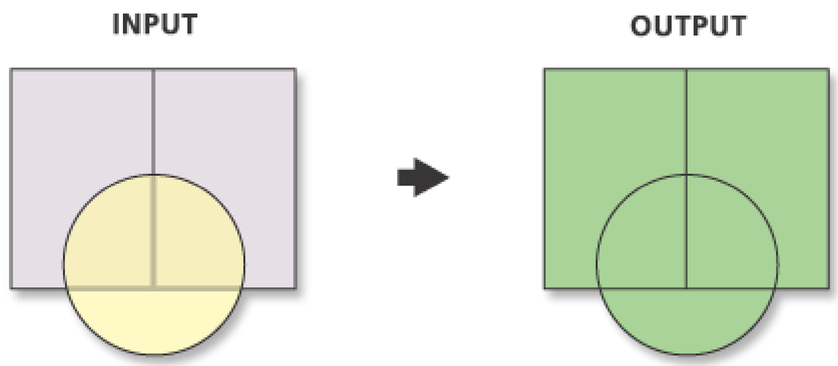


Figure A.5: *The Union Function is found in the ArcToolbox in: Analysis toolbox > Overlay > Union tool (Source: ArcMap Online Help)*

The ***Identity*** function maintains all features of the input layer, but takes features from the identity layer that overlap with the input layer. The output layer's coordinate properties are dependent on which of the inputs is the identity layer. This is very similar to the Union function, but it includes a clip to the polygon boundary of the input layer.

A.2. Analysing spatial relationships

Many of the reasons GISs were developed were to answer conceptually simple, but technically difficult spatial questions. These questions include relationships of adjacency, proximity, intersection, and containment of features among different layers. ArcGIS 's basic spatial analysis functionality includes methods to deal with these analytical tasks.

A.2.1. Select by location

Select By Location is used to select features in one or more layers based on the spatial, (locational), relationship to another layer. Features in one or more layers that share the same space, or are near to, selected features in another layer, can be selected, displayed, and analyzed. The layers used in select by location are known as the ***target layer(s)*** and the ***selector*** layer. The selector layer contains features that are known or selected, and the target layer(s) contain features that we are curious about.

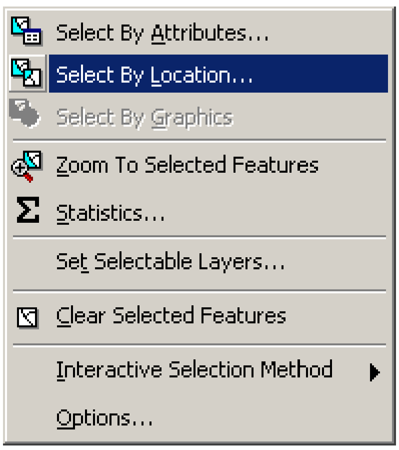


Figure A.6: *All selection options running on feature layers available in the Table of Contents from the ArcMap selection menu*

Based on the feature type of target and selector layers, several spatial relationships exist:

Spatial relationship	*purpose*	*target layer feature types*	*selector layer feature types*
are completely within	selects target layer features that are completely within selector layer features	Point Line polygon	polygon
completely contain	selects target layer features that completely contain selector layer features	polygon	Point line polygon
have their center in	selects target layer features whose centers fall inside selector layer features	point line polygon	polygon
contain the center of	selects target layer features which contain the centers of selector layer features	polygon	point line polygon
intersect	selects target layer features that intersect selector layer features	point line polygon	line polygon
are within distance of	selects target layer features that are within a given distance of selector layer features	point line polygon	point line polygon

A.2.2.Join by location (spatial join)

The powerful tool ***Join by location*** is actually quite similar to tabular joins, but instead of combinations based on one common attribute field, tables are joined using the ***shape*** attribute. While the results are slightly different, ***Join by location*** has in common with normal tabular joins the accretion of source tables to destination tables. Differing from classic primary-foreign key relates, join by location appends the attribute of a source layer to the table of the destination layer based on characteristics of proximity or containment. The spatial relationships that are used to match locations of features in the joined layers are ***inside*** and ***nearest***.

Similar to other functions of spatial analysis in ArcGIS, the application of Join by location depends on the layer feature type. The table below shows the types of relationships accepted between source and destination attribute tables:

		destination layer		
		point	**line**	**polygon**
source layer	**point**	proximity	proximity	containment
	line	proximity	part of	containment
	polygon	N/A	N/A	containment

The source layer is holding the features for defining the selection on the destination layer.

In the ***proximity*** relationship, the record for the feature in the source table that has the greatest proximity to the record for the feature in the destination table is appended to the record in the destination table.

In the ***containment*** relationship, the record for the polygon (source) completely containing the line or point (destination) is appended to the destination table's record.

The ***part of*** relationship applies only to line layers in which lines in one layer are subsets of lines in another layer.

A ***spatial merge*** creates a new layer in which multiple input features one common attribute value are merged into single features. The new features need not be adjacent. The new features, although possibly composed of many objects (points, lines, or polygons), are stored as one single feature with one single attribute record. When one individual object of the feature is selected, all objects of that feature are selected.

A.2.3. Proximity analysis

Within ArcGIS, the tools required to perform proximity analysis are separated into two categories depending on the type of input they accept: vector data or raster data. The vector-based tools vary depending on the types of output they produce. Essentially this means the ***Buffer tool*** creates new polygon features, while the ***Select Layer By Location tool*** outputs only a selection of features. Dispatching the ***Near tool*** results in a distance attribute added to the input features.

The proximity toolset in ArcToolbox contains tools that can be applied to analyse the proximity of spatial features between two feature classes but also within one feature class. The implemented algorithms can evaluate distances between features or calculate the distances around them, or identify features which are nearest to one another. So these tools can help to find areas served by a facility or objects affected by an activity.

Buffer	Creates buffer polygons to a specified distance around the Input Features. Dissolve may be performed optionally to remove overlapping buffers.
Multiple	Outputs new dataset of buffer polygons using set of buffer distances. The new

Buffer	polygons can be dissolved using the buffer distance values.
Thiessen Polygons	Computes Thiessen polygons based on input points. Thiessen proximal polygons divide the space allocating it to the nearest (input) point feature.
Near	Calculates the distance from each point in one layer to the nearest polyline or point in another layer or feature class.

Thiessen polygons

Thiessen polygons are very special since they have the singular property that any location within such a polygon is closer to its associated point than to the point of any other polygon and every polygon comprises only one (input) point.

Thiessen polygon features allocate the available space to the nearest point feature. They can be thought of as "bubbles" around each middle point location. These bubbles meet at locations equidistant from the two centres, along the perpendicular bisectors of the lines joining the centre points. Actually the bubbles divide the space into nearest-neighbour polygons. Other names for Thiessen polygons are *polygons of influence*, *Voronoi polygons* or *Dirichlet cells*.

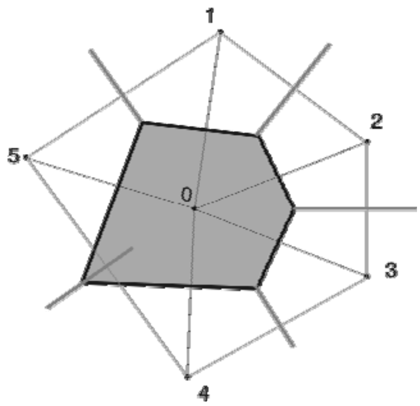


Figure A.7: Source point with encompassing Thiessen polygon

Sometimes Thiessen polygons are used instead of time consuming interpolation techniques in order to generalize a set of sample measurements to the areas closest to them. For instance, Thiessen polygons can be applied to generalize measurements from a set of variables to the areas around them.

In ArcGIS, Thiessen polygons are calculated using the ArcToolbox. Alternatively, ArcGIS Spatial Analyst can be used to compute Thiessen polygons on raster basis (using the ***Allocate*** function).

A.2.4. Network Analysis

Before being able to carry out any network analysis, ArcGIS' Network Analyst has to build and store the network characteristics as ***network datasets***. Such network dataset is generated from all features that will be used in the network analysis. The network dataset stores a powerful network attribute model supporting model impedances, delimitations, and hierarchies for the network. It includes an advanced connectivity model that is able to support complex scenario building, such as multimodal transportation networks (transportation using different carriers). The basic features the network dataset is built on are points, lines and turns.

Using ARC/INFO, coverages can be employed to create networks on-the-fly. In ArcView GIS 3.x, a consistent network was built when network analysis functions were applied based on a shapefile for the first time. In ArcGIS, as mentioned above, the network dataset storing this network persistently has to be build prior to analysis. Its properties can be modified and saved and it can be applied to model a multitude of networks using always the same network dataset.

When creating new network datasets, a variety of options available. A network dataset can be built based on shapefiles or feature classes in a feature dataset of a geodatabase. A shapefile network dataset is built on a line shapefile comprising the network basis (e.g. a road network) and, optionally, a shapefile turn attribute. Such shapefile based network datasets do not support multiple sources and cannot be used for modelling of complex multimodal networks.

A network dataset can be created in the ArcCatalog environment, but only after the Network Analyst extension was activated *(Tools menu – Extension – Network Analyst)*

The ArcMap online help provides more enlightening background information as well as a step-by-step tutorial supporting the creation of network datasets.

A.2.5. Running Network Analysis

Network analysis is carried out by choosing a new type of analysis from the Network Analyst menu (first to be activated and loaded) on the Network Analyst toolbar. The type of network analysis feature created is based on the type of the new network analysis task chosen. The output layer represents all inputs and results being part of the network analysis layer. The network analysis layer can be used and displayed as any other feature layers in ArcMap, this means the analysis layers support ArcMaps extended symbology, joins and any other characteristics common to feature layers. Even export to "on disk" feature layers of these "memory" feature classes is supported.

Network analysis layers can also be created employing Arcmap's geoprocessing tools (*Analysis tools – Network Analyst toolbox*).

Sources:

– Longley P.A., Goodchild M.F., Maguire D.J., Rhind D.W. 2005. *Geographic Information Systems and Science*, 2nd Edition. New York: John Wiley.

– Jones C.B. 1997. Geographical Information Systems and Computer Cartography, Prentice Hal

– ESRI ArcGIS 9.1 2006 *Online Help*

GIS Vector Data Analysis Exercises

E.1. Exercises

E.5.1. Spatial Analysis on vectors

Steps	Data	Remarks	Time
Geoprocessing	Keewwsh1 Kenards1n Kenards1s	Check on the three listed layers (keewwsh1 is the result of the projection carried out in Exercise 1.5) Make sure the three layers have the same Projection Load the three layers and display them: The roads of Kenya have been availed in two separate layers for areas north and south of the Equator. Our area of interest (Ewaso basin) is located at the junction of both areas. In the Data Management Toolbox use Append in the General tool set to merge the two shapefiles. If you want to keep both input shapefiles, copy one of the two road shapefiles and rename it to student\shp\kenards1. This will be the output feature class whereas the other shapefile will be the input feature class. As we are interested in the roads within the basin area, we will now clip the merged shapefile with the watershed boundary. Do this with the **Clip**-tool of the Analysis toolbox. Save the result as student\shp\keewrds1.	30 min
Buffering rivers and roads	Keewrds1 Keewriv1	In order to carry out a field survey on river water, we are interested in finding out those areas located at the same time within less than one km from any river and within less than 1 km from any road. Load the buffer tool from the Analysis toolbox. **Buffer** both roads and rivers with 1000 m distance and save the results as keewriv1buf and keewrds1buf in their respective directories. Make sure you have set the correct units of the data frame in the data frame – properties menu before carrying out the buffering. Check the buffer width with the measurement tool. **Intersect** both results in order to get the areas which are at the same time within 1 km from any river and within 1 km from any road. Save the result as student\shp\keewriv_rds	30 min

Dissolving and unioning	Keewlus1 Keewriv-rds	We wish to find out how many square kilometres of the areas identified in the intersect step above are located within large-scale ranches. Try to find the ***dissolve*** functionality in ArcGIS using the Desktop Help. Load the land use layer and dissolve the polygons according to the lcode (land use code). Save the resulting layer as student\shp\keewlus2 ***Union*** the dissolved land use with the keewriv-rds. Save the result as student\shp\keewunion1 Carry out a query to find out the areas within the buffer zones (bufferdis = 1000) and located in large-scale farms (use the land_use_code.doc) file to help you finding out which code corresponds to this type of land use). Go to the attribute table and switch to view only the selected polygons. Add a new field which you call ***area*** (type "Double"). Click on the header of the new field and select the field-calculator. Switch to the advanced view and type in the following VBA expression: Dim Output as double Dim pArea as Iarea Set pArea = [shape] Output = pArea.area Next, in the textbox below, type: Output /1000000 This will return the area in km^2 for the selected polygons. (Alternatively you may use the ***Calculate Areas*** script in the utility toolset of the Spatial Statistics Toolbox) Go to field – statistics (column header) and under SUM check at the number of square km^2 matching the query.	30 min
Total time:			90 min

E.5.2. Proximity analysis: Neighbourhood influence and queries

Steps	Data	Remarks	Time
1 *Explanatory remarks*		– For planning purposes the relationship between land use type, soil composition etc. and distance to streams has to be analysed. As a consultant you are interested in which land use plot centres are close to streams and what that actual distance is. Instead of analysing whole polygons, you decide to work only with polygon centroids.	
2 *Create centroid layer from poygons*	keewlus1.shp keewlus_cen.dbf keewlus_cen1.shp	– Load *keewlus1.shp* and open the attribute table. Add fields called ***x_coord*** and ***y_coord*** to the table, format type is ***Float***. – Right-click the added x_coord field and choose ***Field calculator***. Click **Yes** to skip the warning message. (Because of editing newly created fields, there is no need to worry about undoing the edit). – Check ***advanced*** button and fill the following VBA statements in the upper field: Dim dblX As Double Dim pArea As IArea Set pArea = [Shape] dblX = pArea.Centroid.X – In the lower text entry field, enter **dblX** – Repeat the calculation for the y_coord (replace the variable ***X*** by ***Y!***) – Export the table to *Keewlus_cen.dbf* using the export function from the attribute table ***Options – Export***. – Load the *keewlus_cen.dbf* into ArcMap, project the events using ***Add XY Data...*** from the ***Tools*** menu. Make sure the appropriate table is selected, check X,Y fields and import the projection from *keewlus1.shp* before you click okay. – Check the results– do the points represent centroids? – Since the resulting points are only events, export the event layer to a new shapefile as *keewlus_cen1.shp.*	

3 ***Select points near line*** ***(Method 1)***	keewlus_cen1.shp keewriv1.shp	– Add keewriv1.shp to the map. From the ***Selection*** menu, choose ***Select By Location***. – Select features from *keewlus_cen1.shp* that ***are within a distance of*** features in *keewriv1.shp* with a selection buffer distance of ***7500*** meters.	
4 ***Select points near line*** ***(Method 2)***	keewlus_cen1.shp keewriv1.shp keewdist.shp	– Now right-click the *keewlus_cen1.shp* layer, then select ***Joins and Relates – Join.*** – In the first dropdown, choose ***Join data from another layer based on spatial location.*** – From step 2, choose the lower option (***Each point will be given all the attributes…***) – Save the output as *keewdist.shp* and add the layer to the view. Prepare a layout with that layer classifying the distance attribute (***Layer properties – Symbology – Quantities – Graduate colours – 5 classes***) – Apply a selection based on the ***Distance*** field (Distance < 7500), then open the attribute table; show ***Selected*** records and sort ascending. → While the selection result in the two methods is identical, using the joined distance field it is possible to understand as well the distribution of distances. → What is the mean distance of land use plots from rivers for those plots within 7500 meters of a stream? (Right-click the ***Distance*** field and select ***Statistics*** to find out)	
5 ***What kind of road is crossing agricultural land?***	keewlus1.shp land_use_code.doc kenards1n.shp	– The selection to be carried out is a ***"line-on-polygon"*** selection. First, select all polygons of type "agriculture" using ***Select By Attributes*** from the ***Selection*** menu (consult ***land_use_code.doc*** for the LCODE). – Next, keeping the previous selection, use ***Select By Location*** from ***Selection*** menu and ***select features from*** *kenards1n.shp* that ***intersect*** features in the layer keewlus1.shp (check ***Use selected features***). – Open *kenards1n.shp's* attribute table and show only selected features; check the attribute ***DCW_DESC*** that indicates the type of road.	
6 ***How many centroids are***	keewlus_cen1.shp	– The solution is a ***"point-in-polygon"*** selection. First, select all centroid points from *keewlus_cen.shp* that are completely within the watershed *keewwsh_geo*.	

outside the watershed?	keewwsh_geo	(Use *Selection – Select By Location*). – Next, open the centroid points attribute table and Switch the selection (*Options – Switch Selection*), since you are interested in all points outside the watershed. Show only selected features and use *Statistics* by right-clicking the header of any number attribute.	
7 ***Which is the preferred lu type for settlements?***	keewlus1.shp keewtow1.shp land_use_code.doc	– To answer this question, you need to apply a "polygon-on-point" selection. To do so, select all features from keewlus1.shp that completely contain features from keewtow1.shp *(→Select By Location).* – Then open the attribute table and check the LCODE item (consult *land_use_code.doc* for LCODE interpretation)	
8 ***Check out soil types and lu classes***	keewlus1.shp kenasot.shp	– This time you will select features based on "polygon-on-polygon" selection. First select (by attribute) all plantation forest polygons, then use *Selection – Select By Location* and select features from kenasot.shp that *intersect* with plantation forest type. – Repeat the procedure by using *are completely within*, *completely contain* and *have the centroids in* instead of *intersect*. – Compare the results and define which one best represents reality (in terms of intersecting area)?	
9 ***Which lu polygons do not have direct access to water?***	keewlus1.shp keewriv1.shp	– Use *Selection – Select By Location* in order to intersect land use with the rivers. The resulting selection contains all polygons with direct access to water. Switch the selection (step 6) in order to get the polygons without direct access to water. – Try to select those polygons that do not have access to water and whose neighbours do not have direct access to water. (Hint: Multiple selection necessary; check out the options available from *Select By Location*...)	
Total time:			140 min

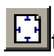
E.5.3. Proximity analysis: Service area allocation

Steps	Data	Remarks	Time
1 *Explanatory remarks*		- Imagine you are hired by a food trading company that has branches in all major towns in Kenya. This company wants to invest and to increase the number of branches. It is your job to tell the managers where opening new branches (covering "service areas") is most profitable. One branch cannot serve more than 1mio customers. In order to determine the locations, you have to analyse existing branches in terms of population and neighbourhood aspects. You will use Thiessen polygons.	
2 *Create Thiessen Polygons*	Kenatow1.shp branch_thi.shp	- Load the kenatow1 point shapefile into ArcMap; these are the locations of existing branches. In order to allocate the service areas, calculate Thiessen polygons (Search for ***Create Thiessen Polygons*** in ArcToolbox). Choose *keep all attributes* and save the output (polygon shapefile) as branch_thi.shp - What is special about the polygon areas?	
3 *Clip*	branch_thi.shp kenapop89.shp branch_thi_c.shp	- Clip the Thiessen polygons with the national boundaries of Kenya; apply ***Clip*** from ArcToolbox. You may use kenapop89.shp as clip feature. There is no need to specify any XY tolerances. Save output as branch_thi_c.shp.	
4 *Calculate areas*	branch_thi_c.shp	- Calculate the clipped Thiessen polygon areas. If you can't figure out how to proceed, check the end of the last exercise E.5.1. - Which branch ("major town") has the largest service area? Which one the smallest?	
5 *Join by location*	branch_thi_c.shp kenapop89.shp branch_stats.shp	- Now you will query the population that is living in the service areas. To do so, you have to spatially join the population data to the Thiessen polygon shapefile. - Right click the Thiessen layer in the table of contents and select join. Next, select *join … on location,* then choose the population layer to be joined. Next, choose the option to join summarized attributes by ***sum*** and save the result as *branch_stats.shp*. If you want to recapitulate what join means, you may press ***About***	

		Joining Data from the bottom of the Join Data interface. – Check the result by loading the layers into ArcMap. – What is the highest number of clients served by which branch location? – Compare the total population number (total of Kenya) based on *branch_stats.shp* with the sum based on *kenapop89.shp* (right click the "total" header in the attribute table and choose ***statistics***). Explain the difference in the total sums.	
6 ***Mapping***	branch_stats.shp	– Now you have extracted the geographic territory for each branch and you know the potential number of customers. Next, you will create a meaningful map and graph output. – Right click the layer in the TOC, select properties and change the layer symbology to Quantities – Graduate Colors. The value you are basing your map classification by is Sum_"xxxx". Click ***Classify*** and choose ***Quantile*** and 10 for the number of classes. Now you have 10% within each class. Adjust the color ramp if you desire. – Check the map and attribute table and decide whether you have to establish new branches and where (rule: not more than 1 mio customers).	
7 ***Create additional locations***	kenatow1.shp	– Convert kenatow1.shp to kenatow2.shp and add the required branch locations to the shapefile (by editing manually). Consider well where you place the new locations. – Redo the necessary steps 2, 3, 4, 5 and 6 in order to get the final ideal branch distribution. – Optionally: Prepare graphs and map layouts and compare the results.	
Total time:			140 min

E.5.4. Vector Analysis using the ArcGIS Model Builder

Steps	Data	Remarks	Time
1 *Explanatory remarks*		- In this exercise you will learn a powerful tool implemented within ArcGIS called model builder. The model builder is an efficient tool which can streamline workflows. One of the outstanding features of using the model builder is its self-documentation. The models can be saved and run again, whereas it may be difficult to comprehend the process exactly if you simply use a series of manual operations. Models can be saved as files for distribution to others.	
2 *Create Buffer*	keewriv1.shp keewriv1_buf1000.shp	- Load *keewriv1.shp* and calculate a buffer of 1000m each side, side type: FULL, end type: ROUND, Dissolve type: ALL. (Search for Analysis – ***Buffer*** in the ArcToolbox). Save output as *keewriv1_buf1000.shp.*	
3 *Extract the lc part from the watershed area*	keewlus1.shp keewwsh_geo.shp keewclp1.shp	- Intersect *keewlus1.shp* with *keewwsh_geo.shp* using the intersection tool from the Analysis tools found in the ArcToolbox. - Save the output as *keewclp1.shp* in your folder ***calculations***	
4 *Clip...*	Keewclp1.shp keewriv1_buf1000.shp keewrivbuf.shp	- Clip the previously extracted *keewclp1.shp* using the clip feature *keewriv1_buf1000.shp*. The tool to run is ***clip*** from the ArcToolbox. - Save the output as *keewrivbuf.shp* - Check the resulting layer - can you imagine of a more straight forward solution to this problem?	
5 *Explanatory remarks*		- Each the step you have just carried was performed on a manual or “tool” basis. Imagine you need to link a series of such tasks together; rather than performing each task sequentially, it is possible to build a model running all the processes on one click.	
6 *Creating new Model*	keewriv1.shp keewlus1.shp keewwsh_geo.shp	- Right-click within ArcToolbox and select ***New Toolbox***. Change the new toolbox name to *your name_Toolbox.* - Click on the new toolbox, next right-click and select ***New > Model***. The model opens in a new window.	

		– Drag and drop the layers *keewriv1.shp*, *keewlus1.shp* and *keewwsh_geo.shp* from the ArcMap table of contents into the new model. They will display as blue ellipses holding its name. – Search for the necessary analysis tools in ArcToolbox and drag them into the model ***Overlay – Intersect***, ***Exract – Clip***, and ***Proximity – Buffer.*** – Use the ***Add Connections*** tool to connect the *keewlus1.shp* and *keewwsh_geo.shp* to the ***Intersect*** tool, and then connect *keewriv1.shp* to the ***Buffer*** tool. – Now connect the output of ***Intersect*** and the output of ***Buffer*** to the ***Clip*** tool. Now all necessary connections are done. – Next you have to double-click the ***Buffer*** tool to set its parameters. Set distance to 1000 meters and set the output to keewriv2_buf1000.shp, then set dissolve type to ALL and click okay. – Open the Clip tool and set the Input Features to the output of the intersection. Set the Clip Features to the buffers keewriv2_buf1000.shp. Save the ***Output Feature Class*** to *keewrivbuf2.shp* – Activate the ***Auto Layout*** button and the ***Full Extent*** button to get an overview of the model. – Right-click the final output and select ***Add To Display*** , then click ***run.*** – The output will be added to the data frame. Zoom in to check the geometry. – Compare the solution with the previous one from step 4	
7		– Try to implement other models from previous exercises if you like.	
Total time:			120 min

E.5.5. Network Analysis I

Steps	Data	Remarks	Time
Preliminary remarks		The roads of Nakuru were digitised on the basis of a satellite image and are differentiated into five types. Travel speed on these roads is not uniform. The following average travelling speed for each road type has been defined: ***Road type*** ***Road code*** ***Speed*** – Main road: A 80 – Secondary road: B 80 – Small streets: C 60 – Unpaved streets: D & T 50	
Calculating travel costs	Kenkrds1 (engineering)	– Set the units in the Data Frame Properties to “meters”. – Load the road shapefile, activate the *Editor* toolbar, the *Topology* toolbar and the *Line Editing* toolbar and change to editing mode. Using the *Map Topology* toolbar, build map topology for the layer, defining an appropriate cluster tolerance. – Make sure that there is a regular node at each intersection (using *Planarize Lines*) and remove any unwanted dangling nodes (using *Line Editing* tools). – Open the attribute table; add a field of type “floating” called LENGTH. Use the field calculator for the calculation of length of the different arcs. Follow the instructions from the Field calculators’ Help (half way down) if you don’t now it. Next, add another field of type “short integer” called SPPED and enter the speed for each class, using “Select by Attributes” for querying and “Field Calculator” for data entry. Add a field of type “floating” called COST. This field is the one that will be used for the calculation of the best route in terms of travel time costs. – Calculate the COST field as follows, using the field calculator: *[COST]* = [length] / [speed] / 1000 * 60	60 min.

Create a Network Dataset		– Activate the *Network Analyst* extension in *ArcCatalog*, navigate to Nk_roads (engineering) and create a *New Network Dataset* (right click on the dataset in ArcCatalog*)*. You may accept the proposed name, then click next, accept connectivity, click next, reject elevation settings, click next, accept turn settings, click next and specify the attributes to be used for network calculations (COST). Here accept the COST field and set the units to minutes Add another attribute, name it LENGTH, set its units to meters and accept. Then click next and reject the direction settings. – Finally you will get a summary of settings where you still can go back and correct any settings. If not necessary, click finish to complete the network dataset before you have to build it for further deployment.	20 min.
Finding shortest distances	Kenkrds1_ND kenk_qb120.tif	– Load the network dataset (kenkrds1_ND) together with kenkrds1 and kenkrds1_ND_Junctions into ArcMap. Load the *Network Analysis* toolbar and select *New Route* from the *Network Analysis* dropdown menu. Show the *Network Analyst Window* and start locating some network locations using the *Create Network Location Tool*. Once this is done, click the *solve* button and check the resulting routes. To check travel costs (in minutes or meters), right click the newly created routes in the *Network Analyst Window* and check the cost and length fields. – Click the *Route Properties* tab next to *Route* in the *Network Analyst Window* and reorder the stops to find optimal routes. Add some barriers (first activate *Barriers* in the *Network Analyst Window)* before creating them using the *Create Network Location Tool* again. You may change the locations using the *Move Network Location Tool*. Play around with these options. – Click the *Directions Window* tab to get a description – Find the shortest and the fastest ways between Pipelines (Elementaita Road) and Prisons. Is it the same way? How far is it in minutes to travel and in meters to drive? – Find the shortest and the fastest ways between the New Sewage Treatment Plant and Flamingo Bottlers Ltd. Do they differ? How far is it?	50 min.

Finding service areas	Kenkrds1 kenk_qb120.tif	– Load the network dataset (*kenkrds1_ND*) together with *kenkrds1* and *kenkrds1_ND_Junctions* into ArcMap. Load the *Network Analysis* toolbar and select *New Service Area* from the *Network Analysis* dropdown menu. Show the *Network Analyst Window* and start locating some facility locations using the *Create Network Location Tool*. Once this is done, click the *solve* button and check the resulting areas. To change the minutes, check the *Network Layer Properties Analysis Settings* tab check travel costs (in minutes). – Add some barriers (first activate *Barriers* in the *Network Analyst Window)* before creating them using the *Create Network Location Tool* again. Again, you may change the locations using the *Move Network Location Tool*. Play around with these options. – Check which part of town can be reached from the central police station, by car, within 4, 6 and 8 minutes. (assuming, there are no one – ways and no traffic jam)	40 min.
Finding closest facility	Kenkrds1 kenk_qb120.tif	– Load the network dataset (kenkrds1_ND) together with kenkrds1 and kenkrds1_ND_Junctions into ArcMap. Load the *Network Analysis* toolbar and select *New Closest Facility* from the *Network Analysis* dropdown menu. Show the *Network Analyst Window* and start locating some facility locations (hospitals) using the *Create Network Location Tool*. Then put an incident location (accident) Once this is done, click the *solve* button and check the resulting areas. To change units, open the *Network Layer Properties Analysis Settings* tab and change the impedance from cost to length). – Add some barriers using the *Create Network Location Tool* again. Again, you may change the locations using the *Move Network Location Tool*. Play around with these options. – Click the *Directions Window* tab to get a description – Is there a difference between the calculated ways when impedance is changed from length to cost?	40 min.
Additional task		– Considering that average walking speed is 3 km per hour, calculate which part of town can be reached from the Post office within half an hour.	40 min.
Total time			250 min.

E.5.6. Network Analysis II

Steps	Data	Remarks	Time
Preliminary remarks		– Contaminating material must be carried efficiently from "Lanet Hospital-Army" to "Mother Kevin dispensary" (check layer *kenkhea2*). Since the area around the water pumping stations (check layer *kenkpum1*) must not be endangered, a "no-go radius" of 1000m or even better 1250m must be respected. – Calculate the 3 scenarios for the transportation considering the shortest path and the fastest path. ***Scenario 1:*** No limitations ***Scenario 2:*** Respect a no-go area of 1000m ***Scenario 3:*** Respect a no-go area of 1250m – Present and discuss the resulting paths in form of a series of maps	
Finding shortest and fastest path I	Kenkrds1 (engineering) Kenkhea2 (socio) F_T_locations	– Set the units in the Data Frame Properties to "meters". – Load the layer *kenkrds1* already prepared and deployed in E.5.5. You may also apply the same Network Dataset used in E.5.5. If not available, create a new Network Dataset following the steps specified under ***Create a Network Dataset*** in E.5.5. – Load the layer *kenkhea2* and set it the only selectable layer. Select the From-location (Lanet Hospital-Army) and To-location (Mother Kevin dispensary) and export the selected points to a new layer, save as *F_T_locations*. – Create a new route using the ArcToolbox; the *Make Route Layer* Tool (from *Network Analyst Tools – Analysis*) will do the job. Select *kenkrds1_ND* for input, *Route* for output and *COST* for impedance attribute. – Add the locations using the *Add Locations* Tool (from *Network Analyst Tools – Analysis*). Input network analysis layer is *Route*, Sub layer is ***Stops*** and input locations is *F_T_locations*.	60 min.

		– Use the *Solve* tool (from *Network Analyst Tools – Analysis*) in order to get the fastest route between the two newly added points. Select *Route* for Input network analysis layer. The result should be a route-line between point 1 and 2. If you are not happy with the order, change it using the Route Properties window. Here you can also change the impedance settings from Cost to Length, just for test reasons. Don't forget to resolve the routing after changing the settings. – Prepare and export a map layout and calculate length and travel time for the final discussion.	
Create barriers from buffer rings	kenkrds1 kenkpum1 kenkpum1_buf kenkpum1_buf_line kenkpum1_buf1000 kenkpum1_buf1250 kenkpum1_buf1000isct kenkpum1_buf1250isct kenkbar1000 kenkbar1250	– Load the layer called *kenkpum1* and calculate multiple buffer rings around it; one at 1250m, another at 1000m. Use ArcCatalogs "Search" function to localize the *Multiple Buffer Ring* tool to be used. Save the output polygon layer as *kenkpum1_bu* in the directory "engineering". – In order to get the intersecting points between buffers and the roads, you have to convert the polygons to lines. The tool to use is called *Polygon to Line* found in the ArcToolbox. The input feature is *kenkpum1_buf*, the output is *kenkpum1_buf_line.* – Next you have to create 2 layers from this output layer. One holding the 1000m buffer lines, the other the 1250m buffer lines. Use the table select tool and the data export functionality in the TOC. Save the outputs as *kenkpum1_buf1000* and *kenkpum1_buf1250.* – Intersect the two layers with the kenkrds1 layer, using the *Intersect* command found in ArcToolbox. Save the outputs as *kenkpum1_buf1000isct* and *kenkpum1_buf1250isct.* Make sure to change *Output Type* to ***POINT***, since we are looking for the points of intersection. – Since the last layers were output as *multipoint* features that are not accepted for calculations within network datasets, you will have to convert the *multipoint* to *simple point* features using the *Feature to Point* tool from the ArcToolbox. – Save the outputs as *kenkbar1000* and *kenkbar1250.* Check the layers in ArcMap – you will use these points	60 min.

		for creating barriers delineating the no-go areas.	
Finding shortest and fastest path II	Kenkrds1_ND Kenkrds1 kenkbar1000 kenkbar1250	– If not available yet, load the layers *kenkrds1_ND* and the *kenkrds1* – Add the newly extracted barrier locations using the *Add Locations* Tool (from *Network Analyst Tools – Analysis*). The Input network analysis layer is *Route*, Sub layer is ***Barriers*** and input locations is *kenkbar1000*. – Now use the *Solve* tool (from *Network Analyst Tools – Analysis*) in order to calculate the fastest route between the two initial locations “Lanet Hospital-Army” and “Mother Kevin dispensary”. Select *Route* for Input Network Analysis layer. – Repeat the same procedure for *kenkbar1250* and compare the results. – Prepare and export map layouts for both scenarios and calculate length and travel time for the final discussion. What are the impacts of the two different buffer sizes, advantages and disadvantages?	40 min.
Total time			240 min.

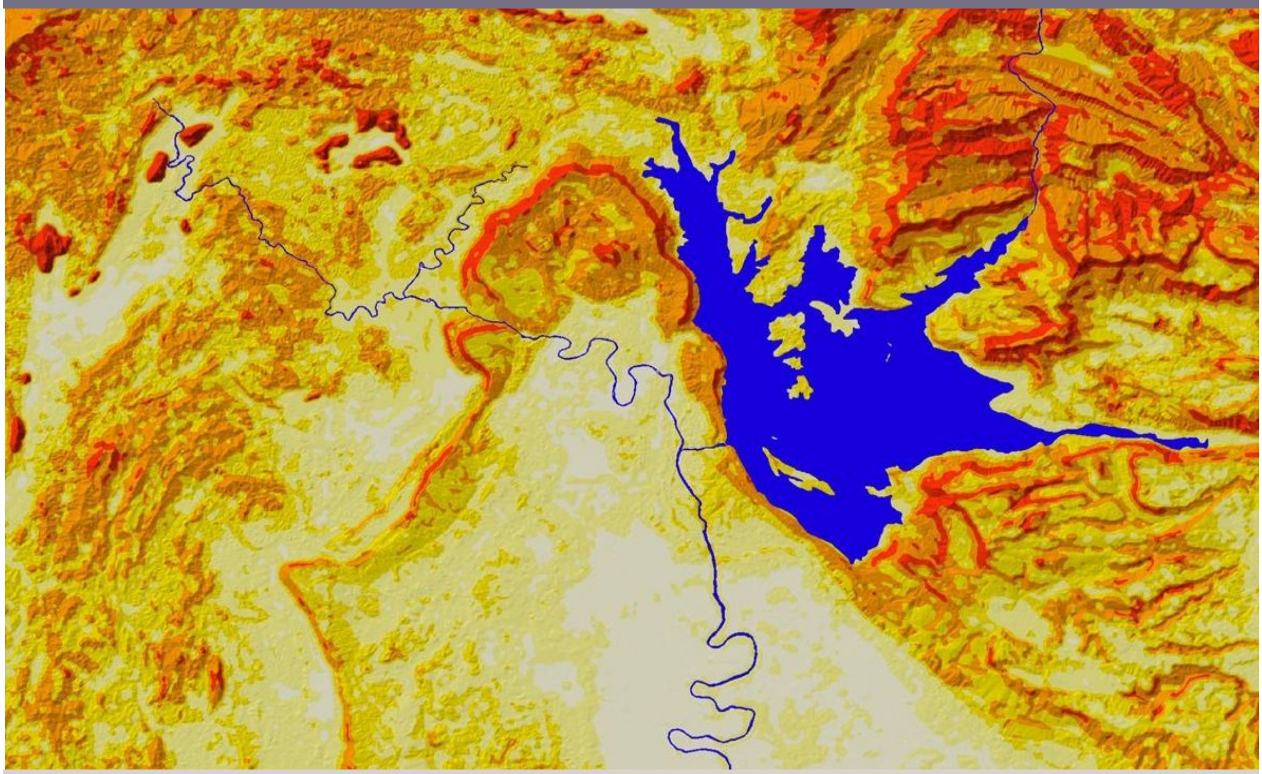
Eastern and Southern Africa Partnership Programme

Capacity Building in Geoprocessing

Module 6

GIS Raster Data Analysis

Centre for Development and Environment



centre for development and environment

Training Concept

This training module is part of a Geoprocessing Training Concept elaborated by the Centre for Development and Environment (CDE). Each module looks into GIS or RS methods and functions. A course in any of the two disciplines can be composed of a varying number of selected modules, depending on the participant's requirements and the duration of the course. Additional modules will be added to the Training Concept based on concrete requests, or on the basis of enhanced expertise of the CDE Geoprocessing unit. Each Training Module is divided into three main parts:

T	Theory	Theoretical background and concepts, as well as available references on the module's main topics
A	Applications	Specificities of selected GIS and RS software regarding the module's main topics. Currently the Training Modules are designed for use with ESRI's ArcGIS 9.x software family, but will be stepwise expanded, depending on the specific requirements of course participants.
E	Exercises	Concrete exercises on the module's main topics for implementation by the course participants with use of selected software

Module 6 deals with the analysis of raster data. The main focus of the module, on one hand is on topographic analysis, including the generation of digital elevation models and their derivatives, on the other hand interpolation of non-topographic data and on hydrologic analysis. Raster overlay operations are also dealt with, particularly conditional statements and arithmetic operations between raster data sets. Module 6 complements Module 5, which deals with the analysis of vector data. Both modules are supposed to equip the participants with a sound understanding of spatial data analysis. Highly specialised and/or complex analysis processes are not included, considering the introductory character of the modular training concept. The results obtained through the exercises of this module are particularly suitable for integration into map layouts. Therefore, the module can be concluded with the generation of a map layout and its printing and commenting in the frame of the workshop.

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Based on various course manuals and guidelines prepared by CDE

Contents

GIS Raster Data Analysis Theory

T.1. Raster Analysis

Most GIS users may be familiar with working and analyzing vector-based GIS data. However, raster data analysis can be even more powerful and actually provides a lot of additional analysis tools not available when using vector data. This module covers the basics of raster analysis in a GIS. The major aim is to introduce a multitude of powerful functions in a raster environment, comprising overlay functions, summary functions, local neighbourhood and distance operators as well as grouping or generalisation functions. GIS raster concepts and basic functions will be discussed.

T.2. Raster Calculations

Raster data calculation is a very powerful method when it comes to the analysis of continuous surface features. Since many of the functions presented for vector analysis are either inefficient in dealing with certain spatial questions or data types, raster based processing introduces a more powerful approach to applying spatial analysis.

Raster data are represented using the ***cell data model*** in a ***raster data structure*** first presented in module one. A raster represents a matrix of cells with numeric values. In cell-based GIS, all cells are uniform and can represent any geographic features such as points, lines, polygons or surfaces. All data types are treated in the same way. However, the main problem with uniformity is that accuracy is lost. It is the resolution of the cell that will determine how much accuracy is lost.

T.2.1. Boolean Logic in GIS

Raster analysis is mainly based on Boolean logic, which is powerful in computing new attributes in topological overlay processing for both vector and raster based systems, as they can be applied to all data types. Boolean algebra uses the logical operators AND, OR, NOT to determine whether a particular condition is true or false. Consider two sets (set A and set B):

The AND operator (∩) is the intersection of two sets – for example those entities that belong to both set A and set B (A ∩ B)

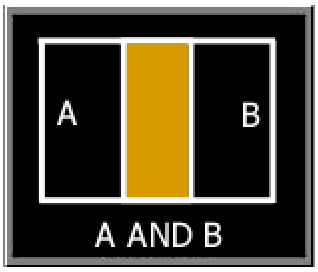


Figure T.1: *Boolean AND operator*

The OR operator (∪) is the union of two sets – for example those entities that belong to either set A or to set B (A ∪ B)

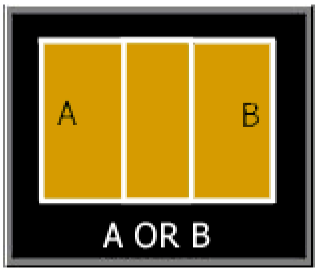


Figure T.2: *Boolean OR operator*

The NOT operator (¬) is the difference operator identifying those entities that belong to A but not B (A ¬ B)

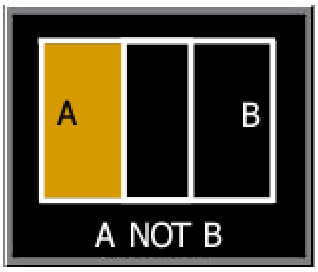


Figure T.3: *Boolean NOT operator*

T.2.2. Reclassification

Reclassification is a generalisation technique used to re-assign values in an input raster layer to create a new raster layer. Reclassification changes the value of the input cells on a cell-by-cell basis within the area under analysis.

This technique is commonly used to convert interval and ratio scale data into an ordinal ranking for land use suitability modelling using map algebra. It has the additional benefit of reducing file sizes of raster layers.

T.2.3. Slicing

Slicing is considered as a global function similar to reclassification; however it uses statistical measurements to subdivide the region from interval/ratio scales to ordinal rankings, rather than user defined intervals. There are two different approaches to slicing: equal interval and equal area.

Equal area means that the input values will be divided into n zones with each zone having the same number of cells, i.e. so that each zone represents the same area.

The **equal interval** slice determines the range of the input values and then divides the range into n zones; therefore each zone could have a different area. Slicing is useful to simplify displays or analysis of continuous data such as elevation and rainfall. It is also used to reduce the number of categories in an interval level map.

Slice changes a range of values of the input cells by specified ranges, zones of equal area, or zones with equal intervals within the analysis window

T.2.4. Zonal operations

Zonal operations are also sometimes called region operations or region functions. Zonal operations are commonly used when there is need to analyse raster data that does not actually fit the shape of an individual grid cell. For instance, neighbourhood operations define their area of interest depending on individual grid cells. With zonal operations regions can be analysed by clustering similar cell values into homogenous regions.

Zones can be defined at the data capture stage such as when vegetation polygons are digitised. But zones can also be created using reclassification techniques. Processing of zones is done on a zone-by-zone basis and not on a cell-by-cell basis as usually in raster analysis.

The zones of a map layer can be defined as sets of contiguous locations that reflect the same values, such as:

- ownership parcels
- political units
- islands or lakes
- patches of the matching vegetation type

T.2.5. Raster Neighbourhood Operations

Neighbourhood operations are one method of analysing data in a GIS environment. They are especially important when a situation requires the analysis of relationships between locations, rather than interpret the characteristics at individual locations.

Neighbourhood operations are commonly called ‘Focal Functions’ since each operation performed generates a value for the ‘focus’ of the neighbourhood. The neighbourhood focus is generally called the scanning cell and its neighbours – that is the cells surrounding it – are known as the scanning neighbourhood. The scanning neighbourhood can take on various sizes and shapes, which are defined by selecting the appropriate options in the GIS package. The most common neighbourhood shapes are:

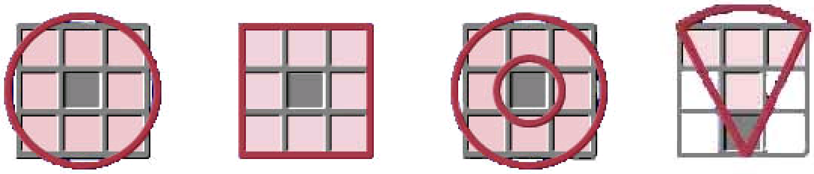


Figure T.4: *In the above examples the scanning cell is shaded grey, and cells in the scanning neighbourhood (delimited by a red border) are shaded pink. Also the scanning neighbourhood for each of these neighbourhood shapes includes the scanning cell, with the exception of the “donut” shaped neighbourhood. At this scale there seems to be no difference between the square and circular scanning neighbourhoods.*

T.3. Topographic Analysis

The earth’s surface is a continuous phenomenon. There are different ways of representing such surfaces in digital manner. Digital terrain models (DTM) are one particular way of representing earth surfaces. A DTM is a model of a topographic surface in a digital format. The term digital terrain model or DTM is often used to describe any digital representation of a topographic surface; however it is also used to refer precisely to a raster or grid of spot heights. The resolution, or the distance between adjacent grid points, is a critical parameter of any DEM. The data sets should be visualized as continuous surfaces.

T.3.1. Digital Terrain Models

A DTM, or Digital Terrain Model, is a map containing one piece of elevation information for each and every point on its own surface. This particularity distinguishes the DTM from a topographic map containing elevation information along linear, 2-dimensional elevation contours only (on topographic maps, the elevation between 2 lines has to be approximated by the user). Several **characteristics** describe a DTM:

- A DTM is a **computer-stored** representation. It is a type of spatial information processed and digitally stored as a file, or a set of files in a Geographic Information System (GIS).
- A DTM attributes **elevation information** to each and every point of the area it covers.
- The elevation information in a DTM is not measured in reality, but calculated from preliminary data (topographic map, elevation contours, spot heights).
- As the DTM is digitally stored, topographic information (elevation, landform, shape, slope, etc.), can be retrieved in subsequent steps.

- In combination with other data sources, the DTM provides an ideal basis for numerous simulations and interpretations.
- A DTM **represents reality** (in this case the topography of an area) as accurately as possible, while being as simple and handy as possible.

There are different GIS-based tools to calculate a DTM. These tools are usually referred to as algorithms. Examples of algorithms are provided in the “Applications” part of this module.

T.3.2. Slope

Slope is an indication of the steepness of the ground surface. Low slope values stand for flat terrain; the higher the slope values, the steeper will be the terrain. Slope is derived by calculating the tangent of the surface by dividing the vertical change in elevation by the horizontal distance. Viewing the surface in cross-section, a right angle triangle can be visualized:

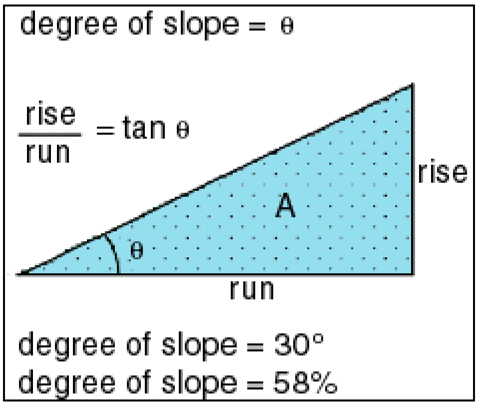


Figure T.5: *Calculation of slope based on digital terrain data*

Normally slope is expressed in percent which is equal to the tangent multiplied by 100.

$$Slope\ (\%) = Height / Base \times 100$$

When the slope angle equals 45°, the rise is equal to the run. As a percentage, the slope of this angle is 100%. When the slope approaches a vertical surface, slope percent can reach infinity as the base distance approaches zero.

T.3.3. Aspect

Aspect is calculated using the north-south and east-west gradients as expressed using the following equation:

$$Aspect = ArcTangent\ (dEW/dNS)$$

The above equation is adjusted to reflect aspect in degrees in a range from 0 to 360. Often -1 is used to represent a cell with no slope (skyward aspect) and the values from 0 to 360 represent azimuths in clockwise degrees from north. North is 0, East is 90 degrees, South is 180 degrees etc. Optionally, the result is then divided by 22.5 and converted to an integer to derive a set of generalized solar azimuths.

T.3.4. Hillshade Analysis

The technique of hillshading is used to generate shaded relief maps. Relief shading is applied to visually enhance and analyze the terrain features by simulating the effects of sunlight. Hill shading is an estimation of surface reflectance from the sun at any aspect and altitude. The artificial reflectance takes values in a range from 0 to 100. Interestingly it seems that natural interpretation of terrain is with the light from north east, even for people living on the northern hemisphere.

T.3.5. Viewshed Analysis

The study of visibility between points on a terrain is referred to as viewshed analysis. It is used for visual impact assessments and for calculating the visibility of each cell from an observer cell. Visibility is computed by measuring the tangent from any observer cell to every other cell. An increase in the tangent in the line of site from the observer means the cell is visible. If the tangent in the line of sight is decreasing, the cell is invisible. As distances involved in viewshed analysis become greater than around 10 km, the effects of earth curvature should be taken into account.

GIS Raster Data Analysis Applications

A.1. Raster data calculation with ArcGIS

Most tools needed for the analysis of raster data (except for operations specific to remote sensing data) can be found in the ArcToolbox, in the Spatial Analyst Tools folder. The tools provided allow for the formulation of conditional statements, the calculation of a variety of distance and neighbourhood functions, the interpolation of vector data and the calculating of mathematical operations on raster data (arithmetic operations on one layer, or between several layers).

T.3.6. Some basic raster functions in ArcGIS

Clipping

To clip a raster is very often useful to limit the study area for any calculations to speed up further analysis. An alternative to clipping is to set the analysis extent and analysis mask accessible under *Options* in the *Spatial Analyst tool bar*. Grid clipping can be done by simply setting the analysis extent and analysis mask under *Options* in the *Spatial Analyst tool bar* and using the *Raster Calculator* function for evaluating the output raster. The setting of analysis mask and analysis extent can be done using a shapefile or any other extent. The command *Extract by Mask* in ArcToolbox can also be used for clipping.

Zonal Statistics

This feature uses one data layer to summarize the values of any other data layer. For example, using zonal statistics it is very easy to summarize the elevation characteristics for each region in Kenya. The zone layer is regions, and the raster layer containing the values is elevation (DTM). The value raster may contain integer or floating point data. The zone data set may be a vector or raster layer. This command is very useful for summarizing data. This type of function is often faster and easier to use than to figure out how to summarize information stored in a vector file.

The Zonal Statistics command is found in the Spatial Analyst toolbar. Advanced options for zonal statistics are accessible in the ArcToolBox.

Tabulate Area (also Cross tabulation)

This feature can be used to compare and calculate coincident areas. For instance, using Tabulate Area, one can calculate the area of each land cover type in each zone region. The first input would be the land cover raster; the second one is the zone. Unfortunately the implementation of this command proved to be instable and limiting in ArcGIS. The Tabulate Area command can found in the ArcToolBox.

Data Reclassification

This function is mainly used to generalize or create new classes of data. For example, reclassification is applied to generalize land cover data. “Evergreen forest” and “mountain forest” can be reclassified to the new class “forest”. Reclassification can also be used to create discrete classes from a continuous data range. For example elevation data may be reclassified to classes (0 to 200 m = 1, 201 to 400 m = 2, …). Reclassify is accessible from the Spatial Analyst tool bar and in ArcToolBox. However, ArcGIS does not allow to reclassify integer to floating point data or vice versa – instead, the Con statement has to be used in this case.

Conditional Statements

The “Con” statement is quasi the “workhorse” of raster analysis; it is very useful in several situations, for instance to extract cells that meet particular requirements. It has a lot of variations. ESRI’s online support page (support.esri.com) provides lots of discussions concerning the use of the con statement. In ArGIS, the Con statementi is found in ArcToolBox, but it is also accessible from the Raster Calculator on Spatial Analyst’s tool bar.

Group

The group function generates unique “groups” of contiguous cells holding the same value. For instance, it can be used to extract areas of snow covered land. Each area can then be evaluated separately.

Mosaic

Mosaic is used to combine adjacent grids. However, there is also the Merge function which is basically used for the same thing. ArcGIS has many variations of this command. Most of the mosaic commands may be found in the ArcToolBox.

Map Algebra

Map algebra is the cell-by-cell combination of raster data layers. Since numbers are stored in the raster grid, each number gives a value at a specific raster cell location. Any operations can be applied to each of the numbers in a raster layer. Rasters can be combined by operations like layer multiplication, addition or subtraction. For instance, siting is usually a map algebra problem and can involve the inclusion of many raster layers such as slope, land cover type, proximity to towns, etc. There are lots of resources available on map algebra and the ArcGIS help and manuals also explain a lot of the concepts behind.

A.2. Calculating a DTM in ArcGIS

A.1.1. Algorithms

ArcGIS offers a number of algorithms for the calculation of surfaces: IDW, Kriging and Spline are the most commonly used. ArcInfo also includes "Topogrid", an algorithm based on the "Anudem" application developed by the Australian National University (http://cres.anu.edu.au/outputs/anudem.php). In the frame of this training module, the Spline algorithm will be used:

The **Spline algorithm, or interpolator** is a general purpose interpolation method that fits a minimum-curvature surface through the input points. Conceptually, it is like bending a sheet of rubber to pass through the points, while minimizing the total curvature of the surface. It fits a mathematical function to a specified number of nearest input points, while passing through the sample points. This method is best for gently varying surfaces such as elevation, water table heights, or pollution concentrations. It is not appropriate if there are large changes in the surface within a short horizontal distance, because it can overshoot estimated values. The most problematic regions are those where areas with high information density (mountains) are located next to areas with low information density (plains). This problem can be solved by the addition of further elevation points in the areas containing only low information density, prior to calculating the DTM.

All in all Spline provides **rather satisfactory elevation and slope models** – if parameters are set appropriately – and it can be adapted to the particular situation in the project area. However, special attention should be given to areas where the information density changes abruptly (see above). The fact that Spline – as well as IDW – operates with **points only**, requires the conversion of elevation contours into elevation points, which can be done in the ArcToolbox (data management tools – features).

Spline sometimes is unable to fit a surface through the input points and therefore bails out. Finding out the causes for these errors is often difficult, and thus, one is sometimes forced to divide the input data into several subsets, to run spline on each subset and therewith to try identifying where the problematic area is located.

A.1.2. Using Spline: DTM calculation in ArcGIS

The calculation of a DTM with the Spline algorithm is done with help of the Spatial Analyst extension. The tools are found in the ArcToolbox, in spatial analyst tools – interpolation. When choosing Spline, the dialogue asks for the input theme and the input z-field, i.e. the attribute item containing the elevation information. The interpolation type has two options: The ***regularized*** method yields a smooth surface. The ***tension*** method tunes the stiffness of the surface according to the character of the modelled phenomenon. When choosing *regularized*, the weight parameter defines the weight of the third derivatives of the surface in the curvature minimisation expression. When choosing *tension*, the weight parameter defines the weight of tension.

A.1.3. Viewing and controlling a DTM

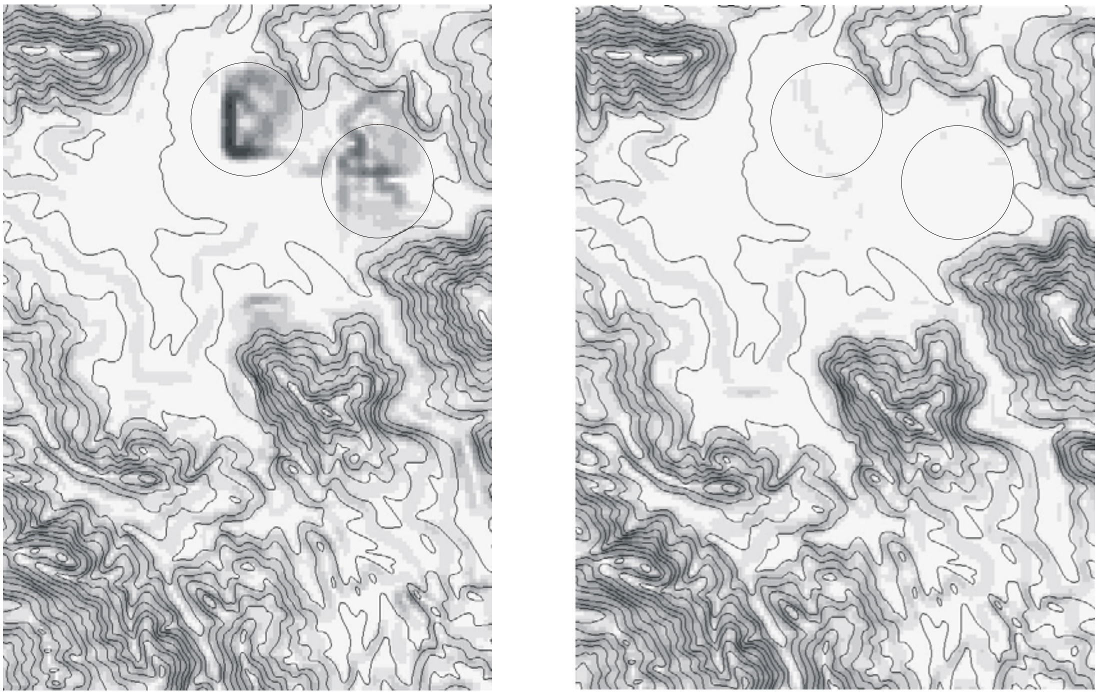
Digital Terrain Models are usually visualised by computing a **hillshade**, which provides a realistic view of the relief of the area covered by the DTM. The hillshade allows to localise rough errors, like wrongly labelled contours provoking unrealistic relief features (gullies or ridges). However, the hillshade does not provide sufficient control over smaller inaccuracies resulting from the interpolation method used, the overall quality of the input data, or the fine-tuning of the tolerances during interpolation.

A second control possibility is to check the **DTM's value range,** either in the table of contents or by making a histogram of the DTM, with the histogram tool in the Spatial Analyst Toolbar. Check if the values of the DTM are within the range of what can realistically be expected for the mapped area. Some interpolation overshoots or undershoots, resulting from abrupt changes in the information density might produce unrealistic elevation values. A **map query** (from the analysis menu) displaying the areas above and below the realistically expected elevations allows to localise the problematic areas. Supposing that you do not expect any location in your study area to be higher than 2300 meters above sea level, or lower than 300 meters above sea level, you can formulate the following map query to find out locations that do not fulfil this condition:

([DTM] > 2300) or ([DTM] < 300)

Yet another way to control the DTM quality is to **derive slope values** from the DTM and to view the resulting slope map in a view. The slope map shows quite well whether the DTM interpolation led to a stairway effect or not, as the latter would lead to alternating steep and less steep stripes which could easily be identified optically on the slope map. Unrealistic depressions in plain areas as well as areas with extreme roughness values can also be identified, as for example in Figure A.1: The regularized option on the left side led to two undershoots in the middle of a plain area (circles). These undershoots are due to the low information density in this area in combination with the"elastic" interpolation method of the regularized option, as opposed to the more "rigid" interpolation method of the tension option (on the right).

Slope values in degrees are easily calculated from the DTM, using either the Spatial Analyst – surface analysis menu in the Spatial Analyst toolbar, or the Spatial Analyst Tools – Surface tools in the ArcToolbox.



Slope map from DTM calculated with:
Spline
Weight = 0.1
Points = 20
Type = Regularized

Slope map from DTM calculated with:
Spline
Wieght = 5
Points = 10
Type = Tension

Figure A.1: *Comparing two DTMs – through their slope maps –, both calculated with the Spline algorithm, but with different calculation parameters.*

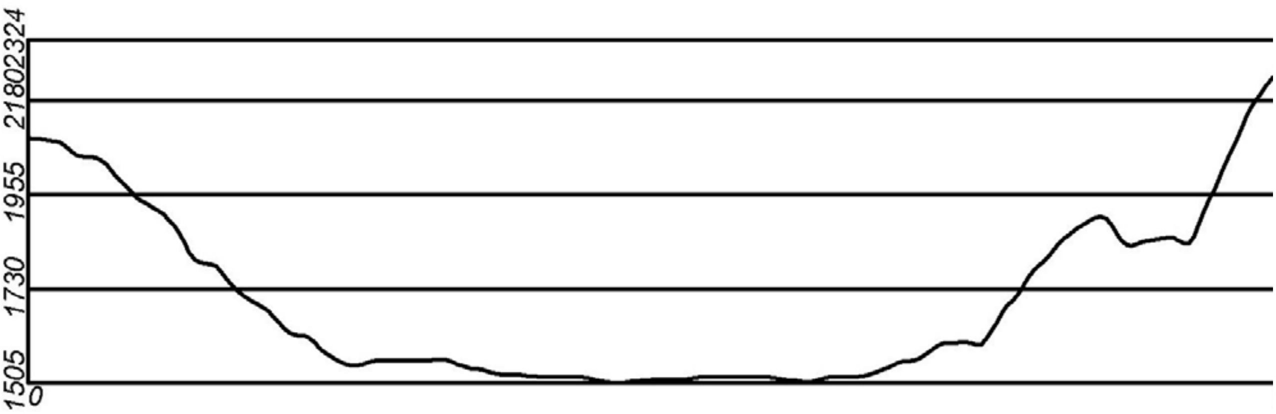


Figure A.2*: Profile through DTM calculated with the tension option*

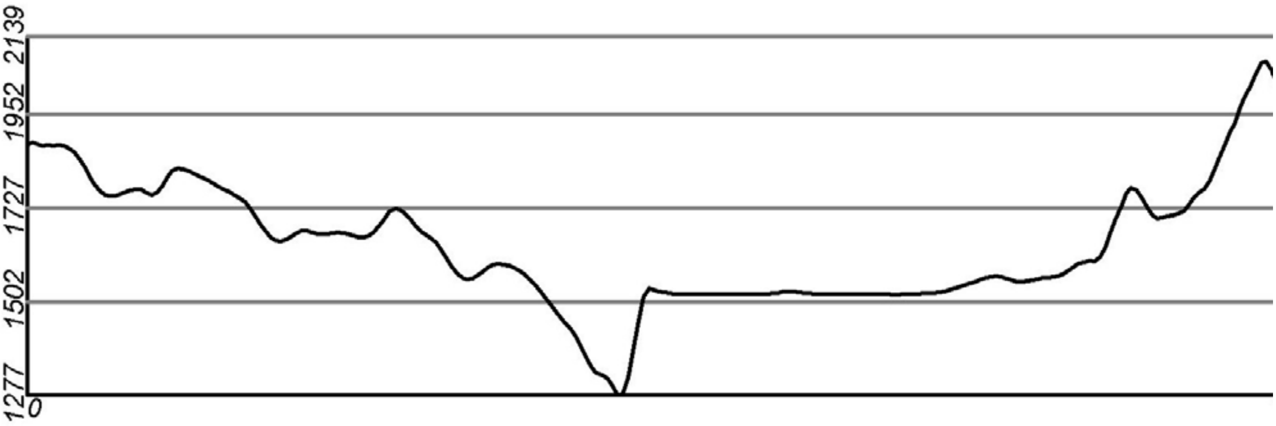


Figure A.3: Profile through DTM calculated with the regularized option

Finally, a **profile** through selected parts of a DTM will help visualising the interpolation style and adapting it to the situation found in reality.

Creating a profile is done in the 3D-Analyst extension by first drawing a line along the area for which a profile should be created (using the interpolate line tool) and then generating the profile (with the create profile graph tool). The interpolated line can be straight (two points, one at the beginning and one at the end), but it can also contain numerous vertexes and follow a specific path, a road, a boundary etc. The figures A.2 and A.3 show two profiles through the plain shown in the slope map above (figure A.1). The profile in figure A.2 reflects the result from the DTM calculated with the tension option and the profile in Figure A.3 reflects the result from the DTM calculated with the regularized option. The abrupt depression in the middle of the plain is evident, as well as differences in the relief of the surrounding mountains. In these mountainous areas, the regularized option seems to offer a more diversified picture of the reality than the tension option.

A.3. Hydrologic analysis in ArcGIS

The ArcToolbox in ArcMap features a set of tools for hydrologic analysis based on topographic input data. These tools are located within the Spatial Analyst Tools. Therefore the Spatial Analyst Extension is required to carry out hydrologic modelling in ArcGIS.

Hydrologic modelling usually starts from a DTM (see above). The elevation model has to be verified and sinks that it may contain have to be removed. The enhanced DTM is then used for the calculation of a set of derived layers that will serve as inputs for the hydrologic modelling functionalities. These derived layers are:

- Flow direction, which calculates for each cell of the input DTM the direction of flow, i.e. the cell(s) from which a particular cell receives surface runoff (those that are located above it) and the cell(s) to whose surface runoff it contributes (those located below it)
- Flow accumulation, which calculates for each cell of the input layer the number of contributing cells, i.e. from how big an area a particular cell gets surface runoff.

Both these input layers are then used for the delineation of watersheds. Watersheds are normally represented as polygons, which show areas which drain their surface runoff into one pour point (the point of exit of the system, where all surface runoff leaves the watershed). Watersheds are important planning units, for many activities and concerns pertaining to sustainable natural resource management. Therefore, the definition of watersheds and the description of their characteristics, the overlay with other input data like soil classes, land cover and human use can provide a useful basis for a wide range of public and private management and decision-making processes.

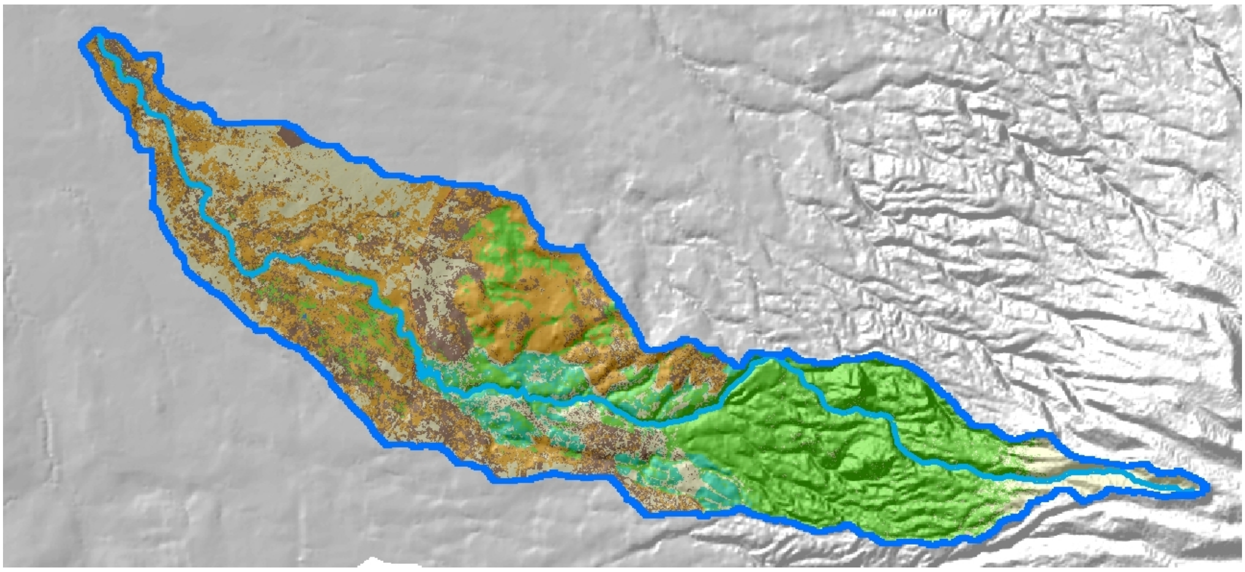


Figure A.4: *Watershed of the Burguret River in the Mount Kenya area. The background shows a hillshade, which is overlaid with land cover classes within Burguret watershed. The blue outline shows the boundaries of the watershed and the light blue line shows Burguret river, exiting the watershed at the pour point at the upper-left corner of the image*

Sources:

- Longley P.A., Goodchild M.F., Maguire D.J., Rhind D.W. 2005. *Geographic Information Systems and Science*, 2nd Edition. New York: John Wiley

- Jones C.B. 1997. *Geographical Information Systems and Computer Cartography,* Prentice Hal

- ESRI ArcGIS 9.1 2006 *Online Help*

GIS Raster Data Analysis

Exercises

E.1. Exercises

E.6.1. Mount Kenya DTM Calculation

Steps	Data	Remarks	Time
Transforming elevation contours into elevation points	Kemkcnt1	- Load the shapefile containing the elevation contours of Mt Kenya area. - Transform the elevation contours into elevation points. Decide on an adequate distance between elevation points, remove points with “Simplify Line” using the “Point_Remove” simplification algorithm (Arc Toolbox – Data Management Tools – Generalization). Check ArcGIS Online Help for more information on the algorithms. - Start the “Feature Vertices to Points” conversion tool (Arc Toolbox – Data Management Tools – Features).	30 min.
Calculating first DTM	Point theme calculated in the first step	- Make sure the spatial analyst extension is loaded. - Calculate a 50 m resolution DTM using the curvature spline technique (ArcToolbox – Spatial Analyst Tools – Interpolation – Spline), the correct elevation item, the regularized interpolation type, the default weight and 20 points.	30 min.
Calculating second DTM	Point theme calculated in the first step	- Calculate a 50 m resolution DTM using the curvature spline technique, the correct elevation item, the tension interpolation type, a weight of 5 and 10 points.	30 min.
Calculate hillshades and make a first visual analysis	Both calculated DTMs	- Using the surface menu, calculate a hillshade for both DTMs, using the default settings. - Display the hillshades using a grey monochromatic ramp and 255 “equal interval” classes. Make a rough visual interpretation of both calculations. What are the main differences? What are the strengths and weaknesses of both methods? Which method would you choose and refine with more accurate tuning of weight and number of points?	30 min
Total time			120 min.

E.6.2. Profile calculation

Steps	Data	Remarks	Time
Calculate a profile through the first DTM calculated in Exercise 6.1.	First DTM calculated in the Exercise 6.1	- Load the 3D-Analyst extension - Activate and display the first DTM - Draw a line with the interpolate line tool - Open a new layout and set the paper format - Draw a profile with the profile graph tool	20 min.
Calculate a profile through the second DTM calculated in Exercise 6.2.	Second DTM calculated in the Exercise 6.1	- Activate and display the second DTM - Draw a line with the interpolate line tool along the same track as the first line - Make sure the second line is selected - Open a new layout and set the paper format - Draw a profile with the profile graph tool, making sure to use the same vertical exaggeration factor as for the first profile	20 min.
Compare both profiles	Profile 1 and Profile 2	- Display both profiles next to one another and compare them - Draw conclusions on the way the spline algorithm interpolated the DTM with the different options	20 min.
Total time		-	**60 min.**

E.6.3. Interpolating rainfall data

Steps	Data	Remarks	Time
First interpolation of the point data	Etnarnf1	- The point coverage contains rainfall data for Ethiopia. The information density is very low. - Conduct an IDW interpolation on the point theme, using the total yearly rainfall, a cell size of 1000 m, 12 neighbours and a power of 2	20 min.
Second interpolation of the point data	Etnarnf1	- Conduct a second IDW interpolation on the point theme, with same parameters as above except power = 1.	20 min.
Comparing the results of the interpolation	Both rainfall grids calculated in the steps above	- Compare the rainfall grids and draw relevant conclusions concerning their quality and accuracy. What is the influence of the “power” option? Which version should be kept in such a case? - Which additional data could be added to the interpolation model to improve its accuracy?	20 min.
Displaying rainfall map with hillshade	rainfall grids calculated in steps 2 and 3 etnahil1	- Add the hillshade of Ethiopia to the view - Find an adequate colour ramp for the rainfall grid and add the hillshade as a brightness grid.	10 min
Total time			**70 min**

E.6.4. Delineating the watershed of Siakuu River

Steps	Data	Remarks	Time
1 Preparing input data	keewdtm1 keewclp1_siakuu dtm_clip.img dtm_hls.img	- The DTM at our disposition for the areas of interest covers the entire Ewaso Ngiro basin. Therefore you need to clip the DTM using the clip_siakuu shapefile and the "Extract by Mask" tool in the ArcToolbox (*Spatial Analyst Tools – Extraction – Extract by Mask*). Calculate a hillshade from the clipped DTM.	20 min.
2 Filling sinks	dtm_clip.img	- Run the fill sinks function, save the output as *dtm_filled.img*. (Spatial Analyst Tools – Hydrology – Fill)	15 min
3 Calculate flow direction	dtm_filled.img flowdir.img	- View the filled DTM of Siakuu area and try to identify changes from the original DTM. - Run the flow direction utility on the filled DTM - Name and save the output correctly	15 min
4 Calculate flow accumulation	flowdir.img flowacc	- Run the flow accumulation utility on the flow direction grid - Name and save the output correctly	10 min
5 Capturing the watershed outlet	outlet.shp	- Capture the outlet at the coordinate x (long): 304'130 y (lat): 10'067'100 - Save output as *outlet.shp.*	10 min
6 Delineate the watershed of Siakuu river	flowdir.img outlet.shp wshed1.img	- Delineate the watershed of the Siakuu River using the *watershed* tool from ArcToolbox. The inputs are *flowdir.img* for flowdirection and *outlet.shp* for pour point data , save output as *wshed1.img* - Check the output (→cells next to the pour point). Is this the result that you were expecting?	10 min
7 Snap pour point to a high accumulation cell	Flowacc.img snappour_outlet.img	- Now you will correct the previous output applying the tool *"Snap Pour Point"*. Input feature is *Outlet*, input accumulation raster is *flowacc.img*. Save the output as *Snappour.img*. Set the snap distance to 100m.	10 min
8 Delineate the watershed of Siakuu river	flowdir.img snappour.img wshed1.img	- Rerun step 6(delineation) based on *Snappour.img* and save output as *wshed2.img*. Compare *wshed2.img* with the results from step 6. - Guess what may be the reason for the difference.	10 min
9 Calculate the watershed area	wshed2.img	- Calculate the area multiplying the number of cells with their area.	10min
Total time			110 min.

E.6.5. Simulating a water reservoir

Steps	Data	Remarks	Time
Calculating sub-catchment upstream of dam site	Flow direction and flow accumulation grids of previous exercise	- The input grids for watershed delineation were calculated in the previous exercise. Use them to calculate a watershed the pour point of which is at 306,180 / 10,044,000. - Save the output as a grid.	30 min.
Creating horizontal DTM	Sub-catchment calculated in previous step	- The sub-catchment grid has a value of 0 for the area located within the sub-catchment and a value of "No Data" for all other parts of the grid. - Use a conditional statement in raster calculator to change the values to 1600 (inside the catchment) and to 10 (outside the catchment), save the result of the map calculation as lake_dtm: lake_dtm CON (isNull ([Subcatch]), 10, 1600). Whereas Subcatch is the grid calculated in the first step.	30 min.
Calculating new DTM including lake surface	Filled DTM of Siakuu area Lake_DTM	- Start the raster calculator and enter the following conditional statement to return the values of the DTM if the latter is higher than the lake surface and to return the value of the lake surface if the DTM is lower than the lake surface, Save the result as Siakuu_dtm_lk: Siakuu_dtm_lk CON ([DTM_Siakuu] > [Lake_DTM], [DTM_Siakuu], [Lake_DTM])	20 min.
Calculating hillshade	Siakuu_DTM_lk	- Create a hillshade with the newly created DTM and control the result - Save the hillshade as Siakuu_hil_lk	10 min.
Map query	Siakuu_DTM_lk	- Conduct a map query to return the areas exactly located at the elevation of the lake surface	5 min.
3D representation	Siakuu_DTM_lk Siakuu_hil_lk	- Create a 3D scene in ArcScene with Siakuu_DTM_lk and Siakuu_hil_lk. Load Siakuu_hil_lk in ArcScene and obtain heights from Siakuu_DTM_lk. Use a z-factor of 2 for the display. Navigate in the 3D view until you have a nice overview. - Enhance the resolution of the 3D View. - Save the 3D view as a bitmap (Export Scene – 2D) and print it out.	45 min.
Total time		-	140 min.

E.6.6. Volume calculation

Steps	Data	Remarks	Time
Volume calculation 1	Original DTM (without lake) and flat DTM (lake surface) Map query (lake area)	- Calculate the lake volume with the manual method, using the instructions below	30 min.
Volume calculation 2	id.	- Calculate the lake volume with the CutFill method, using the instruction below.	30 min.
Comparing volume calculation	Results from steps 1 and 2	- Compare the results of both calculations above. Do the results match?	10 min.
Total time			**70 min.**

The manual way:

1. Clip the original DTM (without reservoir) with a polygon shapefile representing the lake surface.
2. Do the same with the flat DTM equivalent to the elevation of the water surface.
3. In the map calculator calculate the difference between lake surface and relief underneath.
4. Make sure the resulting grid is in integer format (no decimals). If this is not the case, calculate an integer grid in the map calculator using the following syntax: Int(InGrid).
5. Add a new field to the attribute table of the integer grid and calculate the new field = [value] * [count]. Then get the field statistics and write down the sum (go to layer properties of the grid layer. The statistics are available on the source tab). If the map units are meters and if the grid resolution is 50 meters, the volume of the reservoir can be calculated as follows:

[sum] * 50 * 50

Using CutFill:

1. Clip the original DTM (without reservoir) with the polygon shapefile representing the lake surface.
2. Do the same with the flat DTM equivalent to the elevation of the water surface.
3. Load the 3D-Analyst extension, make both clipped grids active and select CutFill in the 3D Analyst Toolbox).
4. Chose the flat DTM (lake surface) as before grid
5. Open the attribute table of the newly created cut-fill grid, select the volume field and conduct statistics on this field (field - statistics). The sum in the statistic report is equivalent to the lake volume in map units.

E.6.7. 3D Analysis and Viewshed calculation for Nakuru

Steps	Data	Remarks	Time
Generating view points	Kenkdtm1 Kenkhil1	- Create a new point shapefile called kenkview1. Pay attention to define its projection correctly. - Open the DTM, the hillshade and the newly created point shapefile in ArcMap and start an editing session. Digitize a view point on Lion Hill. Be careful to locate the point exactly on the highest cell of the location chosen. Use the identify tool on the DTM to help you identifying the best location. - Save the edits and save the MXD file for later use	30 min.
Loading data to ArcScene	Kenkdtm1 Kenkhil1 Kenkview1	- Load the DTM, the hillshade and the viewpoint of Nakuru to ArcScene - Select the DTM as a surface from which the hillshade's and the point feature's base height will be calculated. Set the rendering and transparency option in a way as to obtain a good 3D view.	20 min.
Calculating viewshed	Kenkdtm1 Kenkhil1 Kenkview1	- Using the 3D-Analyst extension calculate a viewshed for the digitized location on Lion Hill. - Observe the results and draw relevant conclusions	10 min.
Adapting DTM for better results	Kenkdtm1 Kenkhil1 Kenkview1	- To improve results, the viewpoint needs to be slightly higher than its surroundings: - In ArcToolbox transform kenkdtm1 into an integer raster. Call it kenkdtm1in - Start editing kenkview1. Add four points located slightly beyond the four corners of the DTM (display NoData for better positioning). Open the attribute table and make sure these points have an ID of 0 and the viewpoint an ID equal to the underlying DTM cell + 5 meters. Save your edits. - In ArcToolbox (Conversion Tools – To raster – Feature to Raster) transform the shapefile into a Grid (cell size = 3 m; value = ID field). Name the output kenkviewgr. - In Spatial Analyst select the Raster Calculator tool and enter the following conditional statement: Con(Isnull(kenkviewgr),kenktop12in,kenkviewgr) - Save the output calculation as kenkdtm12view.	30 min
Calculating new viewshed	Kenk12view kenkview	Calculate a Viewshed in the 3D Analyst using kenk12view	20 min
Total time			**110 min.**

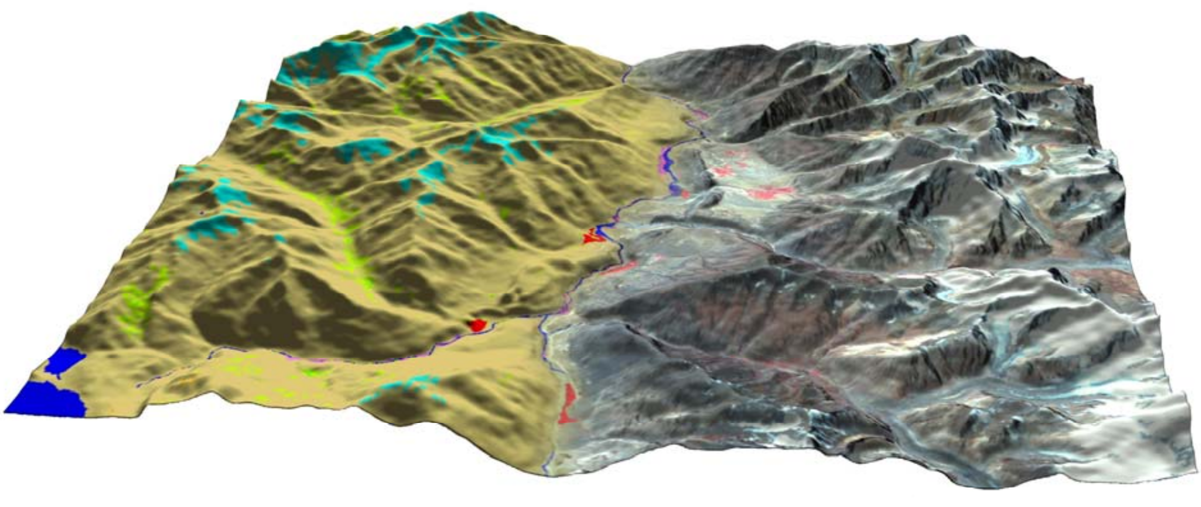
Eastern and Southern Africa Partnership Programme

Capacity Building in Geoprocessing

Module 7

Remote Sensing Data Analysis

Centre for Development and Environment



cde centre for development and environment

Training Concept

This training module is part of a Geoprocessing Training Concept elaborated by the Centre for Development and Environment (CDE). Each module looks into GIS or RS methods and functions. A course in any of the two disciplines can be composed of a varying number of selected modules, depending on the participant's requirements and the duration of the course. Additional modules will be added to the Training Concept based on concrete requests, or on the basis of enhanced expertise of the CDE Geoprocessing unit. Each Training Module is divided into three main parts:

T	Theory	Theoretical background and concepts, as well as available references on the module's main topics
A	Applications	Specificities of selected GIS and RS software regarding the module's main topics. Currently the Training Modules are designed for use with ESRI's ArcGIS 9.x software family, but will be stepwise expanded, depending on the specific requirements of course participants.
E	Exercises	Concrete exercises on the module's main topics for implementation by the course participants with use of selected software

Module 7 deals with remote sensing as an additional source for GIS data. In the theory part, the focus is on an introduction to the concepts of remote sensing, discussing the most important issues for beginners. In the application part, traditional remote sensing workflows are discussed, introducing the "light" RS software Multispec as a helpful platform for image transformation and image classification.

Imprint

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Based on various course manuals and guidelines prepared by CDE

Contents

GIS Raster Data Analysis Theory

T.1. Theoretical Aspects of Remote Sensing

T.1.1. History and Definition

Modern remote sensing started more than 100 years ago with the invention of cameras. Even though the early photographs have been taken from the ground, the idea of looking down to the Earth's surface came up around 1850 when first pictures were taken from cameras attached to a balloon for topographic mapping purpose. During World War one, cameras fixed on planes provided aerial views of quite large surface areas, being highly valuable for military reconnaissance. This kind of aerial photographs were the standard for displaying the surface from an over ground vertical perspective until the early 1960s.

However, satellite based remote sensing started as an approach to image surfaces using several types of sensors from spacecrafts. In a timely perspective, it can be tracked to the early days of space age (both American as well as Russian programmes). With the emergence of the space programme in the 1960s, cosmonauts and astronauts simply took photos out the window of their Earth-orbiting spacecrafts.

The term ***remote sensing*** was introduced in the US in the 1950s and is nowadays commonly accepted and used to define the science (and art) of observing, analysing and measuring an object without touching it. Such process needs the detection and measurement of radiation of various wavelengths emitted or reflected from remote objects or materials, through which they can be identified and classified by type, material and spatial arrangement. In other terms remote sensing refers to methods employing electromagnetic energy such as light, heat or radio-waves as means for the detection of target characteristics. As a consequence, satellite imagery, radar as well as aerial photography are all forms of remotely sensed data (SABINS, 1987).

T.1.2. Radiation

Any object – unless it is very cold (exactly -273°C) –emits, absorbs, or reflects energy in a very specific manner. The emitted energy is able to transmit energy from one place to another in form of electromagnetic radiation. Any imaginable object – trees, the sun, the earth, air molecules and all the stars and planets reflect and emit electromagnetic energy in form of waves. The source of the waves consists of millions of vibrating electrons, emitting and absorbing electromagnetic energy in very specific ranges of wavelengths.

The kind and intensity of electromagnetic radiation an object emits depends principally on its temperature. The hotter an object is, the faster its electrons vibrate and the shorter is the peak wavelength of the emitted radiation. Inversely, the lower the temperature of an object, the slower its electrons vibrate, and the longer the peak wavelengths of the emitted radiation.

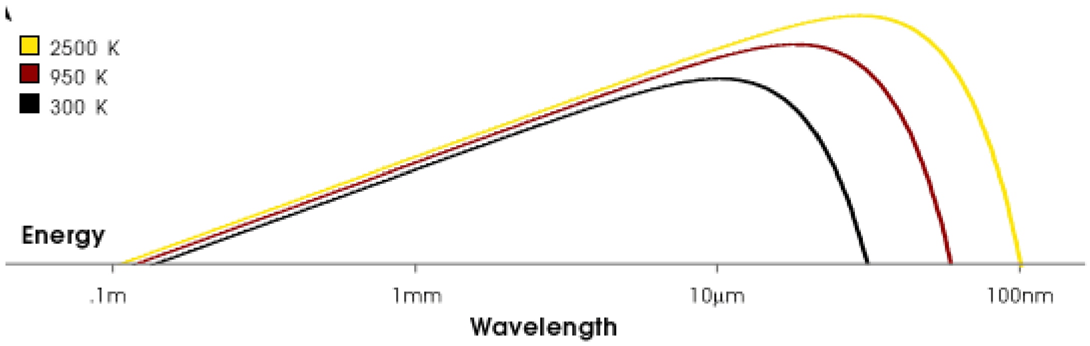

Figure T. 1The curves above show the amount of energy an object will emit at 300, 950, and 2500 Kelvin.(RST)

T.1.3. The electromagnetic spectrum

The basic unit of electromagnetic energy is the photon, which is the smallest possible amount of electromagnetic energy given a specific wavelength. Photons move at the speed of light ~300,000 km/sec in form of waves without mass. The photon's energy determines the wavelength and frequency of light that it is associated with. The greater the energy of the photon is, the greater is also the frequency of light emitted and vice versa.

The whole wide range of all electromagnetic waves comprises the electromagnetic spectrum (EM). Waves are called electromagnetic when they consist of combined electric and magnetic waves that results when a charged particle (electron) is being accelerated. The EM spectrum is divided into particular regions with distinctive names. The very high energetic segment (short wavelength, high frequency) comprises gamma rays and x-rays. Subsequently radiation in the ultraviolet part extends from about 1 nanometer to about 0.36 micrometers. The mid-regions of the spectrum is conveniently measured in two units: micrometers (µm), a unit of length equivalent to one million part of a meter, or nanometers (ηm), a unit of length equivalent to one billion part of a meter. The visible region occupies the range between 0.4 and 0.7 µm, or its equivalents of 400 to 700 ηm. The infrared (IR) region finally extends from 0.7 to 100 µm. At shorter wavelengths (near 0.7 μm) infrared radiation is detectable by special film, while at longer wavelengths it is felt as heat radiation.

Longer wavelengths are measured in units of millimetres (mm) to meters (m). The microwave region spans between 1 mm and 1 m; this includes all of the intervals used by human-made radar systems, which generate their own active radiation directed towards (and reflected from) targets of interest. The lowest frequency (means longest wavelength) region – beyond 1 m – constitutes the radio waves.

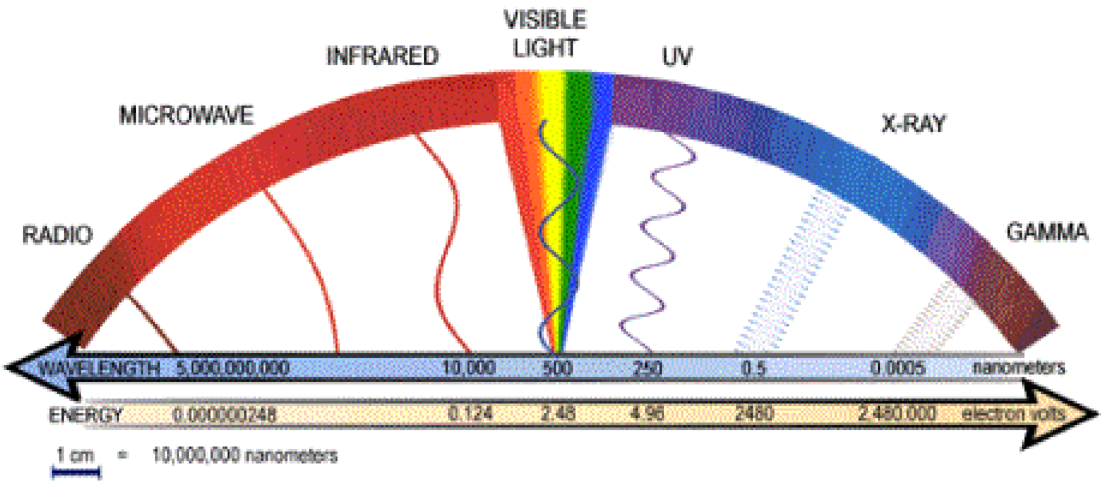

Figure T. 2: The electromagnetic spectrum modified from NASAexplores

Different types of land cover (vegetation, water rock, etc.) absorb a very characteristic portion of the electromagnetic spectrum, resulting in a well distinguishable signature of the electromagnetic radiation. With the knowledge of which wavelengths are absorbed by certain features and the intensity of reflectance, it is possible to analyze a remotely sensed image and make assumptions about the land cover types represented on the scene.

T.1.4. Absorption Bands and Atmospheric Windows

While the atmosphere is penetrable for radiation from some parts of the electromagnetic spectrum, it is closed to other types. The nature of the atmosphere to selectively allow radiation to pass through it is referred to as its transmissivity that varies with the wavelength and type of the radiation. Basically it is a function of the gases that comprise the atmosphere absorbing radiation in certain wavelengths while allowing radiation with other wavelengths to pass through. The areas of the EM spectrum that are absorbed by atmospheric gases such as carbon dioxide and water vapour are known as absorption bands. In the figure, absorption bands are represented by a low transmission value that is associated with a specific range of wavelengths.

Compared to the absorption bands, in the electromagnetic spectrum there are areas where the atmosphere is almost transparent (little absorption of radiation) to particular wavelengths. These wavelength bands are referred to as “atmospheric windows" since they allow the radiation to pass easily through the atmosphere to the Earth's surface.
Usually remote sensing instruments based on aircraft or space borne platforms operate by making their measurements with detectors tuned to specific frequencies (wavelengths) that pass through the atmosphere in one or more of the discussed atmospheric windows. When a remote sensing instrument has a line-of-sight with an object that is reflecting sunlight or emitting heat, the instrument collects and records the radiant energy. While most sensors are designed to collect reflected radiation, some remote sensing systems particularly measure absorption phenomena, such as those caused by carbon dioxide absorption.
The figure below shows that the atmosphere is almost opaque to electromagnetic radiation in parts of the mid-infrared and most of the far-infrared regions. The microwave region however is well penetrable, this is why radar waves can reach the earth surface (not to be confused with weather radars that are able to detect precipitation and clouds since they are optimized to observe backscattered radiation from raindrops and ice particles).

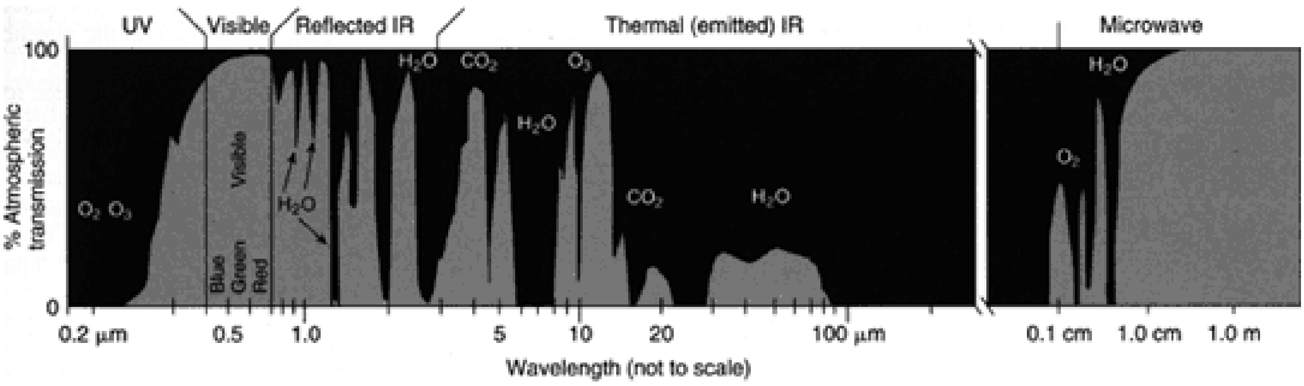

Figure T. 3: *Diagram of atmospheric windows - wavelengths at which electromagnetic radiation will penetrate the Earth's atmosphere. Chemical notation (CO_2, O_3) indicates the gas responsible for blocking sunlight at a particular wavelength (RST)*

T.1.5. Spectral Signatures

Classifying features in a remotely sensed scene into meaningful categories or classes is one of the primary uses of remote sensing technology. As a consequence, the image becomes a thematic map (which themes are selectable e.g., land use, geology, forest stands…). In agriculture, a farmer can use thematic maps to monitor the health of the crops without going out to the field. A biologist may want to study the variety of plants in a certain location. A geologist may use the images to study the types of minerals or rock structure found in a certain area. For example, at certain wavelengths, sand reflects more energy than green vegetation while at other wavelengths it absorbs more energy. So in principle various kinds of surface materials can be distinguished from each other by these differences in reflectance. Of course, there must be some suitable method for measuring these differences as a function of wavelength and intensity (as a fraction of the amount of radiation reaching the surface). Using reflectance differences, the four

most common surface materials (GL = grasslands; PW = pinewoods; RS = red sand; SW = silty water) can be easily distinguished, as shown in the next figure.
When more than two wavelengths are used, the resulting images tend to show more separation among the objects. Imagine looking at different objects through red lenses, or only blue or green lenses. In a similar manner, certain satellite sensors can record reflected energy in the red, green, blue, or infrared bands of the spectrum, a process called multispectral remote sensing. The improved ability of multispectral sensors provides a basic remote sensing data resource for quantitative thematic information, such as the type of land cover. Resource managers use information from multispectral data to monitor fragile lands and other natural resources, including vegetated areas, wetlands, and forests. These data provide unique identification characteristics leading to a quantitative assessment of the Earth's features.

T.1.6. Pixels and Bits

From earth-orbiting satellites recorded data is transmitted to ground stations using radio waves. As the data is received it is transposed into a digital image array that can be displayed on a screen. Simply like the pictures on a television set, satellite imagery is made up of tiny squares, each of a different gray tone or color. These pixels represent the relative reflected light energy recorded for that part of the image.
Each pixel represents a square area on an image that is a measure of the sensor's ability to resolve (see) objects of different sizes. For example, the Enhanced Thematic Mapper (ETM+) on the Landsat 7 satellite has a maximum resolution of 15 meters; therefore, each pixel represents an area 15 m x 15 m, or 225 m2. Higher resolution (smaller pixel area) means that the sensor is able to resolve smaller objects. By adding up the number of pixels in an image, it is possible to calculate the area of a scene. For instance, by counting all the green pixels in a false colour image it is possible to calculate the total area covered with vegetation.

T.1.7. Color Images

Another important ingredient in most remote sensing images is color. While variations in black and white imagery can be very informative, the number of different gray tones that the eye can separate is limited to about 20 to 30 steps (out of a maximum of about 200) on a contrast scale. On the other hand, the eye can distinguish 20,000 or more color tints, enabling small but often important variations within the target materials or classes to be discerned.

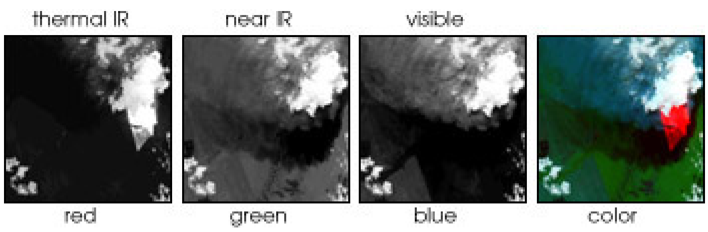

Figure T. 4: Different "sub" regions in the electromagnetic spectrum correspond to different image bands

Since different bands (or wavelengths) have a different contrast, computers can be used to display a colour image from a black and white remote sensing data set. Remember that satellites record the reflected and emitted brightness in the different parts of the spectrum, as is shown in the figure above.
Like the screen on a color television set, computer screens can display three different images using blue light, green light and red light. The combination of these three wavelengths of light will generate the color image that human eyes can see. This is accomplished by displaying black and white satellite images corresponding to various bands in either blue, green, or red light to achieve the relative contrast between the bands. Finally, when these three colors are combined, a color image – called a "false color image" – is produced (the name "false colour" refers to the fact that "any" colours are assigned so we can see and easily interpret with our eyes).
In order to understand what the colors mean in the satellite image, one must know which band (or wavelength) is used for each of the blue, green and red parts of the computer display device. Without detailed knowledge of how each band has been changed for contrast and brightness, it is very difficult to associate the features and colours.

T.2. Methods of Remote Sensing

Basically there are two types of remote sensing instruments – passive and active. Passive instruments detect natural energy that is reflected or emitted from the observed scene. Passive instruments only sense radiation emitted by objects being viewed or reflected from a source other than the instrument. As a matter of fact, reflected sunlight is the common external source of radiation sensed by passive instruments. A wide range of different systems is being applied:

Radiometer
An instrument that quantitatively measures the intensity of electromagnetic radiation in some band of wavelengths in the spectrum. Usually a radiometer is further identified by the portion of the spectrum it covers; for example, visible, infrared, or microwave.

Imaging Radiometer
A radiometer that includes a scanning capability to provide a two-dimensional array of pixels from which an image may be produced is called an imaging radiometer. Scanning can be performed mechanically or electronically by using an array of detectors.

Spectrometer
A device designed to detect, measure, and analyze the spectral content of the incident electromagnetic radiation is called a spectrometer. Conventional, imaging spectrometers use gratings or prisms to disperse the radiation for spectral discrimination.

Spectroradiometer
A radiometer that can measure the intensity of radiation in multiple wavelength bands (i.e. multispectral). Oftentimes the bands are of a high spectral resolution – designed for the remote sensing of specific parameters such as sea surface temperature, cloud characteristics, ocean color, vegetation, trace chemical species in the atmosphere, etc.

Active instruments provide their own energy (electromagnetic radiation) to illuminate the object or scene they observe. They send a pulse of energy from the sensor to the object and then receive the radiation that is reflected or backscattered from that object. Scientists use many different types of active remote sensors.

Radar (Radio Detection and Ranging)
A radar uses a transmitter operating at either radio or microwave frequencies to emit electromagnetic radiation and a directional antenna or receiver to measure the time of arrival of reflected or backscattred pulses of radiation from distant objects. Distance to the object can be determined since electromagnetic radiation propagates at the speed of light.

Scatterometer
A scatterometer is a high frequency microwave radar designed specifically to measure backscattered radiation. Over ocean surfaces, measurements of backscattered radiation in the microwave spectral region can be used to derive maps of surface wind speed and direction.

Lidar (Light Detection and Ranging)
A lidar uses a laser (light amplification by stimulated emission of radiation) to transmit a light pulse and a receiver with sensitive detectors to measure the backscattered or reflected light. Distance to the object is determined by recording the time between the transmitted and backscattered pulses and using the speed of light to calculate the distance traveled. Lidars can determine atmospheric profiles of aerosols, clouds, and other constituents of the atmosphere.

Laser Altimeter
A laser altimeter uses a lidar (see above) to measure the height of the instrument platform above the surface. By independently knowing the height of the platform with respect to the mean Earth's surface, the topography of the underlying surface can be determined.

T.3. Aspects of Resolution in Remote Sensing

T.3.1. Spectral Resolution

Spectral resolution refers to the specific wavelength ranges in the electromagnetic spectrum that a sensor records. Wide intervals in the spectrum are referred to as coarse, and narrow intervals are referred to as fine spectral resolution. For example, the SPOT panchromatic sensor is considered to have coarse spectral resolution because it records EMR between 0.51µm and 0.73µm. On the other hand, band 3 of the LANDSAT ETM+ sensor has fine spectral resolution because it records EM radiation between 0.63µm and 0.69µm (JENSEN, 1996). Spectral resolution refers to the bandwidth of the bands and the noise of the system (referred to as signal-to-noise ratio).

T.3.2. Scale and Spatial Resolution

Spatial resolution is the measure of the area on the ground represented by a pixel. The finer the resolution, the lower the number. The terms large-scale imagery and small-scale imagery often refer to spatial resolution. Scale is the ratio of distance on a map as related to the true distance on the ground (STAR and ESTES, 1990). Large-scale in remote sensing refers to imagery in which each pixel represents a small area on the ground, such as IKONOS data, with a spatial resolution of 1m,whereas small scale refers to imagery in which each pixel represents a large area on the ground, such as MODIS data, with a spatial resolution of 500 km. This terminology is derived from the scale of the map, such as 1:50,000. Small-scale imagery is represented by a small fraction (one over a very large number). Large-scale imagery is represented by a larger fraction (one over a smaller number).

T.3.3. Instantaneous Field of View

Spatial resolution may also be described as instantaneous field of view (IFOV) of the sensor, although the IFOV is not always the same as the area represented by each pixel. The IFOV is a measure of the area viewed by a single detector in a given instant in time (ERDAS, 1999).
For example, LANDSAT MSS data have an IFOV of 79 × 79 meters, but there is an overlap of 11.5 meters in each pass of the scanner, so the actual area represented by each pixel is 56.5 × 79 meters. Even though the IFOV is not the same as the spatial resolution, it is important to know the number of pixels into which the total field of view for the image is broken. On the one hand, objects smaller than the stated pixel size may still be detectable in the image if they contrast with the background. On the other hand, objects of the same size as the stated pixel size (or larger) may not be detectable if there are brighter or more dominant objects nearby.

T.3.4. Temporal Resolution

Temporal resolution describes the frequency of image collection for the same area. For example, the LANDSAT satellite can view the same area of the globe once every 16 days. SPOT, in comparison, can revisit the same area every three days.

T.3.5. Radiometric Resolution

Radiometric resolution refers to the dynamic range, or number of possible data file values in each band. This is referred to by the number of bits into which the recorded energy is divided. For example, in 8-bit data, the data file values range from 0 to 255 for each pixel. The total intensity of the energy from 0 to the maximum amount the sensor measures is broken down into 256 brightness values for 8-bit data. Radiometric resolution is determined by the sensitivity of sensor to detect differences in signal strength and represents the smallest brightness value that can be distinguished (ERDAS, 1999).

Sources:
- The Remote Sensing Tutorial
- http://nasaexplores.nasa.gov

GIS Raster Data Analysis Applications

A.1. Image Processing Steps

The term pre-processing is referred to as the correction of geometric and radiometric deficiencies and the removal of data errors. It seems obvious that errors within the data are removed before image interpretation starts. The choice of methods should always be purpose dependent. For instance, if a check of an object with a satellite image is the aim, visual interpretation is sufficient and even geometric correction may be omitted.

The importance of pre-processing methods becomes obvious in change detection or monitoring applications, where the operator must distinguish data noise, pre-processing and data handling errors from real changes. There are currently no automated applications available for pre-processing high spatial resolution data such as LANDSAT ETM+ as there are for high temporal resolution data such as MODIS. Therefore, most of the pre-processing steps discussed herewith have to be carried out manually and usually require considerable work inputs.

A.2.1. Geometric Correction

The integration of data from various sources, such as topographic maps and satellite images require the data being stored in the same reference system. This is essential for the use of a homogeneous and operational GIS database. Before geo-correction of the satellite data can be done a cartographic reference system has to be chosen.

Raw digital imagery obtained from the data provider or spacecraft usually shows geometric distortions so that it needs subsequent processing before usage. These distortions can either be of systematic nature and induced by factors such as panoramic effects, earth rotation, change in platform velocity or non systematic.

Geometric correction is generally a two step process, where the systematic errors can be reduced directly after image recording by modelling the sources of errors mathematically. Most data are distributed as systematic corrected products. So LANDSAT level 1G data are radiometrically and systematically corrected and have undergone a two dimensional resampling according to user-specified parameters including output map projection, rotation angle and pixel size.

Depending on the chosen resampling algorithm, some spectral integrity of the data my be lost during rectification. Some analysts recommend classification before rectification since the classification will then be based on the original data values. However, it may be beneficial to rectify the data first, especially when using GPS and other geo-referenced data. This data can only be superimposed on the imagery if their geometric position matches.

A.2.2. Atmospheric Correction (Calibration)

As discussed in the theory section of this module, electromagnetic radiation is submitted to different effects when travelling through the atmosphere. Therefore, in some cases it is important to correct the data for these atmospheric effects. Analysis using uncorrected data assumes that the radiance of vegetation, soil, water and other objects of interest have sufficiently different reflectance characteristics for differentiation and that atmospheric effects are not sufficiently great to affect their basic spectral separations.

A.2.3. Illumination and Terrain Correction

Digital imagery from mountainous regions normally contains radiometric distortions known as topographic effects. Topographic effects result from the differences in illumination due to the angle of the sun and the angle of the terrain. This may cause major variations in the image brightness values.

Topographic effects are a combination of:

incident illumination – the orientation of the surface with respect to the rays of the sun

exitance angle – the amount of reflected energy as a function of the slope angle

surface cover characteristics – rugged terrain with high mountains or steep slopes

Therefore identical land cover might be represented by totally different intensity values depending on its orientation and on the position of the sun at the time of data acquisition.

One way to reduce topographic effect in digital imagery is by applying transformations based on the Lambertian or non-Lambertian reflectance models. These models normalize the imagery, which makes it appear as if it were a flat surface. When using the topographic normalization model, the following information is needed:

- solar elevation and azimuth at time of image acquisition
- DTM file in the same (or better) pixel size than the satellite image
- original imagery file (after atmospheric corrections)

A.2. Image Enhancement

Image enhancement is referred to as the process of making an image more interpretable to the analyst. Enhancement techniques are often used instead of classification techniques for feature extraction (ERDAS, 1999).

Generally, the following three types of enhancement can be distinguished:

Spatial: enhancing images based on the values of individual and neighbouring pixels

Radiometric: enhancing images based on the values of individual pixels

Spectral: enhancing images by transforming the values of each pixel on a multiband basis

A.2.4. Spatial Enhancement

Spatial enhancement modifies pixel values based on the values of surrounding pixels. Spatial enhancement deals largely with spatial frequency, which is the difference between the highest and lowest values of a contiguous set of pixels. Spatial frequency is often defined as the number of changes in brightness value per unit distance for any particular part of an image (JENSEN, 1996). One very common application of spatial enhancement is the so-called resolution merge (also referred to as pan-sharpening), combining the advantages of a multispectral imagery with the high spatial resolution of a broadband panchromatic image.

In order to assess the fine structures especially of the village area, the multispectral LANDSAT scenes (30 m resolution) covering the Western Pamir area have been merged with the 15m resolution panchromatic band, resulting in a output resolution of all bands of 15 m ground resolution.

A.2.5. Radiometric Enhancement

While spatial enhancements operate on the pixel values taking account of neighbouring pixels, radiometric enhancement works on the individual values of the pixels in a band.

Radiometric enhancement techniques do not necessarily improve the contrast of every pixel in an image, while contrast is gained on some pixels, it is lost between other pixels.

When radiometric enhancements are applied on the display device, the transformation of input data file values into output brightness values (BV) may be demonstrated by the graph (linear or non linear functions) of a lookup table.

In figure 28, the histogram of the band 4 yields that the scene is composed of BV ranging from a minimum of 4 to a maximum value of 104. When this data is displayed on a device without any contrast enhancement, less than one-half (104 of 255) of the full range of BV that could be displayed are utilised. The image is low in contrast and difficult to interpret visually. A more effective display can be performed if we expand the range of original BV to use the full dynamic range of the video display. Applying a min-max histogram stretch, all original BVs between 5 and 104 would be linearly distributed between 0 and 255.

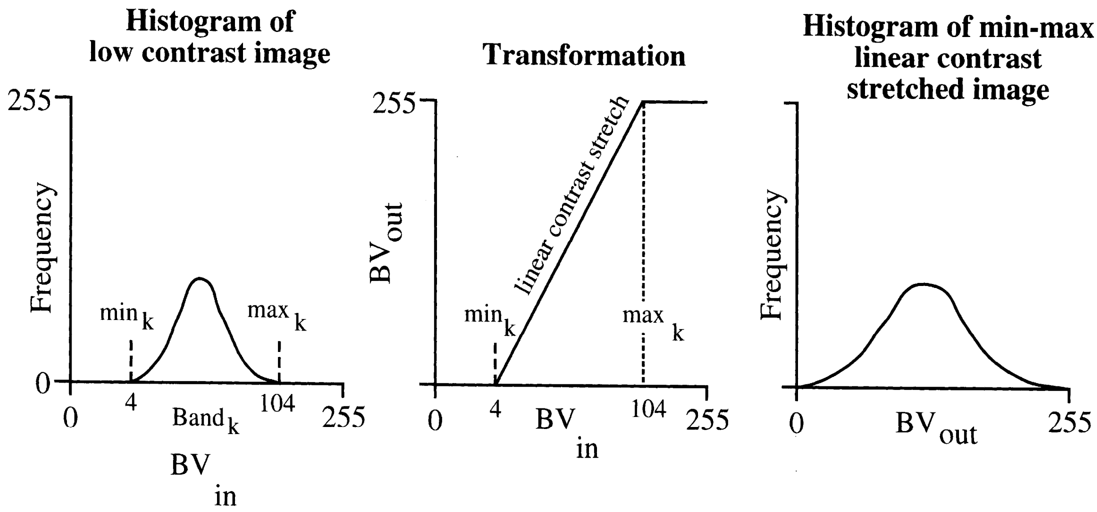

Figure T. 5

Figure 31: Application of a minimum-maximum stretch to normally distributed data (JENSEN 1996)

A.2.6. Spectral Enhancement

These functions enhance the image by transforming the values of each pixel on a multiband basis. Spectral enhancement techniques are widely used for feature extraction.

In this respect a very common approach is the application of specific band ratios or indices, such as the Normalized Difference Vegetation Index NDVI.

Generally all vegetation indices are based on the fact that a green leaf's chlorophyll pigment strongly absorbs sun radiation at wavelength between 0.5 and 0.7 μm (visible red) and the reflection factor is usually below 0.1. In the near-infrared region (0.75 – 1.35 μm), multiple scattering occurs due to the leaf's internal mesophyll structure and the reflection oscillates between 0.4 and 0.6 .This physiological relationship has been used to estimate the greenness of plant canopies through the use of various ratios.

However, the literature indicates that vegetation indices are generally based on empirical evidence and not basic biology, chemistry or physics. This should be kept in mind when using vegetation indices (RAY, 1994).

The NDVI has developed to a standard index in many remote sensing applications.

It is defined as the difference between the NIR and the red radiation reflected by the surface, normalised by the sum of both.

The NDVI is calculated as follows:

$$NDVI = \frac{IR - R}{IR + R}$$

With this equation, the NDVI values for non-vegetated areas (e.g. water, rock, bare soil) are negative (reflection IR < R) or oscillating around zero (reflection IR and R are almost equal). These features are dark coloured on the screen. Vegetated areas show positive values (reflection IR > R). The higher the amount of photosynthesising material, the higher the NDVI value and the brighter the colour in the image is. NDVI and vegetation indices are particularly resistant to varying scene illumination because they are ratios of two reflectance values, and thus provide quite consistent measurements across complex terrain.

However, in sparsely vegetated areas, bright soils tend to dominate the measured pixel reflectances, resulting in low signal-to-noise ratios. So vegetation is overestimated if the soil background is dark whereas it is underestimated if the soil background is light. Therefore, a number of alternative vegetation indices have been developed to minimize these problems, but their judicious use typically requires additional information about soil properties and other surface characteristics, complicating their application over large areas.

A.3. Multispectral Classification

Multispectral classification is the process of sorting pixels into a finite number of individual classes, or categories of data, based on their data file values. If a pixel satisfies a certain set of criteria, the pixel is assigned to the class that corresponds to that criteria. This process is also referred to as image segmentation.

Depending on the type of information to be extracted from the original data, classes may be associated with known features on the ground or may simply represent areas that look different to the computer. The usual example of a classified image is a land cover map, showing categories such as vegetation, bare land, water or urban.

Supervised classification requires significant localized ground information for training areas, whereas unsupervised classification typically depends on information about spectral properties of classes to interpret clusters.

Generally, the classification breaks down into two different parts – training of the classifier (selection, aggregation and evaluation of signatures) and subsequent classification (applying a decision rule).

A.2.7. The Selection of Classifiers

The choice of an adequate classifier is generally done simultaneously when defining the classification scheme, because this decision may have implications on the field campaign.

However, there may be reasons to make this choice during field sampling is done, which is more the case in the thesis at issue.

In this study the first stage of classification was characterised by running divers unsupervised classifications with different band combinations in order to find meaningful clusters in the data. For this step the ISODATA algorithm implemented in ERDAS software package was used.

The first results were quite sobering. Whereas features like water, snow and dense vegetation were well distinguishable, bare soil was hardly differentiated from sparse vegetation. Uncertainties mainly occurred between dark shadow areas and water. Finally, the separation of irrigated arable areas from meadow areas was simply impossible, since biomass and soil moisture are almost identical. Nevertheless the set of spectral signatures derived from this first segmentation process was further used for the training of supervised classifiers in the next step.

Remote Sensing Data Analysis

Exercises

E.1. Exercises

E.6.1.