Geographic Information Systems and Public Health: Mapping the Future

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Looking toward the 21st century, we anticipate that health planning, particularly at the community level, will be substantially improved by developments in informatics—that is, through the application of information science and technology to public health practice and research.[1] Ideally, each community will have the capability to link together health information from a variety of different data sources and to recognize spatial data patterns that suggest where cost-effective public health interventions can be applied.

We believe that geographic information system (GIS) technology will be an important part of the toolkit to support this capability, but only if epidemiologic principles and methods provide the foundation for the data analyses to be displayed in GIS maps.[2–6] Here, we provide our thoughts about current trends and future directions for GIS technology in public health and the challenges to institutionalizing this technology as a standard part of public health planning and practice by the Year 2010.

Current Trends

During the 1990s, local government use of GIS technology has grown substantially.[7] A national survey in 1997 of a sample of 200 cities and counties concluded that use of GIS technology in at least one department of local government had increased from 20% of jurisdictions in 1990 to a predicted 87% by the end of 1997.[7] Respondents named planning departments as the most frequent local government users (almost 80% of respondents in all jurisdictions).

Based on informal discussions with representatives of many local public health departments, the National Association of County and City Health Officials (NACCHO) reports that interest in GIS technology has increased during the 1990s, but many local public health departments still do not have the software, hardware, or trained staff that would enable them to apply GIS technology.[8] Local public health departments would like to see GIS components added to NACCHO's community planning tools such as the *Assessment Protocol for Excellence in Public Health* and its new iteration, *Assessment and Planning Excellence through Community Partners for Health,* scheduled for release in year 2000 in electronic format (for more details about these tools, see NACCHO's website at **www.naccho.org**). NACCHO is currently developing plans for a national survey to document local public health departments' GIS activities.

One of the initial steps in any GIS project is to geocode (georeference) each data record to the desired level of accuracy (for example, county, Census tract, Census block, US Postal Service zip code, or street address). (The smallest area of US Bureau of Census geography is the Census block. In urbanized areas, a Census block typically is a quadrangle bounded by four streets (a city block). In sparsely populated areas, a Census block has a population of about 70 people and is bounded by visible features such as roads, streams, or railroad tracks or by invisible boundaries such as city or county limits. In rural areas, a block may encompass many square miles.)

During the 1990s, geocoded public health data have been in relatively short supply, limited to states with initiatives to geocode vital statistics data or to individual investigators who could geocode their own data. In a 1997 survey of state Vital Statistics Project Directors, only 21 of 49 respondents reported that their states had some type of automated geocoding of vital statistics.[9]

The growing interest in GIS applications in public health is illustrated by the Third National Conference on GIS in Public Health, held in San Diego in August 1998. Participants addressed a wide variety of topics, ranging from the use of satellite images to measure ocean temperatures and forecast cholera epidemics in India to the use of global positioning system (GPS) technology to determine latitude-longitude coordinates for locations of billboards with cigarette advertisements in relation to school bus routes.

Epidemiology and GIS Technology

Epidemiologic principles and methods provide the foundation for public health and preventive medicine. To avoid drawing false conclusions from maps, users of GIS technology need to understand and apply these principles and methods in formulating study questions, testing hypotheses about cause-and-effect relationships, and critically evaluating how data quality, confounding factors, and bias may influence the interpretation of results. Conversely, epidemiologists need to be able to understand and critically evaluate maps prepared using modern GIS software, data, and spatial statistical methods.

A recent special issue of the *Journal of Public Health Management and Practice* was devoted to GIS technology. (A second special issue is due out in July 1999.) In an editorial, Melnick and Fleming discuss the "promise and pitfalls" of GIS technology.[5] They note that "perhaps the greatest potential of GIS lies in its ability to quickly, clearly, and convincingly show the results of a complex analysis.... The greatest strength of GIS is that its product is a picture." They go on to say, "Ironically, the power of the GIS tool may also be its biggest pitfall. The consequence [of integrating] complex data into a visually easy to understand picture ... is a setup for misunderstanding and misuse." Users, including policy makers, they point out, may be tempted to infer causation from correlation and to make inferences about individuals from population data (the ecologic fallacy).[5]

Another potential problem with drawing conclusions from maps is that, as Monmonier writes, "Not only is it easy to lie with maps, it's essential...."[10] The cartographer's paradox is that "to avoid hiding critical information in a fog of detail, the map must offer a selective, incomplete view of reality."[10] Public health practitioners need to be alert for "lies" that can range from "little white lies" (suppressing details selectively to help the user see what needs to be seen) to more serious distortions in which the visual image suggests conclusions that would not be supported by careful epidemiologic analysis. For example, when some geographic units of analysis have small denominators, disease rates computed for these areas may appear extremely high if any cases have occurred in these areas. When the rates for these geographic locations are displayed on a map, readers may incorrectly conclude that these are "hot spots," high priority locations for targeted interventions. More appropriately, these areas should be labeled to indicate that rates are statistically unstable due to small numbers and therefore not shown.

With advances in desk-top computing, it will become easier to produce multiple maps using different data sources and different methods, each offering a unique perspective on an issue. Again, the principles and methods of epidemiology need to be applied to evaluate the strengths and limitations of the data and the science "behind" the maps, in order to identify the map (or maps) that convey the most truthful messages.

The ability to invest in GIS hardware, software, and data may enable those with greater resources to be more influential in communicating their "selective, incomplete view of reality" to community decision makers.[11] In the future, as advocacy groups, community organizations, hospitals, managed care organizations, and the news media increasingly use GIS technology with health-related data, the need for education about epidemiologic methods and principles becomes even more essential.

Definition

The phrase "geographic information systems" was first used in the 1960s to refer to a computerized system for asking questions of maps showing current and potential land use in Canada.[4] Since that time, a number of definitions have been proposed, with variations that depend on the perspective of the author, the specific application, the software available at a given time, and the level of complexity appropriate for the intended audience. Some authors have begun to suggest that a different term, "geographic information science," might be advantageous in order to place greater emphasis on the underlying general principles and science and to be more independent of developments in software technology.[4]

From a community health planning perspective, the Federal Geographic Data Committee (FGDC) definition provides a useful starting point:

> A computer system for the input, storage, maintenance, management, retrieval, analysis, synthesis, and output of geographic or location-based information. In the most restrictive usage, GIS refers only to hardware and software. In common usage, it includes hardware, software, and data. When organizations refer to their GIS, this latter usage is usually what they mean. For some, GIS also implies the people and procedures involved in GIS operation.[12]

Mapping Rodent Complaints

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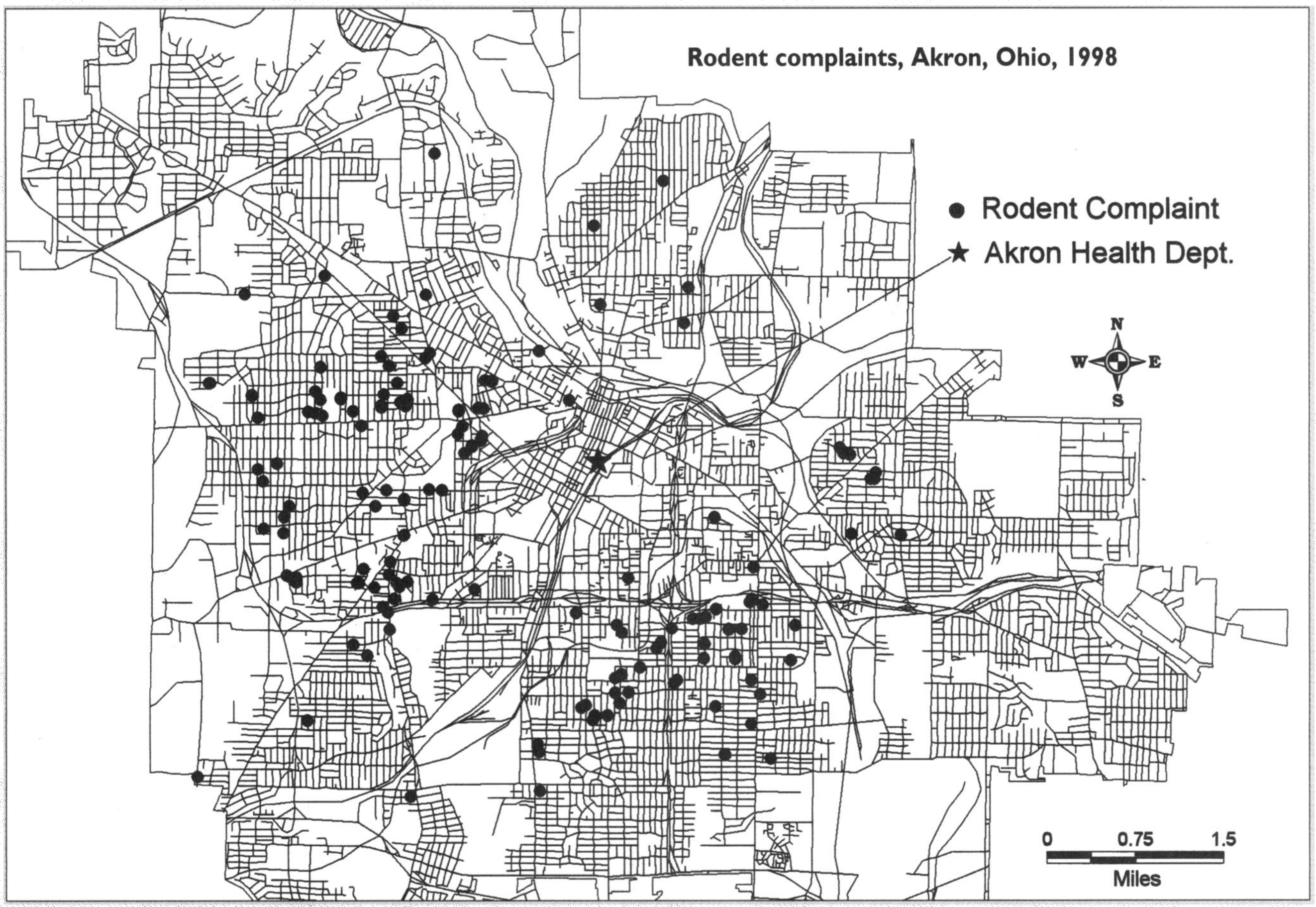

Software used: MapInfo Professional Version 4.0

Rodent control is a responsibility of many local public health departments. In 1998, 295 rodent complaints were phoned in to the Akron Health Department; of these, 166 were "justified." (A complaint of rat activity on private property was verified by a sanitarian inspection that revealed rat burrows, the property owner signed a bait release form giving the Department permission to bait the property, and the property was baited.) Repeat calls about the same address are not logged as new complaints.

Geographic mapping of private addresses with justified rodent complaints has helped the Department concentrate its efforts in areas where rodent problems are evident. Block-by-block surveys looking for conditions favorable to rodents and continuous baiting of sewers are carried out preferentially in neighborhoods generating verified complaints.

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Technology

SOFTWARE, HARDWARE, AND DATA FOR NEW GIS USERS

The appropriate choices of GIS software, hardware, and data depend on the nature of the project, and may vary considerably from project to project. Some caution is prudent in any investment, given that the technology for public health applications is still in early stages of development and a variety of research issues still need to be resolved. Beginners are well advised to start with a small (inexpensive) project that can be completed in one year or less before attempting a larger project. Cost estimates should include estimates for training of personnel as well as recurring costs for maintenance and upgrades. In order to convince key decision makers that an investment in GIS technology is worthwhile, public health practitioners, planners, and researchers should be prepared to explain how the investment would translate into measurable differences in performance, prevention effectiveness, or study results.

Software. An important consideration for local public health practitioners, planners, and researchers who are selecting GIS software is what software is being used by local government agencies within their jurisdiction. The answer may be a key factor in making a decision about software for a new project because, over time, a significant portion of the costs of GIS technology is related to obtaining and geocoding spatial data (assigning latitude and longitude coordinates to the street address where a case is located). The ability to share spatial datasets between local government agencies and other users is essential so that each user does not need to "reinvent the wheel" to create the desired spatial datasets. Another advantage is that that more experienced users in the community may be available to answer questions for a new user. The knowledge gained from informal discussions with other users can be quite helpful in supplementing any formal training. In addition, there may be cost advantages (for example, a discount if the local government purchases multiple units of a software program).

A national survey in 1997 of a sample of 200 county and city governments reported that two software packages were most commonly used by city and county government respondents serving jurisdictions with larger populations.[7] In this survey, a "large" metropolitan county government was defined as a county jurisdiction with more than 50,000 population, and a "large" city government was defined as a jurisdiction with more than 100,000 population. The two most commonly mentioned software packages were ARC/INFO and ArcView GIS (both from Environmental Systems Research, Inc.).

A number of other GIS products exist or are in various stages of development.[22] Several that are frequently mentioned in the context of public health practice, planning, and research are Map Info (Map Info, Inc.), which has been used by the New York State Department of Health; Maptitude (Caliper Corporation), a relatively low-cost product; and Community 2020 (developed by the HUD in partnership with Caliper Corporation), which includes 640 different Census data elements, population estimates and projections to 2007, and HUD project data. These three software programs range in price from about $250 to about $1200; ARC/INFO for NT costs about $7100, and ArcView GIS costs about $1200. More advanced software applications (for example, Web-enabled GIS applications) can involve considerable additional costs (as much as $10,000 or more).

Although each of the five above-mentioned programs have some differences, they have the following technical features in common:

(*a*) The computerized database is in digital format.

(*b*) Geographic boundary files and attribute data are stored with linked geo-referenced identifiers—for example, Federal Information Processing System (FIPS) identifier codes for geographic boundary files such as Census tracts or block groups, or latitude and longitude coordinates for point locations.

(*c*) The system can display street-level maps and geocode points to a street address level of precision.

(d) The system enables the user to zoom from a large area (the nation, a region, or a state) to a small area (for example, street level), and vice versa.

(*e*) The system can display data as *n* multiple layers (and thereby allow the user to add or remove layers to custom design maps with desired features).

(*f*) The system can compare and select data for analysis from different layers

(*g*) The system can measure distances, areas, and events within a boundary area.

(*h*) The system can create buffer zones (for example, draw a boundary line at a fixed distance from a river).

(*i*) The system can change map projections (that is, the system can change the method for representing the curved surface of the earth on a flat surface; different projections are needed, for example, depending on whether the goal of the map is to preserve shape or to measure distances).

A variety of other computer graphics programs and software products can be used to prepare quality maps, but these do not include all of the features listed above, and therefore are typically excluded from reviews of GIS products. Examples include: Microsoft Expedia Streets, Harvard Graphics, and the CDC public domain computer software tools, Epi Info and Epi Map.

Hardware. Compared with text documents prepared using a standard wordprocessing program, GIS maps require much more computer storage space, more speed, and more video memory for processing and display. The hardware configuration depends on the size of the project and the desired goals. For an initial small project, the following desktop computer hardware specifications (estimated total cost about $4000 to $6000) provide a starting point for discussion: Windows 95, 98, or NT; a 300 MHz (or faster) Pentium II processor (or higher) with graphics refresh capability; 128 RAM or greater; a large hard drive (for example, 8 GB or larger); a video card with 8 MB RAM; a 21-inch, graphics-quality color monitor (a larger monitor is advantageous because several desktop windows are often open at the same time); a color printer (laser or inkjet) with at least 300x300 dots per inch resolution; a 24x or faster CD-ROM; a method to store spatial data and mapping projects (for example, a back-up tape or other storage device); and ability to connect to the Internet.

Data. As in any epidemiological research study, high quality, accurate, and current data are needed for GIS analysis. As Rogers has observed, "A general rule of thumb is that data should not be used unless a user has details on the data source, quality, timeliness, and reliability."[28]

Commercial GIS software packages typically include some *geographic boundary files* and some *attribute data* (a defined characteristic of a geographic unit of analysis). For example, if the software package includes shape files for Census blocks (the geographic unit of analysis), then it might also include attribute data such as demographics, poverty level, and age of housing for each Census block unit.

The geographic boundary files and attribute data included in a basic software package can be quite useful as part of an initial community health assessment and in epidemiologic research. More advanced public health planning and epidemiologic research projects, however, are likely to require boundary and attribute data that are not included as part of a basic package. Certain types of public health data (for example, case reports of gonorrhea or childhood lead poisoning) are unlikely to be available from commercial sources because of the need to protect the confidentiality of individuals and households. Staff time and costs related to obtaining and processing additional data for public health projects can be substantial (and in large projects may exceed the cost of the computer hardware and software).

Sources of *spatial data* can be generally categorized as: local, state, federal, and commercial. In an increasing number of communities, an excellent starting point for spatial data are GIS users within local government agencies and regional economic development offices. A state geographic data clearinghouse or coordinating group can be another excellent source for spatial data, especially for geographic boundary files and environmental data. Other useful sources are local government repository libraries where federal government data CD-ROM collections are available. In addition, an increasing number of federal government agencies (including the Bureau of the Census, CDC, the Environmental Protection Agency, the US Geological Survey, and HUD) have spatial datasets that can be downloaded from the Web.

Relative advantages of federal and state government sources are that the data from these sources tend to be low-cost (or free) and that *metadata* (data about the data, such as information on content, quality, condition, source, date, and other characteristics of the data) are available. A relative disadvantage is that data from federal and state government sources may be limited to county or larger geographic units of analysis because of concerns about the statistical stability of estimates or the need to protect the confidentiality of individuals and households.

Data from commercial sources may have their origins in government sources, but commercial firms typically add some refinements (for example, making the data more accessible to users or combining the data with other information). For a public health program or agency with scarce resources, there are several potential disadvantages of commercially available data: the data may be relatively expensive; metadata may not exist or be uncertain; and commercial licensing agreements may be relatively restrictive. For example, if a public health practitioner has a project that requires a geographic boundary file that is not included in the initial software program package, and the practitioner purchases only a single user license for a commercial boundary file, then he or she would not be able to post the file on a local area network (LAN) system or otherwise share the file with another user.

The inclusion of "people" and "procedures" as part of the definition is essential for GIS applications in a public health context, given the need to link the science and methods of epidemiology to GIS maps. Without trained staff, one scenario is that the GIS software will not be used at all (given the time and staff constraints that exist in many public health agencies and organizations). Alternatively, without trained staff and standardized procedures, the technology may be used to develop maps that are invalid or misleading.

Advantages of GIS Technology

Several advantages of GIS technology for public health practice, planning, and research are as follows:

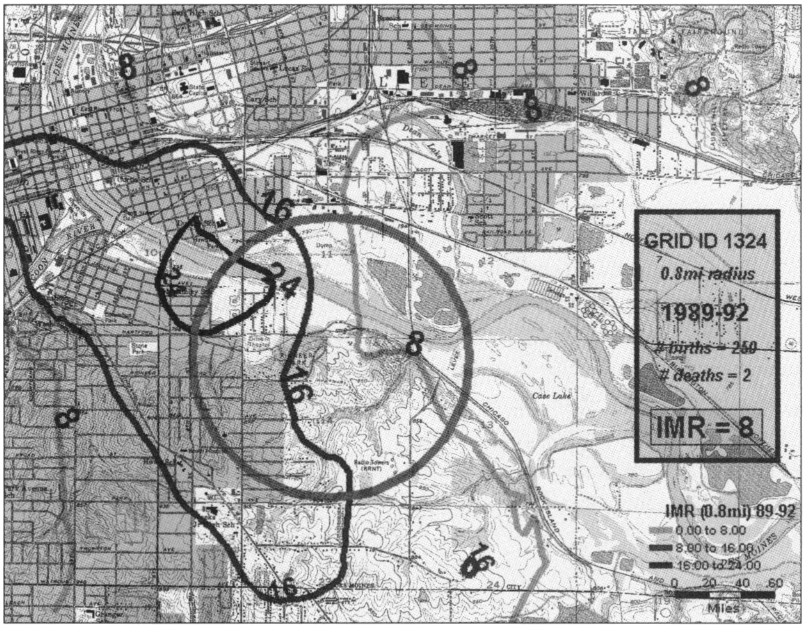
(*a*) GIS technology improves the ability of practitioners, planners, and researchers to organize and link datasets (for example, by using geocoded addresses or geographic boundaries). Geography provides a near-universal link for sorting and integrating records from multiple information sources into a more coherent whole. This ability to link datasets can help public health practitioners plan more cost-effective interventions. For example, suppose that a childhood lead poisoning prevention program could access residential databases maintained by the tax assessor's office and map the street addresses of houses built before 1950 (when lead-based paint was commonly used). Suppose that the prevention program could also access hospital and managed care plan electronic databases to identify street addresses for new births. Combining these datasets, the program could apply GIS technology to identify infants at high risk for exposure to lead-based paint and send a public health worker to follow up with specific households. By matching the addresses of these infants to a street map (from a "topologically integrated geographic encoding and referencing" [TIGER] file), using the "address-match" and "route-scheduling" functions of GIS software, the health worker can implement an efficient schedule of household visitations.

(*b*) GIS technology provides public health practitioners and researchers with several new types of data. For example, with GIS technology, local public health departments can use global positioning systems (GPS) to receive signals from satellites to determine latitude-longitude coordinates for point locations not found in TIGER files, such as rural residences, wells, and septic tanks. Public health practitioners can also use digital imagery from satellites or aerial photos to add details to (or improve the accuracy of) a mapping project (for examples of digital imagery, see **www.terraserver.com, www.spaceimaging.com, www.ogeta.com**, or **www.usgs.org**). If a sequence of digital images for a small area of interest is available, automated change detection can be used to observe changes over time, such as the addition of housing developments, roads, and landfills and other changes in land use and land cover. Public health practitioners can also begin to explore the utility of data collected by marketing firms about consumer spending patterns, retail expenditures, and lifestyle segmentation profiles (for examples, see **www.natdecsys.com**, **www.demographics.com**, or **www.claritis.com**). Businesses use these marketing data to identify likely customers—for example, to optimize targeting of cigarette advertising. Public health practitioners could also potentially use these data to identify the best "customers" for prevention interventions—for example, anti-smoking programs.[13]

(*c*) GIS technology encourages the formation of data partnerships and data sharing at the community level. For example, to develop a map of motor vehicle injuries and fatalities in a community, a local public health department could develop data partnerships with the Department of Transportation (for information about traffic flow and accidents), local ambulance services (for information about injuries requiring transportation by ambulance to hospital emergency rooms), and the Medical Examiner's office (for information about fatalities). Some GIS projects may be feasible only if all parts of local government join together and contribute (for example, developing a regional data warehouse or obtaining digital aerial photos or satellite images for an entire region).

(*d*) As new GIS methods are developed, they can be added to the "toolkits" of epidemiology and health services research. For example, for an exploratory data analysis in response to community concern about an apparent excess of cancer cases, tests for spatial randomness (such as the spatial scan statistic described by Kulldorff[14]) could be used to evaluate if a cluster is present using Monte Carlo simulations. The National Cancer Institute has developed software known as SaTScan to perform these calculations. Copies of this software are available free of charge.[14] Maps of "smoothed" rates could be developed to reveal neighborhoods at maximum risk using the DMAP Program (University of Iowa) to compute grid values (see Figure).[15] GIS technology also could be used to link data for an individual with contextual information aggregated at a variety of geographic levels (for example, Census block group, Census tract, county, or state). This capability enables preparation of a multi-level spatial model to better

Figure. A smoothed map of infant mortality rates in southeast Des Moines, Iowa, 1989–1992



evaluate and distinguish biologic, contextual, and ecologic effects. While conclusions based on an analysis at the aggregate level are likely to be limited by the ecologic fallacy and by aggregation bias (failing to identify the true nature of cause-effect relationships at the level of the individual), conclusions based on analysis at the individual level may be limited by the atomistic fallacy (failing to consider the context in which individual behavior occurs).[16–18] For each factor considered, a multi-level model can include both individual predictors (data for each individual) and ecologic predictors (average or aggregate measures).[18]

(*e*) Compared with tables and charts, maps developed using GIS technology can be an extremely effective tool to help community decision makers visualize and understand a public health problem.[19] In addition, action is more likely when the decision maker can see on a map that a problem is occurring in his or her "backyard." GIS technology enables detailed maps to be generated with relative speed and ease. In turn, this provides public health practitioners with the ability to provide quick responses to questions or concerns raised in a community meeting, for example, by preparing supplemental maps or by displaying more information about a point on the map during the course of the meeting.

The Figure shows a "smoothed" map of infant mortality rates in southeast Des Moines, Iowa, that was prepared for a public meeting. Births and infant deaths in this area for 1989–1992 were geocoded by matching addresses in vital statistics records to the US Census data TIGER files of streets for the area. The contour lines show the variations in infant mortality rates; the highest rates were found near the McKinley School and the drive-in theater. (The feature names are from the digital data files of the US Geological Survey's 1:24,000 Quadrangle Series, available for most of the US.)

The circle shows the size of the spatial filter used to "smooth" the map. (Small filters show more geographic detail but risk showing patterns of random variability; high-rate areas on such maps are often due to chance variability in incidence of the disease or condition, as discussed above. Consequently, the study of such maps should involve comparing results of varying sizes of spatial filters and statistical analyses of the apparent patterns to determine significant clusters.)

At the meeting, members of the public could comment on specific locations of interest. With each click of the mouse on the map, a circle appeared around the point selected and a box appeared on the screen showing the numbers of births and infant deaths within the area of the circle. This dynamic feature of geographic information technology (the ability to display information linked to the map) can be very useful to public health practitioners and the public in identifying problems and in searching for solutions. By quickly showing the information on which differences in rates are based, this feature helps avoid erroneous interpretations of rate differences that are based on small numbers.

Current Limitations of GIS Technology

Some of the current limitations of GIS technology from a public health perspective are as follows:

(*a*) Community health planning and other public health applications remain a relatively underdeveloped marketplace niche for GIS technology. The Department of Housing and Urban Development's Community 2020 software represents an important first effort by a federal agency to integrate GIS technology into community health planning.[20] Considerable room remains, however, for

Linking GIS Technology with Essential Public Health Services

We predict that, by the year 2010, GIS applications in public health practice will no longer consist of the ad hoc approaches we have seen in the 1990s. By the year 2010, we expect to see GIS technology customized for public health applications. This GIS health software will offer applications that "know" which data systems are needed and where they are located. After loading the appropriate data and performing relevant analyses, the system will offer alternative courses of action ranging from informing other people in the public health system to issuing health advisories.

In what follows, we give several examples of the way public health practitioners are likely to routinely use GIS technology in the year 2010, organized according to the 10 consensus "essential public health services" identified in 1994 by US Public Health Service agencies and major national public health organizations.[29–31] CDC is currently pilot-testing performance standards for state and local public health systems based on this framework (for more details, see the National Public Health Performance Standards Program's website at **www.phppo.cdc.gov/dphs/nphpsp/**).

Monitor health status to identify community problems. As part of a community health report card, a local public health department—serving a county with 300,000 population and 10 high schools—wants to map adolescent pregnancy rates for each high school's attendance area. In a secure environment in which the confidentiality of individuals and individual households is protected, the department codes the street address of each pregnant adolescent and prepares a smoothed (spatially filtered) map of adolescent pregnancy rates using a set of overlapping circles of fixed size. Next, using GIS software, school attendance boundaries are superimposed over the smoothed map. In addition to maps displaying the entire jurisdiction, higher magnification views are developed for each school attendance area, accompanied by a chart with summary statistics on use of prenatal care services, by trimester of pregnancy. The map is used to engage parents, faculty, and students in dialogue about how to best develop and target specific interventions for each district.

Diagnose and investigate health problems and hazards in the community. An epidemiologist in a large urban public health department scans electronic inpatient and outpatient medical records for all hospitals and managed care plans in the community. She uses the data to map asthma cases and compares maps for the current week with those for prior time periods. Inspecting the maps for unusual case clusters or patterns, she finds a new pattern of increased asthma hospitalizations. She expediently "visits" the hospital with the highest rate and reviews the cases. Eight of 10 affected individuals work at the same factory. Subsequently, using GIS technology linked to a "worker right to know" database about workplace chemical exposures, the epidemiologist reviews the potential exposures at the factory and identifies the agents associated with asthma-related hospital admissions. The epidemiologist then requests that an industrial hygienist visit the plant the same day.

Inform, educate, and empower people about health issues. One of a community's identified priorities is to develop an anti-smoking campaign. An anti-smoking coalition uses GIS technology and commercial lifestyle segmentation profiles (or a public health analogue developed by CDC by 2010) to identify subgroups that are most likely to include active smokers, the Census blocks where active smokers are most likely to reside, and the most effective communication media and times of day to deliver anti-smoking messages to these subgroups.

Mobilize community partnerships and action to identify and solve health problems. A community identifies childhood immunization levels as a priority. The local public health department wants to engage the faith community as part of an initiative to increase immunization rates. The department maps the locations of churches in areas with the highest numbers of young children. The ministers of these churches are invited to a meeting, where they decide to join together as a work group to develop appropriate health promotion materials and intervention strategies. During a subsequent meeting, the work group uses GIS technology to develop maps of the locations of school clinics and childcare centers within an inner-city area. Additional maps are used to assign church volunteers to school clinics and childcare facilities so travel distance is minimized. Maps are also developed to evaluate geographic patterns of children with missed immunization appointments, to help target educational interventions.

Develop policies and plans that support individual and community health efforts. The local public health department prepares a map to show the location of each health clinic in the community (including those run by hospitals and managed care plans, as well as those run by public health agencies). Another map is prepared that shows the residences of Medicaid-eligible individuals who use each clinic location. Using GIS technology, community decision makers overlay these maps and use the resultant patterns to help develop plans for better utilization of existing health care resources.

Enforce laws and regulations that protect health and ensure safety. To better provide neighborhood-level services, a local public health agency organizes its services by geographic areas, with a different subdivision of the agency responsible for each service area. Under this new system, environmental complaints need to be assigned to the correct service area. In some cases, an address on one side of the street belongs to one service area while an address on the other side of the street belongs to a different area. Using a Web-enabled public access GIS database, the agency GIS manager extracts geographic boundary files for street addresses and for the boundaries of the service areas. Using a GIS program, the manager creates a geographic polygon for each area and uses "point-in-polygon" assignment procedures to allocate street addresses to the correct service areas. When the agency receives an environmental complaint, the street address is initially processed through a computer program that standardizes the address in conformance with US Postal Service standards (correcting spelling errors, verifying the existence of the address on the computerized system, and so on). The complaint is then automatically assigned to the appropriate service area based on the standardized street address.

Link people to needed personal health services and assure the provision of health care when otherwise unavailable. A non-English-speaking, foreign-born person entering the United States is identified as having tuberculosis (TB). This individual also has a severe heart problem that requires medication. A TB outreach worker uses a GIS health care access map to identify the nearest cardiologist who speaks the same language as the patient. Again using GIS technology, the TB outreach worker also produces a public transportation map printed both in English and in the patient's language that shows the patient how to travel to the physician's office.

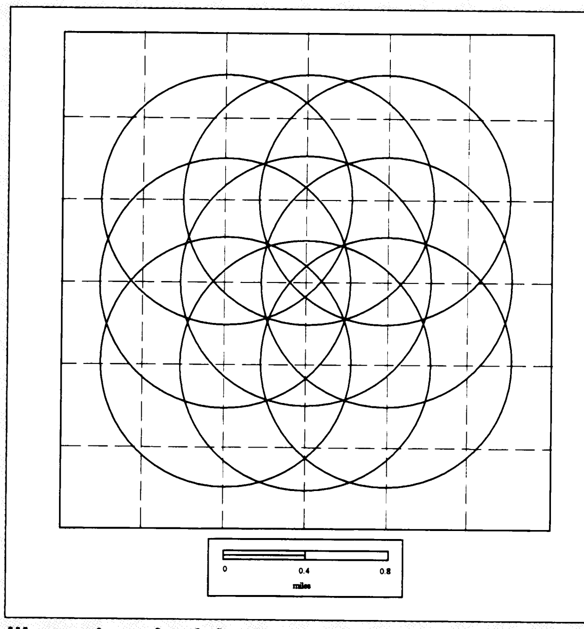


Illustration of a 0.6-mile spatial filter.

Assure a competent public health and personnel health care workforce. CDC is planning a distance-based training program (via satellite) on TB prevention in foreign-born people who have recently entered the United States. CDC uses a GIS map to identify public health departments in areas with large numbers of such individuals; these departments are invited to participate. During the teleconference, the geographic origins of phone calls are automatically displayed on a GIS map to help identify callers and to monitor the number and locations of the callers on "hold."

Evaluate effectiveness, accessibility, and quality of personal and population-based health services. A local public health department prepares GIS maps showing its service delivery points as well as other community health resources. These maps include details about: units of service provided at each location; expenditures; and demographic information such as poverty level for each program participant. By linking clinical data with these maps, the department is able to evaluate whether resources are being deployed optimally to address priority health needs and to evaluate the effect of services on selected preventable health outcomes.

Research for new insights and innovative solutions to health problems. A graduate student in geography conducts an urban morphology study, mapping the history of population growth and forecasting the evolving shape of the city and public transportation needs. Several high-resolution digital earth images, taken over a period of one year, are available for an area under development. The student electronically imports these images and uses automated change detection to determine the changes over a one-year period, for example, the addition of housing developments, roads, landfills, and other features. This information is included in a community health report card and used to help establish community priorities and plans.

improvements and developments in GIS software for public health applications. For example, GIS technology could be linked with community planning tools such as NACCHO's *Assessment and Planning Excellence through Community Partners for Health*, and specialized GIS software products, including data entry forms and automated procedures, could be designed to help public health practitioners map and plan interventions at the community level.

(*b*) Current, accurate, low-cost base street maps are essential for epidemiologic uses. Without an up-to-date base street map, for example, a public health practitioner investigating a disease outbreak may have to spend considerable extra time and effort to digitize the locations of cases or may not be able to map all case reports. Current and accurate base street maps are especially needed for urban areas with high growth and for those rural areas where residents only have post office box addresses.

(*c*) Practitioners, planners, and researchers, and especially state and local public health department staff, need training and user support in GIS technology, data, and epidemiologic methods in order to use GIS technology appropriately and effectively. The cost of training programs offered by commercial GIS vendors can be a financial burden for a small local public health agency or individual practitioner ($500 to $1000 for a two- to three-day course is common). GIS training programs specifically custom-designed for public health professionals are still relatively limited or in the early stages of development. At least two groups have started to "break the ice" in this area. Gerard Rushton, PhD, at the University of Iowa, has developed a CD-ROM on "Improving Public Health Through Geographic Information Systems,"[15] and the Agency for Toxic Substances and Disease Registry (ATSDR) has developed course handouts and a syllabus for a two-day introductory course on GIS technology for ATSDR personnel (for a copy, contact Dr. Virginia Lee at <cvl1@cdc.gov>). The time required for training can be a severe challenge for organizations in which demands on personnel are already high. Another drawback is that public health professional specialties currently do not recognize continuing education credit for individuals who participate in GIS software training.

(*d*) Statistical and epidemiological methods need to be developed to protect individual and household confidentiality.[21] Even if a single database may appear to have effective confidentiality safeguards, when several databases are linked within a geographic information system, the "sum" may be less well protected than the "parts." A false identification may be just as damaging to an individual as a correct identification that is not kept confidential.

(*e*) GIS software continues to evolve rapidly; typically, a new iteration (or upgrade) is released about every 18 months.[22] Every software package has its strengths and weaknesses. Current prices for some GIS products (in particular, for Web-enabled GIS applications and for neighborhood lifestyle segmentation datasets) remain a potential barrier (running as much as $10,000 or more). In addition, costs for maintenance and upgrades can be substantial.

(*f*) The technology to prepare and display maps on the Web is still in the very early stages of development.[23] Models and methods for Web-enabled GIS technology need to be developed for public health applications and field tested.[23] As Foresman points out, full GIS capability on the Web is a considerable technical challenge because GIS software has only recently started to be developed using Web-accessible programming languages, and the size of GIS map images and data files can be large and significantly slow access and display functions over the Web.[23] Spatial statistical software programs will also need to be developed for use with these Web-enabled GIS applications; as Foresman writes, "The next logical step is to actually provide the Web tools to perform spatial statistical analysis over the Web."[23]

Anticipated Developments in the Near Future

The next two to three years will see exciting developments in public health applications of GIS technology:

First, we anticipate that an increasing number of state public health departments will use automated geocoding for some or all of their vital statistics data. The geographic information included in vital records can play a critical role in the distribution of state and federal funds for infrastructure, community development, public education, and initiatives such as Healthy Start.[9] The expanded use of automated geocoding would be consistent with the draft Healthy People 2010 objective of "Increas[ing] the use of geocoding in all major national and State health data systems to promote the development of [GIS] capability at national, State, and local levels."

Second, we anticipate that public health practitioners and researchers will apply GIS technology to analyze data from disease registries, to track patterns and trends in, for example, disease incidence, stage at diagnosis for many cancers, survival, mortality, and use of medical services. Public health agencies, managed care organizations, and other providers will study these geographic patterns to develop and locate services that address the needs of areas which are identified as disproportionately sharing the burden of particular diseases. The Surveillance Implementation Group of the National Cancer Institute, for example, recently recommended that future studies "explore the feasibility and utility of employing GIS for geocoding surveillance data and reporting geographic relationships among screening measures, risk factors (including environmental exposures), and improved cancer outcomes...."[24]

GIS-related statistical and epidemiological methods will be improved, and new methods will be developed. Promising areas include the use of spatial scan statistics to identify disease clusters; the use of smoothed mapping techniques to display and distinguish differences in rates at the neighborhood level; and multi-level spatial models to better evaluate and distinguish biologic, contextual, and ecologic effects.[14–18]

Over the next two to three years, we also anticipate that new software products and training materials will be developed to facilitate wider use of GIS technology by state and local public health practitioners. Training materials will need to be in a variety of formats to facilitate learning at a distance (for example, CD-ROMs; self-instruction training courses on the Web; and national educational broadcasts via satellite). Low-cost, public domain software solutions are needed, especially for small local public health agencies and programs with limited resources. As noted above, NACCHO is currently working to identify support and partnerships to integrate GIS technology, data, and methods with its community planning tools. In addition, the Centers for Disease Control and Prevention (CDC) is currently developing Epi Info 2000, a Windows NT/95/98 version of the public domain Epi Info and Epi Map computer software tools.[25] Epi Info 2000 is being designed to allow public health practitioners to import, utilize, and display map boundary files and data from a GIS system. This additional capability will potentially enable Epi Info 2000 to be used to expand public health use of GIS technology. For example, a state or federal public health agency could make Epi Info 2000 available to smaller agencies, together with map boundaries, data files, and training. Epi Info 2000 will be available free of charge on the Internet.

Over the next few years, an increasing number of state public health departments and other public health agencies are likely to explore development of websites that employ GIS software, data, and methods. In some states, access may be restricted; selected staff members of local public health departments may use passwords to download confidential datasets geocoded by the state public health department. Some states may also begin to explore Web-enabled GIS applications; local health departments could then add their own data and custom-design their own GIS maps. (For early prototypes of interactive Internet mapping, see **www.ciesin.org** and **www.epa.gov/enviro.**)

We also anticipate that, over the next few years, there will be increasing discussion of ways to best protect individual and household confidentiality in a GIS environment. These discussions are likely to result in the development of new statistical and epidemiologic methods to assure data confidentiality, such as methods that mask the geographic location of data but still permit meaningful analysis[21]; the creation of secure environments with limited access (perhaps maintained by federal agencies such as the National Center for Health Statistics), in which public health researchers can be carefully monitored to ensure protection of individual and household confidentiality[1]; and the development and strict enforcement of policies, laws, and regulations to protect individual and household confidentiality.[1]

In the near future, public health practitioners will increasingly have access to aerial photos and satellite digital images, to data from global positioning systems (GPS), and to lifestyle segmentation marketing data. For example, Georgia's Geographic Information Systems Coordinating Committee has recently begun working to develop low-cost, high resolution images (Digital Orthophoto Quarter Quadrangles, or DOQQs) for the entire state. In 1998, the state entered into an agreement with the US Geological Survey to acquire updated aerial photographs through the National Aerial Photography Program. The total cost will be about $1.5 million for more than 4000 DOQQs covering the entire state.

Similarly, the Washington State Department of Health began a project in 1998 in which GPS technology is being used to develop a 10-county regional database on water systems, including information on well depth, ownership, test results, inspection dates, and number of connections.

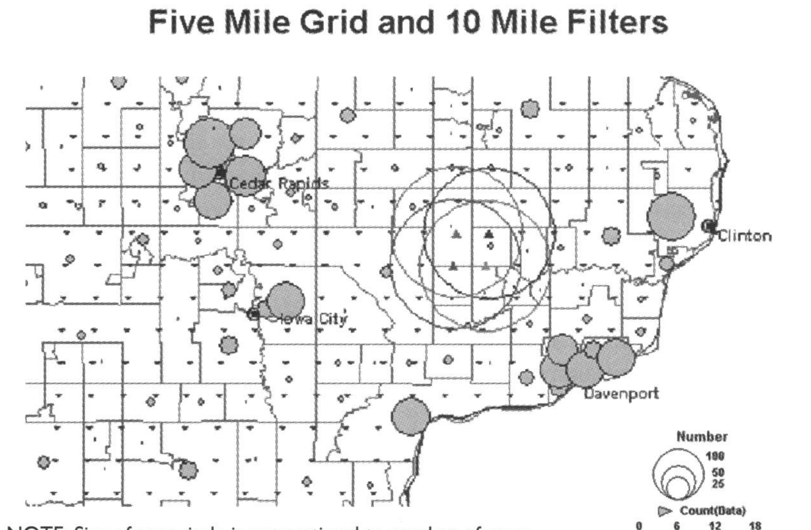
With regard to lifestyle segmentation marketing data, we anticipate increased research in the near future on how to use GIS technology to improve the development, production, and delivery of health promotion and education information for national, state, and local campaigns. Private sector marketing firms have developed ways to categorize consumer behavior patterns at the neighborhood level and to select the best media channels to advertise a product to a specific market segment. Although public health agencies may decide to lease lifestyle segmentation marketing information databases from commercial vendors, the cost is relatively expensive (as much as $40,000 for a national database). With the help of GIS technology, public health researchers should be able to develop a low cost, public domain analog. These public health lifestyle segmentation profiles could potentially be linked to national surveys such as the CDC Behavioral Risk Factor Surveillance System and then used to develop behavioral risk factor projections at the community level. Along these lines, the Health Care Financing Administration is starting to explore the use of segmentation and cluster profiling of populations eligible for services under Medicare, Medicaid, the Children's Health Insurance Program, and the Health Insurance Portability and Accountability Care Act (approximately 70 million people) to help the agency "in its outreach, health promotions, educational campaigns, and in identifying the best channels for reaching these beneficiaries."[26]

Finally, we anticipate that community knowledge and sophistication about the application and interpretation of GIS technology will increase and that a variety of interested groups will develop GIS maps in addition to the maps developed by government public health agencies. The Department of Housing and Urban Development (HUD) provides training so that community representatives can use HUD *Community 2020* software at the neighborhood level. GIS training is now being included in science programs in some schools as early as the 9th grade; the National Geographic Society and Environmental Systems Research Institute, Inc. [ESRI], currently co-sponsor an annual competition for GIS projects by high school students. In addition, the US Geological Survey, a number of other federal agencies, and ESRI have been involved in developing annual Summer Faculty Geographic Information System Workshops for the Historically Black Colleges and Universities.

Women with Localized Breast Cancer Selecting Mastectomy Treatment, Iowa, 1991–1996

Gerard Rushton, PhD; Michele West, PhD

MAP 1. Number of cases of localized breast cancer, by zip code area, Southeast Iowa, 1991–1996



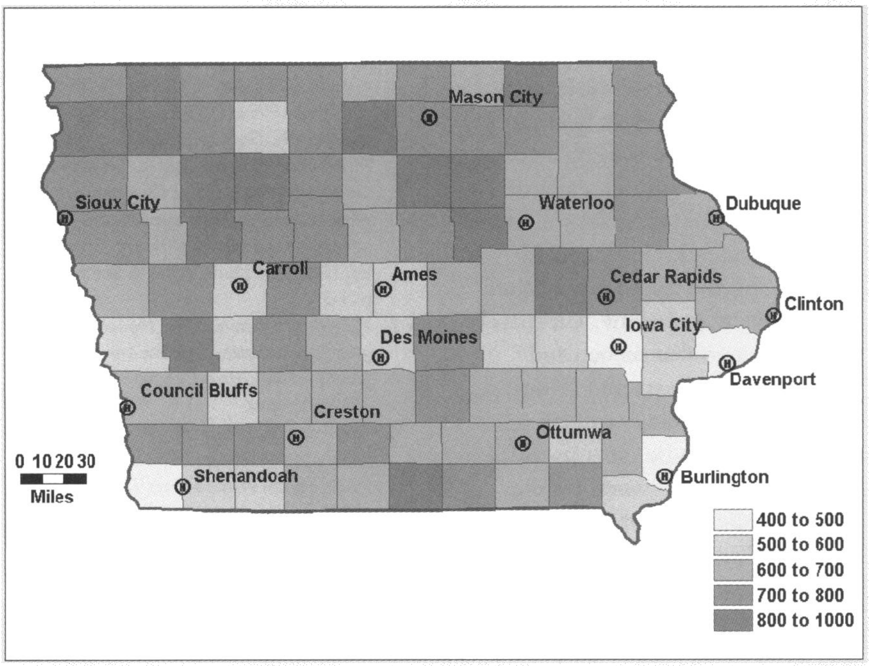
NOTE: Size of gray circle is proportional to number of cases.

Software used: Maps 1 and 2 were prepared using Maptitude by Caliper Corporation. For Map 3, DMAP (University of Iowa) was used to compute the grid. The filter values and contouring were produced with TransCAD by Caliper Corporation.

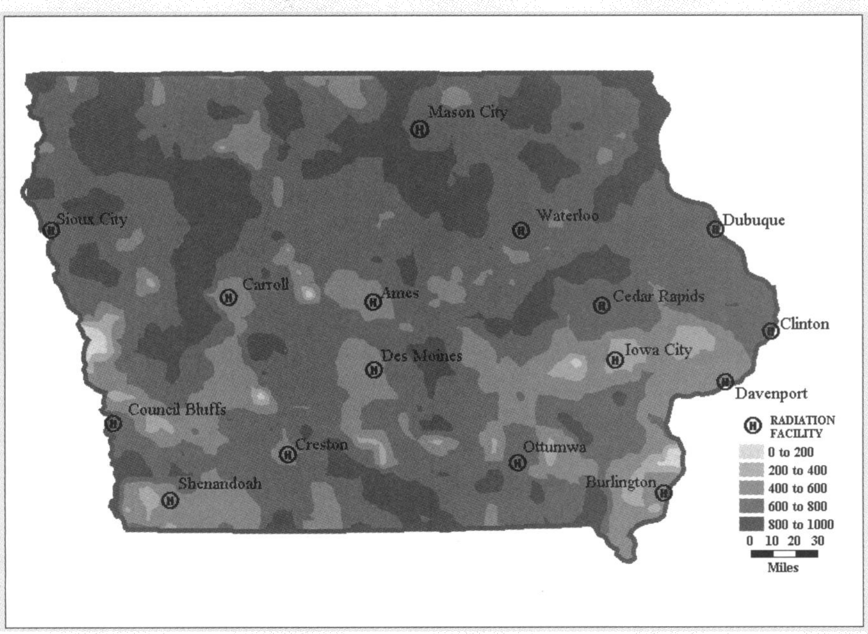
In 1990, the National Institutes of Health declared that breast-conserving treatment (excision of tumor, axillary node dissection, and breast irradiation) was preferable for the majority of women with early stage breast cancer, providing survival rates equal to those seen with total mastectomy. Yet, for 1991–1995, the Iowa Cancer Registry reported higher rates of mastectomy for histologically confirmed cases of localized breast cancer than other registries for which comparable information is available.

Drs. Rushton and West used GIS technology to identify areas in Iowa with high rates of mastectomy among women with localized breast cancer. As shown in Map 1 for a part of Southeastern Iowa, most zip

MAP 2. Number of women selecting mastectomy per 1000 cases of localized breast cancer, by county, Iowa, 1991–1996



MAP 3. Smoothed (spatially filtered) map of number of women selecting mastectomy per 1000 cases of localized breast cancer, Iowa, 1991–1996



code areas have so few localized breast cancer cases that a valid choice rate could not be determined for them. (The large circles show the size of the spatial filter used to generate Map 3.) Spatial aggregation of the data was required. Map 2 shows choice rates by county of residence for the whole state. Map 3 is a "smoothed" map that shows the geographic pattern of choice rates for mastectomy in more detail than the county-level map. One hypothesis accounting for this geographic pattern is that areas close to radiation treatment centers—shown on the map—have lower mastectomy rates.

Matthew Airola, MA, and Aniruddha Banerjee, MA, Department of Geography, University of Iowa, prepared these maps. The National Cancer Institute and the Iowa Cancer Registry provided support for the study for which these maps were developed.

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Anticipated Developments in 5–10 Years

Over the next 5 to 10 years, we expect to see growth in local data partnerships and regional GIS consortia with shared data and automated systems. Three examples of early prototypes along these lines are the San Diego Regional Urban Information System in California (**www.sangis.org**); the Louisville/ Jefferson County Information Consortium in Kentucky (**www.lojic.org**); and the vision for the Clackamas County Community Health Mapping Engine in Oregon described by Melnick et al.[27]

Within 10 years, it is likely that public health practitioners will be able to perform spatial analyses on their computers through the Web in a cost-effective fashion. We anticipate the development of GIS software tools specifically custom-designed for use by local public health departments and other local agencies and organizations with limited staff and resources. To some extent, GIS technology even may become embedded in public health practice to the extent that the technology is so deeply "buried" that it is invisible to the worker. For example, with "embedded" GIS technology, a public health nurse would enter the laboratory data for a childhood lead poisoning prevention program into a computer program, and the computer would automatically generate a GIS map displaying the locations of cases needing follow-up.

As the number of public health practitioners applying GIS technology begins to increase, we also anticipate there will be increasing demand to share GIS maps. For example, suppose public health department X and neighboring public health department Y are addressing a common infectious disease problem and they would like to join their independently developed GIS maps into a common map covering both jurisdictions. Doing so requires consensus on issues such as the software to be used, the baseline street map for geocoding cases, the scale, the projection (the method for representing the curved surface of the earth on a flat surface), case definitions, sources for case reports, the time period for the study, and so forth.

Given the frequent need for sharing and, in some cases, combining maps, we anticipate more efforts at the local, state, and federal levels to develop standards for a truly national public health spatial data infrastructure.[12]

Conclusions

A rise and fall in enthusiasm is a typical part of the lifecycle of any technologic innovation: Early adopters demonstrate initial success. The majority then begin to "jump on the band wagon," and some experience problems or incorrectly apply the technology. Critics then denounce limitations and abuses, and the popularity of the technology may decline. Ultimately, a middle ground is recognized between enthusiasts and critics, where the technology can be demonstrated to be most useful. In terms of this framework, public health applications of GIS technology in 1999 are still in the early stages.

Many challenges remain that will need to be addressed before the full potential of GIS technology can be realized for public health practice, planning, and research efforts. Longer-term solutions are likely to require a series of small successes, carefully built upon in incremental fashion over time. One of the greatest challenges for public health applications will be to incorporate epidemiologic principles and methods into the analysis to be mapped. Another major challenge will be to develop methods and procedures to assure the confidentiality of individuals and individual households. A continuing local/state/national dialogue, interagency and public-private partnerships, and uniform local/state/federal standards will be needed to address these challenges.

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