Chapter 32 Use of Geographic Information Systems (GIS) in Risk Assessment

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32.1 Introduction

A **geographic information system (GIS)** can be defined as an organized collection of software and geographic data that allow efficient storage, analysis, and presentation of spatially explicit and geographically referenced information. Traditional methods of processing such data have been extremely labor intensive, such as manually digitizing a map from an aerial photograph and then adding information about chemical contaminants. A GIS provides a powerful analytical tool that can be used to create and link spatial and descriptive data for problem solving, spatial modeling and presentation of results in tables or maps. For air toxics risk assessment, GIS can be a powerful tool for displaying and analyzing data during the planning, scoping, and problem formulation phases, during the exposure assessment, and displaying and evaluating the results of the risk characterization. It is also a very helpful means for communicating information to risk managers and other stakeholders.

GIS data generally consist of two components: (1) graphical data about geographic features (e.g., rivers, land use, political boundaries), and (2) tabular data about features in the geography (e.g., population, elevation, modeled ambient concentrations of air toxics). GIS combines these different types of data using a "layering" technique that references each type of data to a uniform geographic coordinate system (usually a grid such as latitude and longitude coordinates). Layered data can then be analyzed using special software to create new layers of data (see Exhibit 32-1).

Over the last several years, GIS applications have evolved from very specialized and expensive analyses that required specialized computers (e.g., supercomputers and workstations) to user-friendly desktop applications utilized by everyday users to do such mundane tasks as print maps or driving directions. Libraries of geographical information developed for general use (e.g., topographical maps, infrastructures, natural resources), and for use by EPA and other regulatory agencies, can be easily downloaded from different servers and used in air toxics risk assessments. One example of a GIS Web-based application is EPA's Envirofacts system[1] which provides website access to several EPA databases that provide information about environmental activities that may affect air, water, and land anywhere in the United States (with much of the data available in GIS format).

This chapter provides an overview of GIS and its application to air toxics risk assessment. More detailed information is provided in the Agency for Toxic Substances and Disease Registry (ATSDR)/Southern Appalachian Assessment GIS (SAAGIS) publication *Introduction to ArcView and Spatial Analysis Techniques for Public Health Professionals*.[2]

Exhibit 32-1. Example Conceptual Model Using GIS

Monitoring Wells

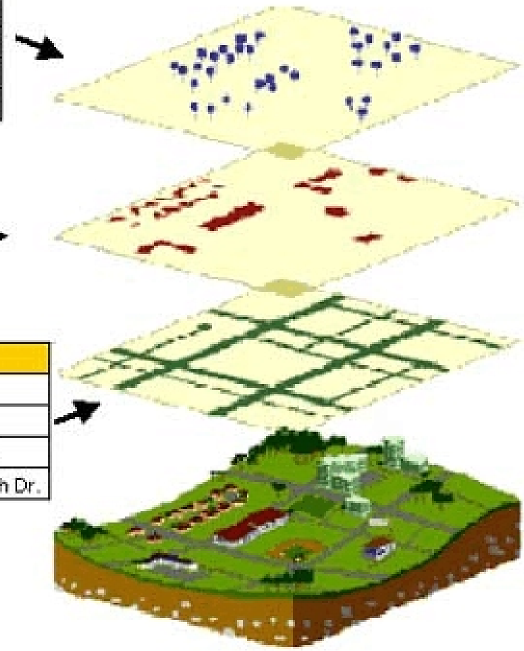
Well ID	Date Sampled	Concentration
C-6A	5/8/94	300
C-8A	5/8/94	20
C-13A	5/8/94	120
C-17A	5/8/94	560

Industries

Facility	Address
Acme	3029 Convington Dr.
Fox	742 West Lake St.
TPC	90 Aspen Dr.

Population

Family Name	Occupants	Addresss
Blake	6	79 Circuit St
Hernandez	2	148 Plain St.
Joy	4	18 Webster St.
Smith	5	4321 Tecumseh Dr.



Example of layering within a GIS. The location of monitoring wells, industries, and potential receptors (homes) are all referenced to the same geographic coordinates. This allows spatial analysis of the overlap of sources, contaminant plumes, and receptors, as well as a visual means to communicate complex data sets.

32.2 Selecting a GIS

After risk assessors decide to use a GIS, they must choose a software system. A variety of GIS software is available from commercial vendors. A key feature in selecting a GIS is identifying a minimal set of capabilities needed. Important functional capabilities to consider include: data capture, data storage, data management, data retrieval, data analysis, and data display.(3)

- **Data Capture**. All data used in a GIS must have a spatial component. This means that all information brought into the system must be geo-referenced (i.e., correspond to some physical location). Data capture is the process of incorporating map and attribute data into the GIS. **Geocoding**, which is the conversion of analog data to geo-referenced digital format, is a common way for GIS users to bring map and attribute data into their GIS analyses. Two common methods of geocoding are scanning and digitizing. Both involve taking non-digital information (e.g., a hard-copy map), and converting it into a digital format. In addition to paper files, GIS users often import files from common formats such as AutoCAD DXF. The newly imported digital information (e.g., the boundary of a state), is geo-referenced by coordinates so that it corresponds to a physical location.

In addition to graphical data, GIS incorporates tabular data for objects included in a data layer. For example, the graphical data associated with a home could consist of its size and location. The tabular data associated with that home consists of attributes such as who lives there, when it was built, where its water supply comes from, and what type of heating system it uses. These attributes would be listed in a table that is linked to the physical location of the house by the GIS. While obtaining geographical base layers that show boundaries is essential, data capture also involves attribute data, which necessitates that the GIS software package have some level of database manager associated with the program. A useful program will generally have features that allow it to import common database files such as those from dBASE®, Access®, Excel®, and Paradox®. The different software packages will vary in their ability to check the characteristics of the databases.

- **Data Storage**. A GIS can incorporate a tremendous amount of data into a map. Space is a key issue related to data storage in a GIS. With the decrease in cost of disk storage, the development of high-density storage media (e.g., CD-ROM), and the incorporation of compression methods, space is not as critical an issue as it has been in the past. However, GIS is still relatively memory-intensive. GIS microcomputer software can take up tens of megabytes of space without data, and a more complete workstation version may use hundreds of megabytes of space. Add to this the datasets with very high resolution (that can move into the gigabyte range in size), and there is a the potential for a significant storage problem. Some storage problems can be resolved by establishing data sets on a common server, accessible to multiple users.

- **Data Management**. A powerful GIS is one which has the ability to manage both map and attribute data. Every GIS is built around the software capabilities of a database management system (DBMS). A DBMS is software that is capable of storing, selecting, retrieving, and reorganizing attribute information. It allows data entry, data editing, and supports several different types of output. Functions include the ability to select records based on their value. Several database functions can work independently of the GIS functions.

- **Data Retrieval**. A GIS will support the retrieval of features by their attributes or by their spatial characteristics. A basic retrieval based on spatial characteristics is used to show the position of a single feature. In addition, a GIS is capable of allowing the operator to use the map as a query vehicle. A simple way of doing this is to point to a feature and retrieve the list of attributes for that feature. The database management function also is important for the data retrieval capacity because it allows for the selection and retrieval based on an attribute. **Buffering** is one retrieval operation that defines a GIS. Buffering allows the user to retrieve features within a specified distance of a point, line, or area. **Overlay** is another spatial retrieval operation in which non-overlapping regions are joined to create a new area. More sophisticated retrieval operations also are available.(2)

- **Data Analysis**. GIS systems vary a great deal in their data analysis capabilities. Basic tasks that should be included in a GIS are: spreadsheet and database analysis, computing new attributes, generating summary statistics, creating reports, statistics such as mean and variance, significance testing, and plotting residuals. In addition, selected geometric tests should be included (e.g., point-in-polygon analysis, surface partitioning).

- **Data Display**. GIS software displays information visually as data layers of a map. GIS users must select the correct map projection to make sure that their maps are not distorted. For example, large areas, such as continents, must be projected with the earth's curvature taken into consideration. Small areas can be projected essentially as flat. GIS software gives users as wide variety of map projection options to ensure that maps are as accurate as possible. Section 32.4.2 discusses map projections in further detail.

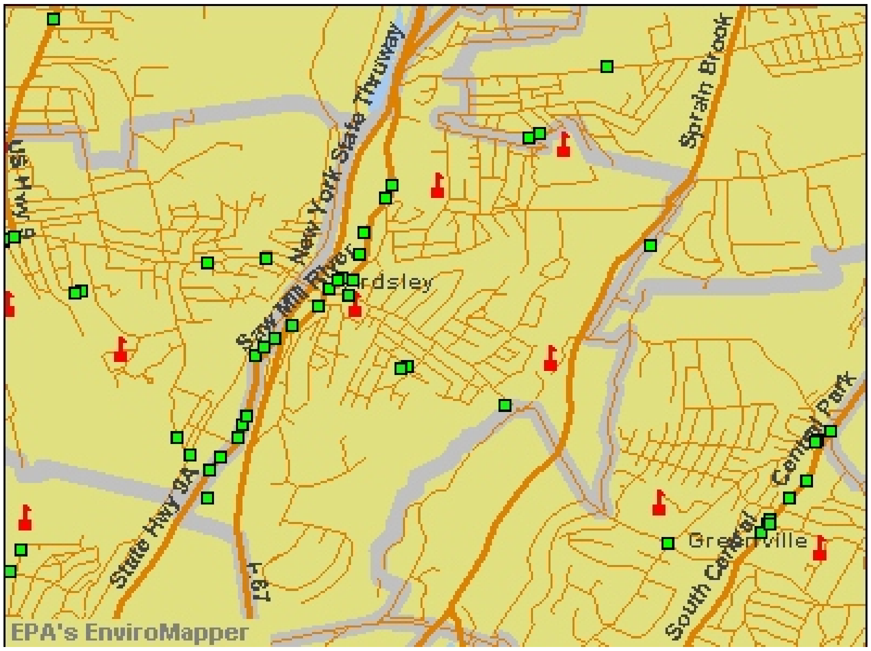
  Different data sources and agencies provide digital data that has been processed using different coordinate systems and map projections. Risk assessors may want to use data layers from many different sources to create a single map. For example, a topography layer from the U.S. Geologic Survey might be combined with a layer showing census blocks from the U.S. Census and a layer showing lead smelters from EPA. Software that can handle a variety of coordinate systems and map projections is essential to GIS capability to overlay layers created from many different sources.

32.3 Acquiring and Using Demographic Data

Demography is the study of the size, composition, distribution, and change in population. Geographers focused on population studies are also interested in the spatial distribution of demographic characteristics.[(4)] Data from the U.S. Bureau of the Census decennial census is the most common source of residential population information for states, the District of Columbia, and many U.S. territories (e.g., Puerto Rico, U.S. Virgin Islands, American Samoa, and Guam). These data also provide the base for current year population estimates and projections. Risk assessors are often interested in using demographic data because it allows them to identify sensitive sub-populations, such as children or the elderly. A GIS lets risk assessors combine demographic data with data on the location of sources (or estimated ambient air concentrations) to visualize where human health is potentially at risk (see Exhibit 32-2).

Within a GIS, political and statistical geographic area boundary files are linked to the attribute data (e.g., age, race, housing value) describing residents and housing units in that area using Federal Information Processing Standard (FIPS) codes. These codes provide unique identifiers for various geographic areas. When analyzing census data that is nested within the data hierarchy (e.g., census blocks within census tracts), it is best to include the FIPS codes for the larger geographic areas in that hierarchy to ensure that you are using a unique identifier. For example, connecting the FIPS codes for block 201, census tract 12, Fulton county, state of Georgia, results in the unique identifier "13089001200201" for that block. Because the codes are nominal numerals, it is best to treat them as character data (or strings) rather than numbers in the GIS database (although this may not be consistent across data sources).

Exhibit 32-2. Illustration of the Use of GIS to Identify Sensitive Receptors Close to Emissions Sources



In this map, the squares represent hazardous waste sites, and the flagged symbols represent schools. Schools and other locations where sensitive subpopulations may occur that are close to air toxics emissions sources may be of particular interest in a risk assessment.

32.3.1 U.S. Census Data

U.S. census data describing the residential population and housing in the U.S. provide the most complete picture of our nation and its subareas, which makes them very valuable demographic data. Exhibit 32-3 shows the type of information collected in the 2000 census. Many of the Census 2000 data files are available for use in GIS.

32.3.2 Current and Small-Area Demographic Estimates

An issue with census data is that the information represents a "snapshot" in time (generally based on April 1 of the census year). As one moves forward in time, such data may be less reflective of the actual demographic conditions in the study area. This problem is more pronounced for small-area data (e.g., census tracts and block groups). While the census data typically are appropriate for screening-level assessments (e.g., some air quality models include the 2000 census data), more refined assessments may require more current information, which is available from several commercial sources.

Exhibit 32-3. Information Collected in the 2000 Census

During census years, households received and were asked to respond to one of two census forms – the "short form," which gives the "100-percent component," or the "long form," which gives the "sample component." Questions on the short form were also found on the long form and thus, were (theoretically) asked of every household in the nation. Basic population and housing data were gathered in this way. More detailed population information was obtained from the long form sent to a sample of households. On average, approximately one in six households received the long form. The rate varied from one in two households in some smaller areas, to one in eight households for more densely populated areas.

100 Percent Component from the Short Form

Population
- Name
- Household relationship
- Sex
- Age
- Hispanic or Latino origin
- Race

Housing
- Tenure – owned or rented

Sample Component from the Long Form

Population

Social characteristics
- Marital status
- Place of birth, citizenship, year of entry to the U.S.
- School enrollment and attainment
- Ancestry
- Residency five years ago (migration)
- Language spoken at home and ability to speak English
- Veteran status
- Disability
- Grandparents as care givers

Economic characteristics
- Labor force status
- Place of work and journey to work
- Occupation, industry, and class of worker
- Work status in 1999
- Income in 1999

Housing

- Units in structure
- Year structure built
- Number of rooms and number of bedrooms
- Year moved into residence
- Plumbing and kitchen facilities
- Telephone service
- Vehicles available
- Heating fuel
- Farm residence

Financial Characteristics
- Value of home or monthly rent paid
- Utilities, mortgage, taxes, insurance, and fuel costs

Source: U.S. Census. *Census 2000 Basics.* Available at: http://www.census.gov/mso/www/c2000basics/00Basics.pdf

A number of commercial entities provide annual small-area population and housing estimates and projections. Estimates are calculated using the most recent decennial census as the population base and incorporating other, often proprietary, data sources to refine the estimates. In addition to providing updated demographics, some vendors have developed segmentation systems that classify the U.S. population into distinct lifestyle segments or clusters depending on residential location ("geodemographics"). The idea of clustering is based on the notion that, more often than not, people will choose to live near others like themselves. This is important to public health because assessors can be more efficient in identifying and understanding where potential hazards are concentrated, as well as developing messages that reach people living in those areas.

32.3.3 Public Health Applications

The use of census data is central for public health communication planning, program planning, implementation and information dissemination. For example, the Georgia Division of Public Health used demographic information to target mammography programs in factory towns classified as "Mines & Mills" because women in those communities were found to have higher rates of breast cancer.(5) As another example, the Centers for Disease Control (CDC) Office of Communication has collaborated with a number of centers on projects that integrate epidemiological and other data for communication planning including HIV status awareness and hantavirus prevention.(6) Because exposure to air toxics is often influenced significantly by proximity to sources, spatial information is essential to identifying areas where human health might be adversely impacted.

32.3.4 Data Access and Distribution

There are numerous sources for acquiring U.S. census data. In addition to the Census Bureau's data access tools, including Factfinder, its Web-based data dissemination system, many public and private organizations are including census data with GIS or mapping software (e.g., ESRI, EPA LandView, HUD Community 2020, Geolytics, Claritas, CACI). State governments, universities, and non-governmental organizations (e.g., CIESIN) are also sources for data. Costs associated with obtaining the data vary.

32.4 Cartographic Concepts

While spatial information and GIS can be extremely useful, people must have assistance in observing and studying the great amount and variety of information that is represented on maps. Geographic data are extensive and voluminous, so cartography, a technique that is fundamentally concerned with reducing the spatial characteristics of a large area, makes maps readable and meaningful. A map is more than a reduction of information to an understandable level. If it is well made, it is a carefully designed instrument for recording, calculating, analyzing, and in general, understanding the interrelation of things in their spatial relationship. This section provides an overview of cartography. A more complete discussion can be found in *The Geographer's Craft Project*.(7)

One of the most useful approaches to the study of cartography is to view maps as a form of visual communication – a special purpose language for describing spatial relationships. Cartography is related to, but different from other forms of visual communication. Cartographers must pay special attention to coordinate systems, map projections, and issues of scale and direction that are in most cases of relatively little concern to other graphic designers or artists. But, because cartography is a type of graphical communication, some insights to the demands of cartography can be gleaned from the literature of graphical communication and statistical graphics. By stressing cartography as a form of communication, it is easier to make the point that maps are really symbolic abstractions – or representations – of real world phenomena. In most cases, this means that the world represented on a map has been greatly simplified, or generalized, with symbols being used like words to stand for real things. Some of the most important decisions cartographers make in the process of cartographic design revolve around: (1) how much to simplify the situation being depicted; and (2) how to symbolize the relationships being represented. In order to make good choices, cartographers often ask themselves the following questions:

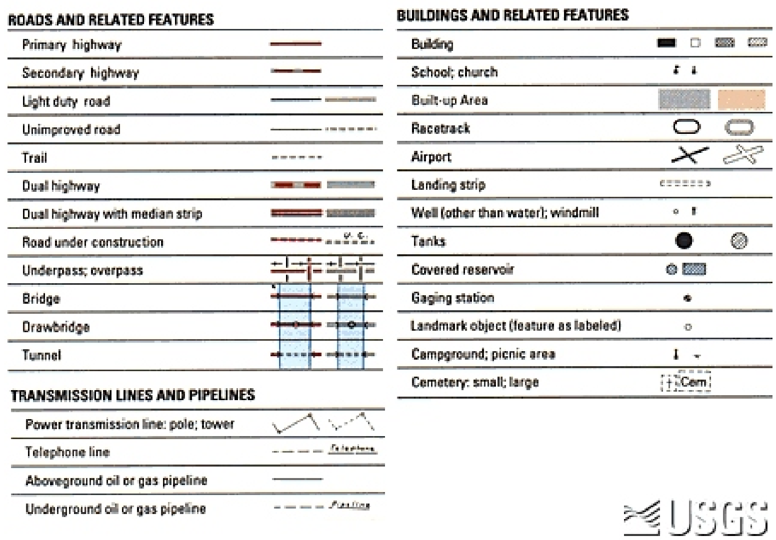
- What is the motive, intent, or goal of the map?
- Who will read the map?
- Where will the map be used?
- What data is available for the composition of the map?
- What resources are available in terms of both time and equipment?

By identifying the most important points to be conveyed by the map along with the map's main audience, cartographers can prioritize where to direct the audience's attention with larger symbols or brighter colors.

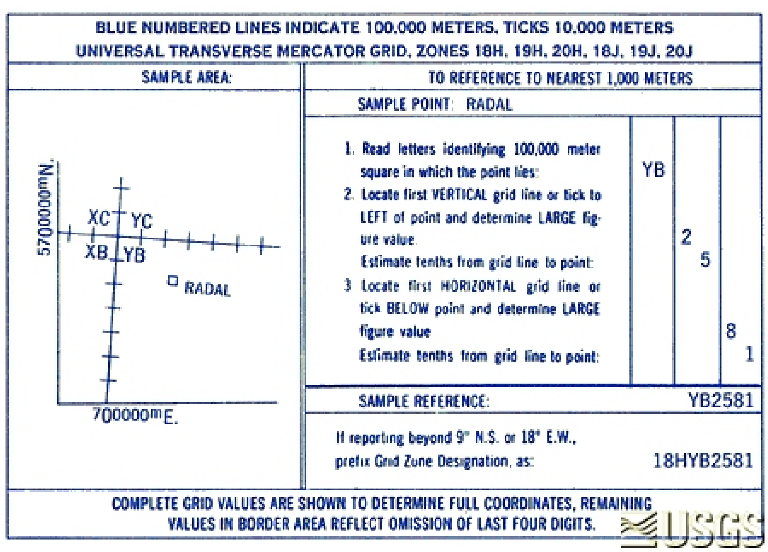
Basic Map Elements

A legend and symbols that inform the viewer of distance, scale, and direction, are basic elements to any map. The USGS (http://edc.usgs.gov/earthshots/slow/Help-GardenCity/legendstext) provides examples of common map legends.

Example U.S. Geological Survey (USGS) Topographic Map Legend



Example Legend for Universal Transverse Mercator (UTM) Projection Zones



32.4.1 Generalization, Simplification, and Abstraction

> **Map Making Tips**
>
> - Experiment with different layouts
> - Think carefully about every element on your map and whether it has an essential function
> - Less is more

As noted above, cartography is a process of abstraction in which features of the real world are generalized or simplified to meet the demands of the theme and audience. Not all elements or details have a bearing on the pattern or process being studied and so some are eliminated to draw the reader's attention to those facts that are relevant. Too much detail can even hide or disguise the message of a map. The amount of detail that can be included is very much dependent on the scale at which the map will be produced (see Exhibit 32-4).

32.4.2 Map Projections

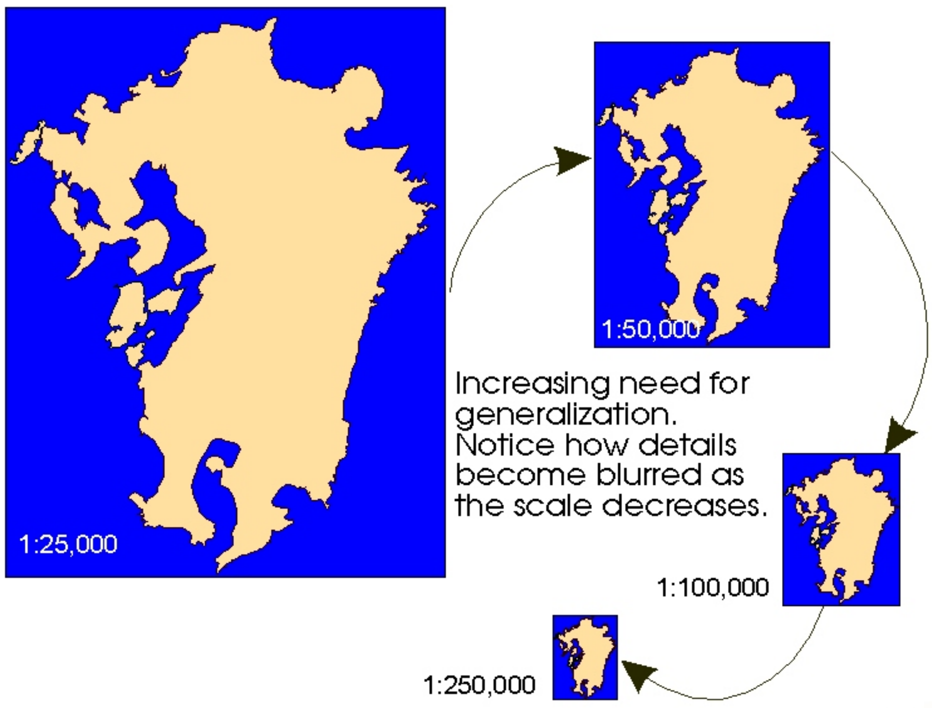
As section 32.2 notes, the projection used to create a map influences the representation of area, distance, direction, and shape. This is readily apparent when looking at a flat map of the world versus looking at a spherical map of the world (i.e., a globe). Maps that ignore the natural shape of the earth distort the places they are trying to represent. It should be noted when these characteristics (e.g., area, distance, direction, and shape), are of prime importance to the interpretation of any map. Some widely used locational reference systems such as the U.S. State Plane Coordinate system and Universal Transverse Mercator system are based on predefined projective geometries that are implicit in the use of the coordinate systems themselves. GIS software packages make it easy for users to choose an appropriate map projection.

32.5 Using the Internet as a GIS Tool

The internet can be a valuable resource for GIS users looking for data. Many federal agencies provide digital data free for download that can be used with GIS. The Census Bureau, EPA, and the United States Geological Survey are all good sources of GIS data. For example, in addition to demographic data, the Census bureau distributes what are called **T**opologically **I**ntegrated **G**eographic **E**ncoding and **R**eferencing (TIGER) files. The TIGER/Line files are a digital database of geographic features, such as roads, lakes, political boundaries, and census statistical boundaries, available for the entire United States. The database contains tabular information about these features such as their location in latitude and longitude, the name, the type of feature, and other important attributes. GIS clearinghouses, universities, and data supply companies are also good places to look for data. A Web search engine can help users locate sites that contain the type of data needed for a given project.

Once users locate relevant data, they must then get the data onto their computer. GIS coverages can take up a lot of computer memory, so choosing the right file transfer method is very important. Many websites allow direct downloads. This type of transfer involves clicking a link and specifying a target directory. Other data providers require users to go through a **file transfer protocol** (FTP) site. FTP sites allow people to exchange large data files more readily than with other protocols.

Exhibit 32-4. Effect of Scale on Detail and Abstraction



Finally, the internet can serve as a resource for users looking for technical support or advice. Most users will find that GIS software manufacturers offer online support. Some companies even have online courses.

32.6 Current GIS Applications at EPA

EPA is an excellent source of GIS data and information for risk assessors. Several offices and branches can serve as resources for those interested in learning more about GIS and its uses, especially in the areas of landscape, land cover, and land use. GIS helps EPA integrate geo-spatial data on a region (e.g., landscape, elevation, climate, slope) with information about potential exposures to give risk assessors a comprehensive picture of that region's hazards.

Because projected land use may be an important input to air models, risk assessors may want more information on landscape change models. For an overview on this subject, see EPA's *Projecting Land-Use Change: A Summary of Models for Assessing the Effects of Community Growth and Change on Land-Use Patterns.*[8]

32.6.1 ORD/ESD

EPA's Office of Research and Development/Environmental Sciences Division (ORD/ESD) conducts research, development, and technology transfer programs on environmental exposures to ecological and human receptors. GIS is an important tool for the type of chemical and physical stressors characterization conducted, especially with ESD's emphasis on ecological exposure. The Division develops landscape and regional assessment capabilities through the use of advanced spatial monitoring and analysis techniques, such as remote sensing and GIS. For more information, go to http://www.epa.gov/nerlesd1/.

32.6.2 ATtILA

Another EPA resource is the Landscape Ecology Branch's ATtILA program, which stands for *Analytical Tools Interface for Landscape Assessments*. The Branch uses ATtILA, which is a GIS, to conducts multiple-stressor regional assessments based largely on geo-spatial landscape data. As part of these assessments, ATtILA generates complicated landscape metrics, which are quantitative measurements of the environmental condition or vulnerability of an area (e.g., ecological region). ATtILA provides an interface that allows users to easily calculate many common landscape metrics regardless of their level of GIS knowledge, despite the complexity of developing the metrics. Four metric groups are currently included in the package (e.g., Landscape Characteristics, Riparian Characteristics, Physical Characteristics, and Human Stresses). ATtILA runs within ArcView®, and is designed to be flexible enough to accommodate spatial data from a variety of sources. More information is available at: http://www.epa.gov/nerlesd1/land-sci/northern_california/attila/background.html.

32.6.3 ReVA

Also from EPA's ORD is the Regional Vulnerability Assessment (ReVA) program. This program is an approach to regional scale, priority-setting assessment meant to expand cooperation among the laboratories and centers of ORD, by integrating research on human and environmental health, ecorestoration, landscape analysis, regional exposure and process modeling, problem formulation, and ecological risk guidelines. Currently, ReVA is working in the Mid-Atlantic region to predict future environmental risk. This will help EPA prioritize efforts to protect and restore environmental quality efficiently and effectively. ReVA is being developed to identify those ecosystems most vulnerable to being lost or permanently harmed in the next 5 to 25 years and to determine which stressors are likely to cause the greatest risk. The goal of ReVA is not exact predictions, but identification of the undesirable environmental changes expected over the coming years.

Many functions work together to provide ReVA's regional assessment capability. GIS puts into a spatial context data on stressors and effects from many sources. Research guides how to apply this data at the landscape and regional scale and helps EPA understand how socioeconomic drivers affect environmental condition. The transfer of data and analytical tools to regional managers is also critical for this tool to be useful. ReVA is considered a GIS because it is designed to analyze the spatial distribution of sensitive ecosystems by analyzing known distributions of plant and animal populations or communities within ecosystems. Modern methods in landscape ecology and characterization help further identify the locations of ecosystems that are vulnerable to future stress through features such as topography (i.e. increased erosion potential) and habitat patch configurations. Multimedia assessments across water, air, terrestrial, and demographic variables are possible at various scales with this tool. For more information on ReVA, see http://www.epa.gov/reva/approach.htm.

32.7 GPS Technology

Global Positioning System (GPS) technology can be integrated with GIS. GPS technology allows users with the appropriate technology to obtain almost the exact location of any GPS receiver. This means that cars can get driving directions while moving, hikers can always know their exact position for navigating in and out of the wilderness, and the military can track movements of troops or vehicles. For risk assessments, the location of specific sources (i.e., vents) or receptor locations can be accurately determined with GPS. GPS is funded and controlled by the U.S. Department of Defense (DOD). While there are many thousands of civil users of GPS world-wide, the system was designed for, and is operated by the U.S. military.

The system works through specially coded satellite signals that can be processed in a GPS receiver, enabling the receiver to compute position, velocity, and time (see Exhibit 32-5). Four GPS satellite signals are used to compute positions in three dimensions and the time offset in the receiver clock (see Exhibit 32-6).

The GPS provides two levels of service – a Standard Positioning Service (SPS), and a Precise Positioning Service (PPS). Access to the PPS is restricted to U.S. Armed Forces, U.S. Federal agencies, and selected allied armed forces and governments. The SPS is available to all users on a continuous, worldwide basis, free of any direct user charge. A nationwide differential GPS service (NDGPS) is being established pursuant to the authority of Section 346 of the Department of Transportation and Related Agencies Appropriation Act. When complete, this service will provide uniform differential GPS coverage of the continental U.S. and selected portions of Hawaii and Alaska regardless of terrain, man-made, and other surface obstructions. NDGPS accuracy is specified to be 10 meters or better. Typical system performance is better than 1 meter in the vicinity of the broadcast site. Achievable accuracy degrades at an approximate rate of 1 meter for each 150 km distance from the broadcast site.[(9)]

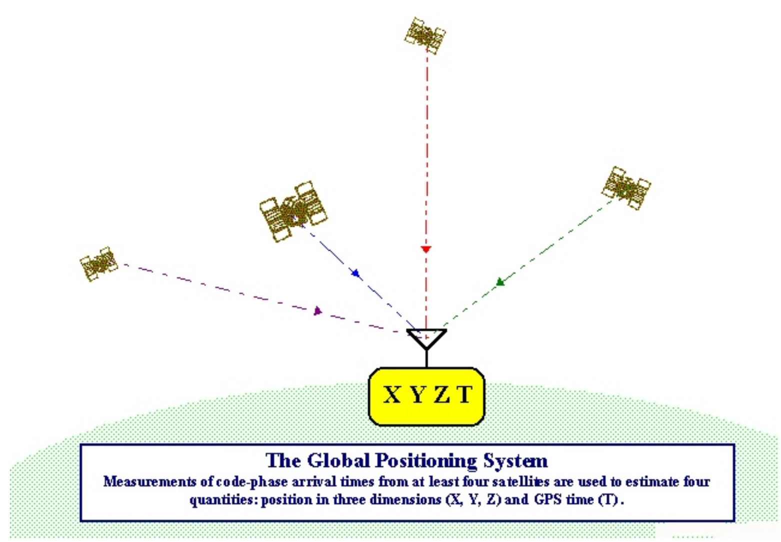
Receiver costs vary depending on capabilities. Small civil SPS receivers can be purchased for under $200. Receivers that can store files for post-processing cost more ($2,000 to 5,000). Receivers that can act as DGPS reference receivers (computing and providing correction data) and carrier phase tracking receivers (and two are often required) can cost many thousands of dollars ($5,000 to $40,000).

Receivers are important because they are the intermediary part of the system that connect real world data to GIS. Satellites send signals to the receiver and users and store the information. Sometimes, the user will have to manually record position and time readings and then type those into a computer later. Other times the user can plug the receiver into a special port on her computer and download the digital data directly.

Exhibit 32-5. Global Positioning System (GPS) Satellites

GPS satellites orbit the Earth every 12 hours, sending signals to receivers around the world

Exhibit 32-6. Positioning and Time from Four GPS Satellites



Measurements of code-phase arrival times from at least four satellites are used to estimate four quantities: position in three dimensions (X, Y, and Z) and GPS time (T).

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