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# Geographic Information Systems and Environmental Health:

## Incorporating Esri Technology and Services

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## An Esri White Paper

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# Geographic Information Systems and Environmental Health: Incorporating Esri Technology and Services

## Introduction and Purpose of Paper

Environmental health (EH) agencies at all levels of government and the partners that support them (e.g., universities, nonprofit organizations, IT vendors and consultants) are increasingly using geographic information system (GIS) technology to assess and protect the health of the populations they serve, understand the impacts of the environment on human health, and improve environmental health services delivery. Environmental health organizations are interested in increasing their overall GIS capacity so they may enhance environmental health practices in both programmatic areas (e.g., air pollution, water, toxics and waste, built environment) and common business functions such as assessment, policy development, and assurance.

GIS technology is a key component in modernizing the IT of EH organizations. After reading this white paper,

- Leadership and senior management of EH organizations should understand the importance of geographically enabling environmental health IT (with GIS) to support the mission and work of environmental health programs and research.

- EH professionals should understand how GIS can support *their* business processes and how to engage with IT and senior leadership to make it happen.

- Environmental health professionals and the IT professionals supporting them should be more knowledgeable regarding specific Esri® technology solutions available.

### *Structure of Paper*

This paper is composed of seven parts. The first part is this introduction, which describes the purpose and structure of this paper. The second section describes the scope of EH programs and services, the development of environmental public health tracking networks, and a broad overview of EH research. The third section provides an overview of GIS. The fourth section describes the benefits of understanding geography as a common frame of reference within EH, including an explanation of enterprise GIS within health and human services (HHS) agencies. The fifth section provides an overview of geographically enabling EH programs and services. The sixth section discusses the future of GIS within EH programs and research. The final section offers suggestions on how to get started, including additional specific resources available from Esri and its business partners for EH agencies, systems integrators, and other software developers.

The appendixes include EH GIS presentations and journal articles from around the world. These publications contain promising GIS practices for environmental health professionals to learn valuable lessons from peers regarding effective GIS solutions.

While this paper includes extensive references to EH in the United States, it is also intended as a reference for GIS enhancement of other countries' EH programs. Finally, EH is a cross-cutting sector. Esri has many additional publications regarding environmental management (see esri.com/industries/environment/business/literature.html).

## What Is Environmental Health?

In layman's terms, environmental health is the health impact of the air we breathe, the water we drink, the homes we live in, the soil growing the food we eat, and the many other environmental exposures in our lives. The study of EH is not new. As early as 400 BC, Hippocrates said that one's health depends on the air one breathes, the water one drinks, and the environment in which one lives.[1] Another way of thinking of EH is that it is everything except genetics and personal behavior. The World Health Organization (WHO) says:

> Environmental health addresses all the physical, chemical, and biological factors external to a person, and all the related factors impacting behaviours. It encompasses the assessment and control of those environmental factors that can potentially affect health. It is targeted towards preventing disease and creating health-supportive environments. This definition excludes behaviour not related to environment, as well as behaviour related to the social and cultural environment, and genetics.[2]

The impact of the environment on human health is substantial. According to WHO, environmental hazards are responsible for approximately 25 percent of the total burden of disease worldwide and nearly 35 percent in regions such as sub-Saharan Africa.[3] WHO also states that as many as 13 million deaths can be prevented every year by making our environments healthier.[4] Below are examples of environment impacting human health:

- **Air:** During the last decade, epidemiological studies conducted worldwide have shown a consistent, increased risk for cardiovascular events, including heart and stroke deaths, in relation to short- and long-term exposure to present-day concentrations of pollution, especially particulate matter.[5]

- **Water:** Arsenic in drinking water is a hazard to human health. The main source is arsenic-rich rocks, through which the water has filtered.[6] Ironically, in some countries, wells dug to avoid surface water risks resulted in the unintended consequence of arsenic poisoning.

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[1] Hippocrates. *On airs, waters, and places*. Retrieved April 21, 2010, http://classics.mit.edu/Hippocrates/airwatpl.mb.txt.
[2] World Health Organization. *Environmental Health*. Retrieved April 8, 2009, http://www.who.int/topics/environmental_health/en/.
[3] World Health Organization. *10 Facts on Preventing Disease through Healthy Environments*. Retrieved April 8, 2009, http://www.who.int/features/factfiles/environmental_health/en/index.html.
[4] Ibid.
[5] American Heart Association. *Air Pollution, Heart Disease and Stroke*. Retrieved May 28, 2010, http://www.americanheart.org/presenter.jhtml?identifier=4419.
[6] World Health Organization. *Arsenic in Drinking Water*. Retrieved May 28, 2010, http://www.who.int/water_sanitation_health/dwq/arsenic/en/.

- **Soil:** Despite leaded paint and gasoline having been outlawed for many years in the United States (due to health concerns), lead in urban soil is a lingering source of lead poisoning in children.[7]

Due to the substantial impact of environment on human health, EH agencies and other EH organizations around the world have developed services and programs to protect the public's health. Government, academics, nongovernmental organizations (NGOs), and the private sector continue EH research initiatives. Some of these programs, services, and research initiatives are discussed later in this paper. Governmental EH agencies have primary responsibility for assessment, policy development, and assurance—the core functions of public health—but they share this responsibility with other sectors. Development of initiatives is under way to further define EH and articulate the services expected of EH agencies.

EH agencies and researchers face many challenges. When conducting environmental health studies, it is often difficult to have an accurate assessment of exposure. When making policy, it is often difficult to measure the impact of the environment on health outcomes. When ensuring the public's health through inspections (e.g., for wells, septic tanks, restaurants, hazardous waste sites, vector control) it is often difficult to prioritize due to the sheer number of sites under supervision. GIS technology is helping EH agencies and researchers address these challenges and many others.

## *Typical Programs and Services*

The delivery of EH services around the world varies in scope and depth due to differing environmental risks, available resources and funding schemes (e.g., general funds, fees, taxes, grants), and governmental structures (e.g., centralized or decentralized). Acknowledging such variations (which are beyond the scope of this paper), there is a surprising amount of commonality. Many subnational EH agencies engage in the following:[8]

- Food safety education
- Vector control (e.g., mosquitoes)
- Indoor air quality assurance
- Groundwater protection
- Surface water protection
- Noise pollution prevention
- Pollution prevention
- Hazardous waste disposal
- Land-use planning
- Collection of unused pharmaceuticals
- Air pollution prevention
- Radiation control
- Hazardous materials response

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[7] Frazer, L. "Children's Health: Soil in the City. A Prime Source of Lead." *Environmental Health Perspectives* 116, no. 12 (2008): A522. Retrieved May 27, 2010, http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2599780/.

[8] National Association of Country and City Health Officials. 2008 National Profile of Local Health Departments. Available at http://www.naccho.org/topics/infrastructure/profile/resources/2008report/upload/NACCHO_2008_ProfileReport_post-to-website-2.pdf.

Many subnational EH agencies conduct regulation, inspections, and/or licensing of

- Food service establishments
- Public swimming pools
- Septic systems
- Private drinking water
- Hotels/Motels
- Schools/Daycare centers
- Body art (tattoos, piercing)
- Children's camps
- Compliance with smoke-free ordinances
- Campgrounds/RVs
- Lead (in homes, soil, etc.)
- Mobile homes
- Solid waste haulers
- Solid waste disposal sites
- Tobacco retailers
- Food processing facilities
- Housing (inspections)
- Health-related facilities
- Public drinking water
- Cosmetology businesses
- Milk processing

Additional programs and services include environmental health surveillance and epidemiology, exposure surveillance, laboratory services (e.g., testing for food-borne illnesses, lead), emergency response (e.g., chemical spills), and outdoor air pollution control. Many researchers and some agencies are focusing on how the built environment influences human health and are taking a more active role in land-use planning via public health impact statements and tools.[9] Another recent development is Environmental Public Health Tracking (EPHT) (see next section). Many national and subnational agencies also provide technical assistance and funding to local agencies.

Given the variability in programs and services, the National Environmental Public Health Performance Standards[10] from the US Centers for Disease Control and Prevention (CDC) are an important benchmark for participating agencies to measure the capacity of their local environmental public health system or program. The assessment process encourages system or program partners to better coordinate and target their activities and is intended to provide a foundation for implementing performance improvement activities.

[9] See San Francisco Department of Health's Program on Health, Equity, and Sustainability at www.sfpdh.org/phes.

[10] Centers for Disease Control and Prevention. National Environmental Public Health Performance Standards. Available at www.cdc.gov/nceh/ehs/EnvPHPS/Docs/Env_Public_Health_Performance_DRAFT_Standards.pdf.

## *Environmental Health Tracking*

Government agencies around the world collect data on human health including routine demographic and health surveys, vital records registries, and disease registries. Government agencies also collect data on environmental hazards including point source pollution, water quality, and air quality. Despite extensive data collection, there is very little consistent analysis of the links between the environmental exposures and health outcomes (such as asthma, birth defects, cancers, lead poisoning, and myocardial infarctions). In 2001, the Pew Environmental Health Commission issued a report entitled America's Environmental Health Gap: Why the Country Needs a Nationwide Health Tracking Network. That report recommended the creation of a "Nationwide Health Tracking Network for disease and exposures."[11] The Pew report stimulated the formation of the Environmental Public Health Tracking Network, an initiative sponsored by CDC's National Center for Environmental Health. According to CDC, the goal of environmental public health tracking is to "protect communities by providing information to federal, state, and local agencies. These agencies, in turn, will use this information to plan, apply, and evaluate public health actions to prevent and control environmentally related diseases."[12] Benefits of CDC's Environmental Public Health Tracking Network are listed in table 1 below.

**Table 1**
**Benefits of the Environmental Public Health Tracking Network**[13]

| | |
|---|---|
| 1 | Provide timely information to all users. |
| 2 | Integrate local, state, and national databases of environmental hazards, environmental exposures, and health effects. |
| 3 | Enable the ongoing analysis, integration, and interpretation of environmental hazards, exposure, and health effects data to control and prevent environmentally related health problems in the community. |
| 4 | Allow broad analysis across geographic and political boundaries. |
| 5 | Aid research by providing easier access to environmental and public health data (e.g., the Institutional Review Board and secondary data look-up information). |
| 6 | Promote interoperable systems via compliance with standards. |
| 7 | Identify gaps in environmental and public health data systems through network development and use. |
| 8 | Increase environmental public health capacity at state and local levels. |
| 9 | Increase collaboration and partnerships among traditional health and environmentally focused entities at the federal, state, and local levels via network development and use. |
| 10 | Provide a means to enhance and improve data (e.g., geocoding). |
| 11 | Contribute to the Public Health Information Network (PHIN) by helping define standards to better integrate environmental and public health data. |
| 12 | Provide a secure, reliable, and expandable means to link environmental and health data. |

[11] Centers for Disease Control and Prevention. National Environmental Public Health Tracking Network: The Need. Retrieved April 21, 2009, http://www.cdc.gov/nceh/tracking/background.htm.

[12] Centers for Disease Control and Prevention. National Environmental Public Health Tracking Network: Development. Retrieved April 21, 2009, http://www.cdc.gov/nceh/tracking/background.htm.

[13] Centers for Disease Control and Prevention. Environmental Public Health Tracking Network: EPHT Network. Retrieved May 28, 2010, http://www.cdc.gov/nceh/tracking/netvision/netvision_overview.htm.

The United States is neither the only nor the first nation to undertake such an initiative. Other nations have tracking-like initiatives under way, and others are exploring the feasibility of tracking. Beale et al conclude, "The scope and importance of such schemes should not be underestimated because they not only provide sources for suitable data and tools for epidemiology but also lead to a more specific, integrated, and standard approach to data collection and analysis."[14]

### *Research*

Governmental health agencies and private foundations fund a substantial portfolio of extramural environmental health research around the world through research centers and institutes at universities as well as awards to individual investigators. Governmental agencies also conduct substantial intramural research. Researchers investigate how environmental agents cause or exacerbate a variety of human diseases and disorders. More recently, there has been an emphasis on understanding the impact of the built environment on public health. Some research initiatives are linked to environmental public health practice and environmental public health tracking networks.

## What Is GIS?

A GIS is an integrated collection of computer software and data used to view and manage information connected with specific locations, analyze spatial relationships, and model spatial processes.[15] The majority of data in public health has a spatial (location) component, to which GIS adds a powerful graphical and analytic dimension by bringing together the fundamental epidemiological triad of person, time, and the often-neglected place.[16]

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 environmental health organizations for explaining events, predicting outcomes, and planning strategies. In this sense, GIS is much more than a computer map; it is a decision support system that integrates spatially referenced data and statistical analyses to address environmental health problems.[17] GIS is a powerful tool for examining population-level effects of exposures as reflected in the geographic and spatial distribution of populations. Mapmaking and geographic analysis are not new, but a GIS performs these tasks better and faster than the old manual methods. Before GIS technology, only a few people had the skills necessary to use geographic information to help with decision making and problem solving.

The major EH challenges in the world today all have a geographic component. GIS organizes geographic data so that a person reading a map can select data necessary for a specific project or task. A thematic map has a table of contents that allows the reader to add layers of information to a basemap of real-world locations. With an ability to combine a variety of datasets in an infinite number of ways, GIS is a useful tool for nearly every field of knowledge within EH.

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[14] Beale, L., et al. "Methodologic Issues and Approaches to Spatial Epidemiology." *Environmental Health Perspectives* 116, no. 8 (August 2008): Retrieved April 21, 2009, http://www.ehponline.org/members/2008/10816/10816.html.

[15] Wade, T., and S. Somer. eds. *A to Z GIS: An Illustrated Dictionary of Geographic Information Systems*. Redlands, CA: Esri Press, 2006.

[16] Public Health Agency of Canada. *GIS for Public Health Practice*. Retrieved March 19, 2008, www.phac-aspc.gc.ca/php-psp/gis_e.html.

[17] Shoultz, J. "South Carolina Community Assessment Network." Presented at the 2005 Esri International User Conference.

A good GIS program is able to process geographic data from a variety of sources and integrate it into a map project. Many countries have an abundance of geographic data for analysis, and governments often make GIS datasets publicly available. Map file databases often come included with GIS packages; others can be obtained from both commercial vendors and government agencies. Some data is gathered in the field by global positioning units that attach a location coordinate (latitude and longitude) to a feature such as a health facility or a storage tank. The wide availability of rugged hardware devices (tablet PCs, ruggedized PDAs, etc.) combined with recent advances in the mobile components of server GIS technology make GIS even more useful for EH agencies.

GIS maps are interactive. On the computer screen, map users can scan a GIS map in any direction, zoom in or out, and change the nature of the information contained in the map. They can choose whether to see the roads, how many roads to see, and how roads should be depicted. Then they can select what other items they wish to view alongside these roads such as hazardous waste sites, vegetation, or population density. Some GIS programs are designed to perform sophisticated calculations for tracking storms or predicting erosion patterns. GIS applications can be embedded into common activities such as verifying an address.

Many people associate specialized software and powerful computers with the idea of geographic information systems. A GIS actually has five equally important components: people, hardware, software, data, and applications. GIS technology is of limited value without the people who manage and use the system, ranging from technical specialists to spatial analysts to casual users. Possibly the most important and costly 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 use a database management system (DBMS), used by most organizations to organize and maintain their data, to manage spatial data. A successful GIS operates according to the data needs, models, and operating practices unique to each organization. Applications are designed to enhance and automate everyday procedures or produce informative statistics on the state of EH or the results of a given program. There are many extensions, plug-ins, and other enhancements to GIS software that are relevant to EH organizations. Examples include Geostatistical Analyst, Spatial Analyst (ModelBuilder™), and the Rapid Inquiry Facility (RIF) tool.

## Understanding Geography as a Common Frame of Reference

Modernizing EH information systems to facilitate more efficient assessment, policy development, and assurance requires geographically referenced information. The science of geography recognizes that almost everything that exists can be expressed in terms of its location and therefore has established a standard framework of spatial coordinates to communicate and relate the placement of people, things, and events, wherever that may be. Therefore, geography provides a spatial baseline that is used for storing, analyzing, and communicating most types of data. Eventually, geography supplies structurally coherent common ground for decision support mechanisms. EH agencies stand to benefit profoundly from enhanced application of geographic intelligence through GIS.

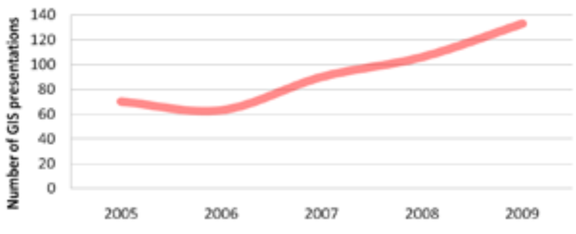
## *Existing GIS within Health and Human Service Agencies*

Public health departments around the world have embraced GIS as a tool for collecting and analyzing data, evaluating health programs, and communicating results (internally, to policy makers, and to the public). WHO, the European Centre for Disease Prevention and Control (ECDC), CDC, US Environmental Protection Agency (EPA), all 50 US state health departments, hundreds of US local health departments (LHDs), and the majority of accredited schools of public health in the United States all use Esri GIS software.

Public health organizations use GIS on a daily basis to analyze the spread of infectious and chronic diseases, promote and encourage healthy behaviors, protect the public against environmental hazards (as discussed throughout this paper), prevent injuries (e.g., analyzing traffic injuries by location), respond to disasters and assist communities in recovery (e.g., situational awareness, identifying vulnerable populations), and ensure the quality and accessibility of health services as well as many other programs and services.

In the United States, GIS and geocoding are also part of HealthyPeople 2020 (National Health Goals for the United States) and the National Public Heath Performance Standards Program. Recently, the number of presentations at the American Public Health Association (APHA) annual meeting referencing use of GIS has increased substantially.[18] This is indicative of the trend of increasing utilization of GIS in public health practice.

**Figure 1**
**GIS at APHA Annual Meetings 2005–2009**




## *Enterprise GIS*

GIS has been embraced by the IT community and has become a strategic component of information technologies incorporated into the central systems of many enterprises. The existing deployments of Esri desktop, server, and mobile GIS technologies referenced above, together with increasing geocoding capacities spurred by HealthyPeople 2020, EPHT, and other initiatives, present many opportunities for shared business capabilities between EH agencies and sister agencies.

In many health agencies, GIS starts out as a stand-alone analytic tool for environmental health investigation, health planning, or epidemiologic research. But over time, GIS spans the entire HHS enterprise, serving multiple divisions, programs, and people from the computer desktop to web applications to mobile phones and PDAs.

[18] Methodology: Searched "geographic information system" by individual year for APHA annual meeting abstracts available at http://www.apha.org/meetings/pastfuture/pastannualmeetings.htm.

Over the last few years, many governmental agencies have developed web services that can be consumed by sister agencies. In some cases, environmental health agencies are hosting and publishing such services. These include map, geocoding, and other analytic services. The geocoding services facilitate real-time geocoding of vital events such as births and deaths. An enterprise-wide geocoding service could be leveraged by EH information systems as a shared business capability.

Recognizing the growing importance of GIS, state chief information officers (CIOs) in the United States placed GIS on their Top Ten Priority Technologies list for 2008. The National States Geographic Information Council (NSGIC) (www.nsgic.org/index.cfm) has also been active in this area. NSGIC is committed to efficient and effective government through the prudent adoption of geospatial information technologies. The most current NSGIC survey of states' GIS initiatives is available at www.gisinventory.net/summaries.

## Geographically Enabling Environmental Health

There are many references supporting the notion that EH practice and research should be geographically enabled with GIS model practices. Over a decade ago, EH professionals came to universal consensus that a GIS can be a useful aid at the beginning of an environmental epidemiology or risk assessment study.[19] More recently, Miranda et al noted, "Many GIS-based projects have been successful in supporting public and environmental health practice, including those investigating toxic exposure, vector-borne disease, health information access, and the built environment."[20] She and her team had engaged local health departments in a capacity-building project. When evaluating the project, "staff and directors alike viewed improved service delivery, as well as time and cost efficiency, as significant outcomes."[21]

Many leading public health organizations have endorsed the use of GIS in public health practice and research. CDC says, "GIS plays an important part in health promotion and protection."[22] WHO says GIS

- Is "highly suitable for analyzing epidemiological data, revealing trends and interrelationships that would be more difficult to discover in tabular format"
- "Allows policy makers to easily visualize problems in relation to existing health and social services and the natural environment and so more effectively target resources"
- Is an "ideal platform for the convergence of disease-specific information and their analyses in relation to population settlements, surrounding social and health services and the natural environment"[23]

[19] Betts, K. "Mapping the Environment." *Environmental Health Perspectives* 105, no. 6 (1997). Retrieved March 31, 2009, http://www.ehponline.org/docs/1997/105-6/innov.html.
[20] Miranda, M. L. et al. "Building Geographic Information Systems Capacity in Local Health Departments: Lessons Learned from a North Carolina Project." *American Journal of Public Health* 95, (2005): 2180–2185.
[21] Ibid.
[22] See http://www.cdc.gov/gis/whatis.htm.
[23] See http://www.who.int/health_mapping/en/.

The draft Environmental Public Health Performance Standards in the United States specifically reference "utilization of appropriate methods and technology, such as geographic information systems, to interpret and communicate data to diverse audiences."[24] The draft standards include a specific indicator (1.3) regarding the identification and use of appropriate data collection, storage, analysis, and communication tools. That indicator asks whether the jurisdiction has identified and used appropriate tools for collecting, storing, analyzing, and presenting data (e.g., GIS). Such references are by no means limited to the United States. For example, the WHO Regional Dengue Plan for 2008–2015[25] includes a string of GIS-related items under Expected Goal 10. In the WHO Dengue Plan, ministries of health were encouraged to conduct basic GIS workshops in 2009–2010 and to include GIS as part of their integrated vector management.

GIS offers many practical opportunities for improving the efficiency of existing business processes by leveraging the power of place. These opportunities are described more fully in the following section.

## *Environmental Health Business Processes and GIS*

GIS provides tools and capabilities for performing a wide array of activities associated with geographic and spatially referenced information. Associating data with location optimizes analysis, visualization, and reporting/communication of information, thus maximizing the value of the data. Below are examples of enhancing EH business processes (organized by three core functions) with GIS.

- **Assessment.** In the field, using GIS/GPS capabilities facilitates better navigation (e.g., finding locations) as well as the ability to geocode precisely the point sources of EH risks and pollution through GPS. Precisely measured locations and distances enable not only immediate decision support but also a higher degree of precision in future analyses. Once EH data is geographically enabled, GIS provides a platform for making assessment data more actionable through multilayer data analysis (e.g., determining populations within specific distance buffers for emergency notifications) and more advanced spatial and statistical analyses. Increasingly, geocoding, buffering, and kriging are utilized in methods assigning exposure in EH studies. EH professionals digitize data (e.g., district boundaries), geocode residential or business addresses, and link to a variety of data (e.g., satellite, aerial photography, third-party, and census data) for exploratory spatial data analysis and prefieldwork. GIS also empowers EH professionals to prepare for field visits while still in the office. They use satellite photography, soil layers, and various geoprocessing tools to predetermine best locations for septic tanks. GIS also helps EH organizations conduct specific surveillance and meet tracking requirements. During emergencies, GIS quickly calculates the depths of floods and numbers of affected homes and can speed up reimbursement from emergency management agencies. Increasingly, EH professionals are utilizing spatial statistics tools and GIS analysis to proactively identify significant community health problems.

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24 Centers for Disease Control and Prevention. *National Environmental Public Health Performance Standards: Local Environmental Public Health Self-Assessment Instrument.* Retrieved April 8, 2009, http://www.cdc.gov/nceh/ehs/EnvPHPS/Docs/Env_Public_Health_Performance_DRAFT_Standards.pdf.

25 See http://www.searo.who.int/LinkFiles/RC61_pa_11inf.Doc.pdf.

- **Policy development.** EH organizations use GIS-based models to determine the impacts of proposed EH policies. GIS-based site location models help determine the best locations for hazardous waste and the safest routes to get it from point A to point B. Such analyses may incorporate multiple layers (e.g., population density, transportation networks). Increasing GIS synergies with common document formats, such as PDF reports, enable the publishing of GIS layers when communicating policy and administrative decisions to partner agencies, regulated entities, and other constituents. Business intelligence software is increasingly integrated with GIS, facilitating enhanced analysis, visualization, and reporting options.

- **Assurance.** EH organizations use GIS to increase efficiency. GIS facilitates targeting vector control efforts. Agencies use GIS tools and methodologies to measure compliance with specific legislation (e.g., specific types of industry/businesses being prohibited from operating within certain distances of rivers or other environmentally sensitive areas or restrictions regarding advertising tobacco within certain distances of schools). GIS helps determine the prudent use of staff in implementing EH inspections (calculating location-based workload assessment, finding efficient routes, and determining which vehicle should serve each location in the best stop sequence). Geocoding and address management help reduce undeliverable mail and save time and money spent correcting wrong addresses.

Recently, EH professionals have articulated and mapped their business processes and objectives to the Public Health Essential Services framework. Table 2 provides an overview of selected EH essential services[26] and GIS. In addition to the references cited in this table, there are numerous additional examples in appendixes C through H.

**Table 2**
**GIS Relevance to Essential Environmental Public Health Services**

| Essential Service | GIS Relevance |
|---|---|
| 1. Monitor environmental and health status to identify and solve community EH problems. | GIS is a tool for assessing EH, analyzing trends, and communicating EH problems and risks to the public through static or interactive maps. GIS also has many functions helpful for exposure assessment, data aggregation, data management, and other linkages. A good example of using GIS for this essential service is the work of EPHT. |
| 2. Diagnose and investigate EH problems and health hazards in the community. | GIS supports EH surveillance systems with more efficient data collection methodologies, better understanding of disease transmission dynamics, and a framework for outbreak investigation and response. As mentioned above, there is universal consensus that a GIS can be a useful aid at the beginning of an environmental epidemiology or risk assessment study. GIS also facilitates targeting of prevention and control measures based on priority locations.[27] |

[26] Centers for Disease Control and Prevention, National Center for Environmental Health. 10 Essential Environmental Public Health Services. Retrieved April 10, 2009, http://www.cdc.gov/nceh/ehs/Home/HealthService.htm.

[27] Kittayapong, P., et al. "Suppression of Dengue Transmission by Application of Integrated Vector Control Strategies at Sero-Positive GIS-Based Foci." *Am. J. Trop. Med. Hyg.* 78(1), (2008): 70–76. Available at http://www.ajtmh.org/cgi/reprint/78/1/70.

| Essential Service | GIS Relevance |
|---|---|
| 3. Inform, educate, and empower people about EH issues. | GIS facilities targeting health communication geographically and demographically. Desktop GIS and web-based portals such as ToxMAP (http://toxmap.nlm.nih.gov/toxmap/main/index.jsp) and South Carolina Community Assessment Network (SCAN—http://scangis.dhec.sc.gov/scan/) educate and empower people to understand EH issues. |
| 4. Mobilize community partnerships and actions to identify and solve EH problems. | Maps are great tools for community engagement. Desktop GIS and web-based portals such as the ones listed above help mobilize community partnerships. Another example is the "rat information portal" in New York City (http://www.nyc.gov/html/doh/html/pest/rats.shtml). GIS provides a framework for analyzing and solving many other EH problems (e.g., lead poisoning mitigation and prevention and integrated vector control to prevent malaria or dengue). |
| 5. Develop policies and plans that support individual and community EH efforts. | The quote "Documenting need is not enough; documenting *where* there is need is critical to intervention strategies"[28] holds true for EH practice. GIS has helped policy makers understand the scope of environmental health emergencies, the built environment, and the "zone of influence" of mobile sources of air pollution. GIS also plays a central role in public health impact assessments (see www.sfdph.org/phes). |
| 6. Enforce laws and regulations that protect EH and ensure safety. | GIS-based methods help measure compliance with local laws (e.g., environmental setback regulations) and spatial advertising restrictions in local and national laws (e.g., tobacco advertising near schools). GIS-based methods are also utilized to geocode facilities and sites under regulation, route the inspectors who regulate them, and track progress. GIS-based models allow planners to consider the safety of citizens. |
| 7. Link people to needed personal EH services and ensure the provision of health care when otherwise unavailable. | GIS helps identify underserved populations and barriers to service and coordinate service delivery among multiple agencies. GIS-enabled services locators help citizens understand what services are available in their area and which offices are responsible. |

[28] Hillier, Amy. "Why Social Workers Need Mapping." *Journal of Social Work Education* 43, no. 2 (2007): 205–221. Retrieved April 2, 2009, http://repository.upenn.edu/spp_papers/86.

| Essential Service | GIS Relevance |
|---|---|
| 8. Ensure competent EH and personal health care workforces. | Agencies and researchers have utilized GIS to assess workforce gaps in many different professions, including the EH workforce in California (see 163-page PDF at http://www.llu.edu/llu/sph/ophp/documents/eh_report2006.pdf).[29] Geospatial analysis can characterize the pattern of deployment of the EH workforce and (with statistical modeling) analyze factors associated with the deployment pattern. |
| 9. Evaluate effectiveness, accessibility, and quality of personal and population-based EH services. | GIS provides a framework for monitoring and evaluating programs and services. One of the most popular applications of GIS in health and human services is analyzing access to services. |
| 10. Search for new insights and innovative solutions to EH problems. | GIS enables testing and considering options in both temporal and spatial contexts. Geospatial accuracy provides EH professionals and research partners with a more specific baseline for implementing and evaluating EH interventions and programs. GIS helps researchers aggregate data and understand complex, multidimensional relationships between pollution and disease. |

## Programmatic Areas and GIS

There are numerous examples of GIS supporting specific programmatic areas in EH, in many cases to partially or fully meet program mandates. The following subject headings are taken from HealthyPeople 2020 Environmental Health Objectives.[30] This brief overview is complemented by publication and presentation references in appendixes C through H.

■ **Outdoor Air Quality**

Examples include

- Improving the accuracy of air pollution health impact assessments with GIS
- Examining residential proximity to heavy-traffic roadways and associated adverse health outcomes
- Estimating at what distances the impact of direct traffic emissions on ambient particulate matter concentrations are significant
- Developing semiautomated GIS approaches to estimation of daily air pollution concentrations (e.g., using kriging)

[29] Note the main findings from the report were in published in: Dyjack D. T., P. Case, H. Marlow, S. Soret, and S. Montgomery. "California's County and City Environmental Health Services Delivery System." *Journal of Environmental Health* 69(8), (2007): 35–43, 56.
[30] See HealthyPeople 2020 Objectives, available at http://www.healthypeople.gov/hp2020/objectives/TopicAreas.aspx.

- Using land use-based regression (LUR) and GIS-based estimation to estimate exposure to pollutants (over the traditional area-average approach)

- Using GIS to develop web-based carpooling programs

■ **Water Quality**

Examples include

- Using GIS to track violations, health advisories, boil water orders, and reported illnesses that may be related to drinking water

- Using GIS-based spatial analysis and statistical analysis to determine clustering of cholera

- Using Web-based maps to display oil spill information, coliform levels for beaches, well-water quality data, etc.

- Spatially locating residences and pipes (e.g., vinyl lined)

- Monitoring naturally occurring contaminants in public drinking water (such as arsenic and nitrates)

- Developing GIS data models to determine arsenic contamination (safe and vulnerable areas) as well as where to focus intervention campaigns

- Examining relationships between arsenic levels in water and various cancers

- Assigning cases to corresponding water supply zones using point in polygon techniques

- Producing attack rate maps based on water districts

- Producing color-coded, GIS-based consumption advisory maps providing location-specific information on the amount of methylmercury in fish

- **<u>Toxics and Waste</u>**

  Examples include

  - Applying thematic mapping and analysis (e.g., buffering) to identify locations where potentially noxious land uses may be having a disparate adverse impact on minority and low-income populations
  - Achieving community buy-in for the enactment of public health regulations to control waste, junkyard, and recycling facilities
  - Using mobile GIS/GPS technologies to conduct surveillance (exposure assessment) for radiation, asbestos particles, radio frequency exposure, etc.)
  - Finding associations between maternal residence near agricultural pesticide applications and autism spectrum disorders among children
  - Modeling plumes (smoke, dust, asbestos, PCBs, and other pollutants)
  - Comparing mapped reports of respiratory problems with plume locations
  - Testing the efficacy of aerial spraying of mosquito adulticide in reducing incidence of West Nile virus
  - Using GIS-based methods to recruit participants for prospective pesticide exposure studies, thereby increasing efficiency and enhancing accuracy

- **<u>Healthy Homes and Healthy Communities</u>**

  Examples include

  - Assessing the size and dimensions of green spaces and their respective distances from the population of potential users
  - Using GIS to expand policy makers' awareness of the proximity of environmental hazards to schools
  - Examining environmental conditions (criteria pollutants, pollens, mold spores, and pyrethrin pesticides) and respiratory problems (especially asthma)
  - Using GIS in asthma surveillance, such as the relationship between asthma hospitalizations by ZIP Code and environmental factors
  - Using GIS portals to track rats and rat complaints
  - Using exploratory spatial data analysis to assess the extent of lead poisoning clustering and examine the geographic distribution of lead poisoning rates throughout a jurisdiction

- Examining the geographic distribution of important lead poisoning risk factors and prioritizing lead poisoning prevention programs (e.g., through GIS data linkages to cadastral records)
- Detecting radon hot spots and producing national radon risk maps
- Using GIS in disaster preparedness drills (mass vaccination, stockpile location and logistics, geographic emergency notification)
- Using GIS–CAD integration and robots to monitor indoor environments

■ **<u>Infrastructure and Surveillance</u>**

Examples include

- GIS-based models to estimate exposure to pesticides
- Environmental Public Health Tracking portals
- West Nile virus surveillance systems
- GIS-based well inspection systems
- Spatiotemporal analysis of the relationship between vector-borne disease dissemination and environmental variables
- Other GIS-based inspection systems

■ **<u>Global Environmental Health</u>**

Examples include

- Mapping the burden of diseases
- Investigating cholera epidemics
- Detecting regions of higher incidence of diarrhea and other water-borne diseases
- Measuring distances from households to water sources
- Analyzing travel time for obtaining clean water
- Analyzing the spatial distribution of standard morbidity rates per area

## *Environmental Health Tracking and GIS*

EPHT is described earlier in this paper. According to the GeoPrimer[31] (a guide developed by CDC's EPHT), "Information about geography and location is critically important to environmental public health tracking, primarily because exposure to environmental hazards is often a function of place." GIS functions including geocoding help in this regard. The GeoPrimer also states that GIS can be used to integrate, analyze, and display the locational data in various ways to establish relationships among variables. A critical role of EPHT programs is establishing standards. The GeoPrimer provides many useful suggestions, including steps for implementing GIS.

Through the EPHT network in the United States, health agencies have begun by defining their GIS technical capabilities, policies, and procedures.[32] Over time, EPHT participants are building web-based portals (secure versions and public versions). Many of these portals use server GIS technology for geocoding, interactive mapping, and spatial analysis. EPHT participants have also used specific GIS extensions such as the Rapid Inquiry Facility tool, an extension to ArcGIS® developed by Imperial College London in collaboration with CDC.[33]

## GIS Software Considerations

Identifying common software needs will make specification, standardization, and implementation of GIS applications for modernization of EH information systems more cost-effective and enhance the sharing of data, software, and other resources. This section provides general GIS considerations of software capability needs. The type of software utilized in EH organizations must be able to do the following:

- **Data management:** EH agencies must store and maintain enormous volumes of information securely in databases and integrate new data collected during routine inspections and investigations. Successful data management by EH agencies is enhanced by the inclusion of standardized location information, whether obtained by GPS device, geocoding, or other methods. Esri technology provides a comprehensive array of tools for successful adherence to standard geographic and spatial references. In addition, mobile GIS technology facilitates field staff capturing, updating, and analyzing geographic information for rapid decision making.

- **Relational database management system (RDBMS):** Enhanced and more accurate RDBMS-maintained data provides an EH decision support system with reliable, usable, and accurate data necessary to support the agency's critical business operations such as analysis, visualization, and reporting. An RDBMS provides the following advantages to an EH information system:

  - Improved performance, scalability, and portability
  - Improved data integrity
  - Enhanced flexibility and maintainability
  - Enhanced security features

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[31] See http://www.cdc.gov/nceh/tracking/pdfs/geoprimer.pdf.

[32] For a recent overview, see http://proceedings.esri.com/library/userconf/feduc10/papers/user/craig_kassinger.pdf.

[33] See http://gis.esri.com/library/userconf/proc07/papers/abstracts/a1125.html and http://www.ehponline.org/members/2008/10816/10816.html.

Esri technology meets this requirement fully. The geodatabase is the common data storage and management framework for ArcGIS and can be utilized wherever it is needed—on desktops, in servers (including the web), or on mobile devices. ArcGIS implements the geodatabase either as a collection of files in a file system or as a collection of tables within an RDBMS. Table 3 describes geodatabase types, licensing levels, RDBMS technology, and differentiating characteristics.

**Table 3**
**Geodatabases and RDBMS**

| Geodatabase | Licensing | RDBMS Technology | Differentiating Characteristics |
|---|---|---|---|
| Enterprise | ArcGIS Server Enterprise | DB2, Informix, Oracle, SQL Server, PostgreSQL | - Multiuser editing<br>- Supports versioning<br>- Supports spatial types |
| Workgroup | ArcGIS Server Workgroup | SQL Server Express | - Supports versioning<br>- Maximum of 4 GB of data<br>- 10 concurrent users |
| Desktop | ArcGIS Desktop<br>ArcGIS Engine | SQL Server Express | - Supports versioning<br>- Maximum of 4 GB of data<br>- 4 concurrent connections |
| File | ArcInfo®, ArcEditor™, ArcView® | No RDBMS—Uses local file structure | - No versioning support<br>- 1 TB per table size limit (default) |
| Personal | ArcInfo, ArcEditor, ArcView | Microsoft Access (Jet Engine) | - No versioning support<br>- Maximum of 2 GB of data |

- **Data accuracy:** To ensure that all mapped information is correctly positioned requires verification of geographic data supplied by staff, partner agencies, and entities. The EH information system requires stringent address management, ensuring that locations of services are correctly identified and authenticated as well as ascertaining that residential locations are accurate. Esri technology supports geocoding in ArcGIS Desktop, and it is also possible to build simple geocoding web applications with ArcGIS Server. In addition, a number of Esri partners offer services in address management and geocoding. There are also efforts to standardize GPS accuracy necessary for various analyses.[34] Esri's GIS solutions meet this requirement fully.

- **Geographic analysis:** GIS offers a number of geographic analyses. This is done by combining map layers of different themes to derive new information that describes the relationship between the combined layers. Geostatistical analysis capabilities also enable EH to apply science to both geography and statistics in the analysis of health issues to calculate the probable risks and success associated with different programs and initiatives. Esri's GIS solutions provide a sound foundation for extensive data integration and analyses across all databases containing geographic information.

[34] Esri. *HL7 and Spatial Interoperability Standards for Public Health and Health Care Delivery* at esri.com/library/whitepapers/pdfs/hl7-spatial-interoperability.pdf.

- **Map creation and display:** GIS will enable EH staff to create and display their results in different forms—maps, charts, graphs, and other graphics. Maps dynamically linked to charts, graphs, and other graphics (such as scatterplots) allow greater exploratory spatial data analysis. In addition to maps produced in traditional paper formats, maps can be easily exchanged in digital format across the intranet or Internet or via other storage media. Esri's GIS solutions meet this requirement fully.

- **Web functionality:** The web has become a way of sharing and transmitting information. The EH information system will leverage web functionality to deliver and improve services that seek to lower costs. GIS services must support multiple interfaces in an efficient manner. Esri's GIS solutions meet this requirement fully.

- **Query and display of databases:** GIS query tools are frequently used to search for data in the database and display results in both map and tabular formats. The public may also be provided with access to data that is appropriate for public consumption. Esri's GIS solution meets this requirement fully and is the foundation for many web-based data query systems developed by health and human services agencies.

- **Service-oriented architecture (SOA) capabilities:** Esri has responded to recent fundamental shifts in the technology landscape by making ArcGIS SOA enabled with full web service integration. This allows customers to readily expose ArcGIS standards-based functionality to other applications and interfaces, thus dramatically improving its value and return on investment (ROI).[35] With SOA-enabled GIS from Esri, EH information systems can be assured they can leverage their GIS advances as they progress in SOA maturity. More information is provided in a section below. Esri's GIS solutions meet this requirement fully.

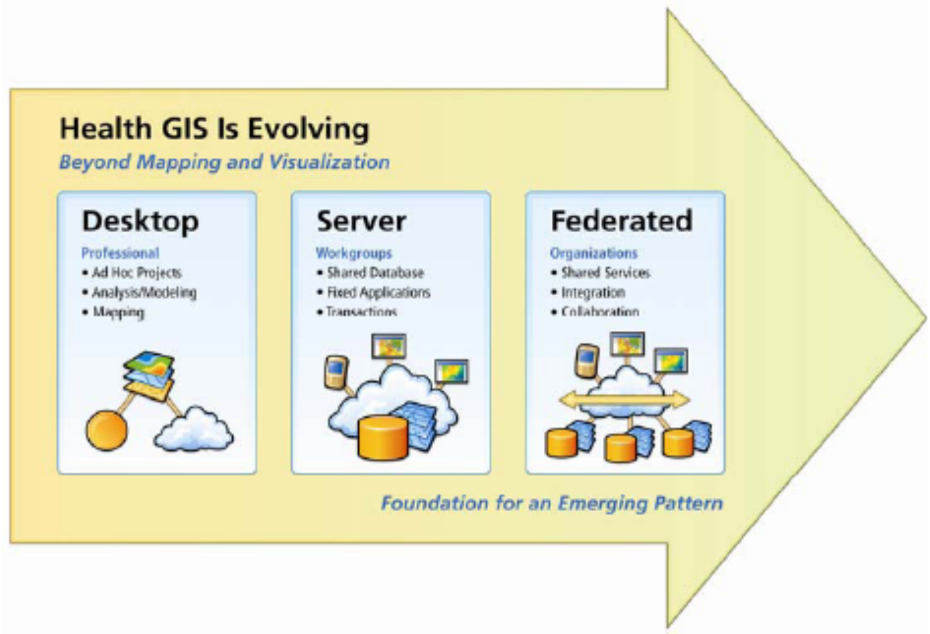
## Esri GIS and Environmental Health

Many EH agencies are already using ArcGIS software. Esri's strength in the public health marketplace is legendary. All 50 state health departments use Esri GIS technology, so all EH agencies can build sound geographic knowledge about programs and operations with unparalleled confidence. Esri can demonstrate a proven track record of successful GIS technology solutions throughout the environmental health, public health, and environmental management sectors. Esri has both the technology and experience to assist potential bidders to any proposal seeking to meet comprehensive GIS requirements. Maps and precise geographic information have become critical service delivery standards.

Over the coming years, it is anticipated that more EH information systems will become federated and integrated with enterprise GIS efforts at the agency-wide or statewide level (as illustrated in the third stage of figure 2). As agencies issue proposals for needs assessments and application developments, agencies and vendors should consider geographically enabling EH information systems.

[35] Esri. *Geospatial Service-Oriented Architecture*, retrieved May 27, 2010, esri.com/library/whitepapers/pdfs/geospatial-soa.pdf.

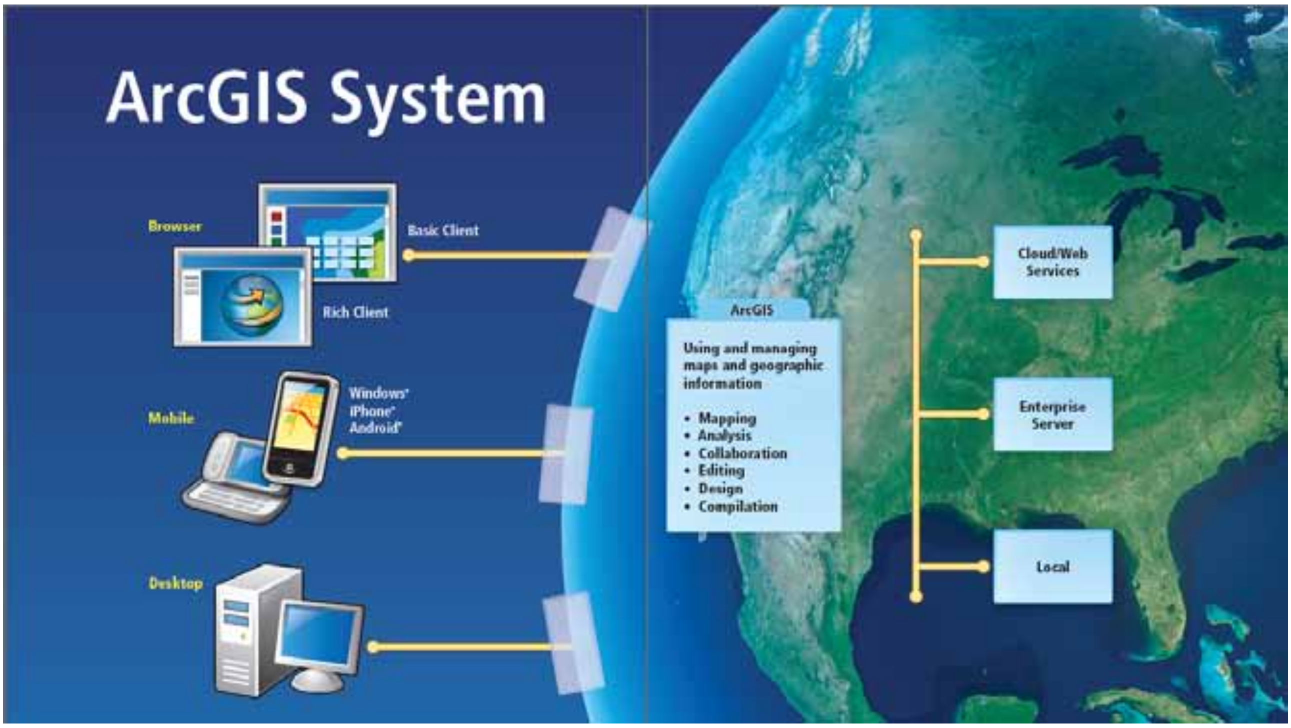
**Figure 2**
**Evolution of Environmental Health GIS**




Esri offers a complete range of GIS software and services including software, database design and development, customized applications programming, training, and installation. Esri GIS software packages are now the most widely used in the world. By adhering to relevant industry standards, Esri's software packages are able to interoperate seamlessly with other software and are therefore ideal for EH agencies and applications.

ArcGIS is a family of complementary products that work together both on the desktop and server (see figure 3). Detailed descriptions of selected Esri products relevant to EH are available in appendix B.

**Figure 3**
**ArcGIS**




*The ArcGIS system provides an infrastructure for making maps and geographic information available throughout an organization, across a community, and openly on the web. It can be implemented on individual local desktops or across desktops and browsers leveraging central servers. ArcGIS can also be hosted in the cloud.*

## Esri Interoperability and SOA

Esri recognizes that data and software capabilities need to be available to a wide range of users in an organization, each of whom may access and use different business tools. The distributed nature of GIS has many implications for interoperability with respect to hardware environments, operating systems, data management, deployment of application logic (desktop, server, mobile, ESB), web services integration, openly documented application programming interfaces (APIs), and documented XML data schemas. Esri has addressed interoperability comprehensively by implementing a variety of standards, strategies, and techniques in ArcGIS. The chart below (table 4) briefly summarizes Esri interoperability regarding platforms such as business applications, development, web servers, databases, operating systems, and hardware.

**Table 4**
**Esri Interoperability**

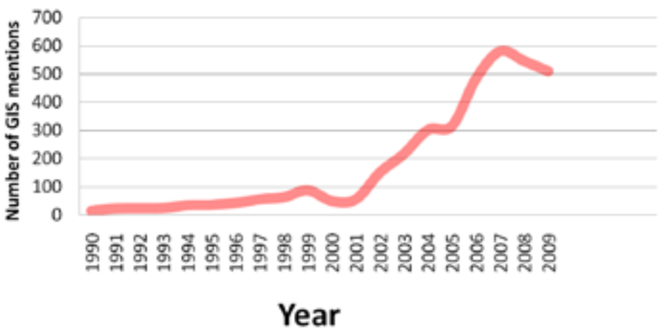
| Platforms | |
|---|---|
| Business Application | SAP, Microsoft Office SharePoint, Cognos, IBM Maximo, Primavera, ARCHIBUS, FileNet, Cityworks, Citilabs, EMC Documentum |
| Development | Microsoft .NET, Java, Adobe Flex, Microsoft Virtual Earth, Google Earth |
| Web Server | Apache, Apache Tomcat, JBoss, Windows IIS, WebSphere, Oracle WebLogic, Oracle Application Server |
| Database | Microsoft SQL Server, Oracle, IBM DB2 Informix, PostgreSQL |
| Operating System | Linux, Solaris, Windows |
| Hardware | Intel, AMD, Sun, HP, IBM |

Esri is also positioned to assist EH agencies and their partners as they pursue information systems planning and development. In addition to Esri's products (mentioned in the previous section), Esri offers many resources to facilitate the governance, business, and architecture of SOA deployment. Esri's Professional Services Division includes health domain specialists. Esri's partner program includes both organizations that have developed SOA connectors and organizations with domain specialty in EH.

## The Future of GIS and Environmental Health

In the future, EH researchers will continue to explore the complex, multidimensional relationships between pollution and disease.[36] Many of the increasing mentions of GIS in peer-reviewed health literature will make their way into environmental public health practice. A recent Medline search for "geographic information systems" from 1990 to 2009 revealed a total of 3,621 results. The upward trend is highlighted in figure 4.

**Figure 4**
**GIS in Peer-Reviewed Health Publications[37]**




[36] Betts, K. "Mapping the Environment." *Environmental Health Perspectives* 105, no. 6 (1997). Retrieved March 31, 2009, http://www.ehponline.org/docs/1997/105-6/innov.html.
[37] Methodology: Searched PubMed site at http://www.ncbi.nlm.nih.gov/sites/entrez for "geographic information systems" by year.

As more EH agencies assess how they are delivering essential services, they will identify opportunities for business process improvement and enhancing workflows and information systems with GIS. Below are additional predictions regarding the next decade of GIS and EH:

- ***Capacity building with local health departments.*** Miranda et al's GIS capacity-building work with health departments will be replicated around the world.
- ***Environmental public health tracking.*** EPHT networks will emerge in many other countries and form a global network.
- ***Integrated vector control.*** GIS will continue to be used widely for risk mapping, targeting interventions, and monitoring and evaluation, among other functions.
- ***Public health impact assessments.*** These will have a huge role for GIS.[38] Applications such as San Francisco's Healthy Development Measurement Tool (HDMT) (see Farhang et al in Appendix G) will be replicated.
- ***Remote sensing (RS).*** This will transition from research to routine public health practice as more satellite imagery is available at a lower cost and more frequently. RS will be central to growing interest in studying climate change and public health.
- ***Spatial epidemiology.*** This will make substantial progress and overcome some of its current limitations.[39]
- ***Geomedicine.*** Place history[40] will become a valuable component of medical history.[41]
- ***Enviromics and environment-wide association studies (EWAS).*** As researchers use the template for genome-wide association studies to study environmental factors contributing to diseases, GIS will help refine EWAS methodologies (e.g., reducing confounding by controlling for location).[42]
- ***Indoor buildings and GIS.*** The Indoor GIS Data Model[43] will stimulate EH research regarding indoor air quality as well as built environment.

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[38] For a review of health impact assessments, see Bhatia, R., and A. Wernham. "Integrating Human Health into Environmental Impact Assessment: An Unrealized Opportunity for Environmental Health and Justice." *Environmental Health Perspectives* 116, no. 8 (August 2008). Available at http://www.ehponline.org/members/2008/11132/11132.html.

[39] See http://www.ehponline.org/members/2008/10816/10816.html for a good summary.

[40] See http://www.esri.com/industries/health/geomedicine/index.html.

[41] See http://www.jabfm.org/cgi/content/abstract/23/1/22.

[42] See http://www.plosone.org/article/info:doi/10.1371/journal.pone.0010746.

[43] See http://www.vector1media.com/news/top-stories/53-corporate-news/5232-penobscot-bay-media-collaborates-with-esri-to-publish-open-data-model.

- ***Cloud computing.*** EH applications will leverage GIS functionality more easily as GIS services become more web based and available in the cloud. For example, BP stood up www.Gulfofmexicoresponsemap.com quickly.[44]

Esri has an extensive user community—the Health and Human Services. User Group (HUG). Many HUG members based in universities and research organizations are interested in partnering with entities such as EH agencies for spatial analysis research and development projects. In addition, Esri has a history of partnering with organizations to collaborate on cutting-edge spatial analysis.

## How to Get Started

As jurisdictions assess where they are and where they want to go with EH business processes and GIS, Esri stands ready to support them in determining how best to incorporate GIS capacities to support their work. Contact an expert now.

### *Environmental Health Agencies*

Esri's health team includes domain specialists who are prepared to have discussions with staff from EH agencies regarding how GIS can support their programmatic goals. Staff of EH agencies should also consider the following resources:

- Subscribe to *HealthyGIS*, a quarterly newsletter about software news, events, and user stories affecting the health and human services GIS community.
- Join the Esri Health and Human Services User Group, an active community of more than 1,000 professionals dedicated to sharing information, ideas, and experiences about Esri technology in the health and human services industry.
- Order *GIS Tutorial for Health* and other titles from Esri Press.
- Attend the Esri Health GIS Conference or Esri International User Conference.
- View content from the Esri Virtual Campus.
- Learn more about Esri Professional Services.
- View ArcGIS Server live user sites.
- Download the ArcGIS Server Functionality Matrix.
- Download ArcGIS Server white papers.
- Download *HL7 and Spatial Interoperability Standards for Public Health and Health Care Delivery*.

[44] See the blog post at http://aws.typepad.com/aws/2010/10/cloud-computing-and-the-world-of-geoapps.html for a description of how quickly the application was deployed using the Amazon cloud and Esri ArcGIS Server.

Another resource is the Esri Partner Network, which has more than 2,000 partners providing best-in-class GIS solutions. Esri partners have built expertise in

- Web portals
- Data warehouses
- Inspections and field data collection
- Data mining
- Integration kits with business intelligence/dashboard solutions
- EH and other HHS domain expertise

## *Vendors, Systems Integrators, and Developers*

As indicated previously in this paper, Esri has an extensive array of software products and professional and technical services that can assist any prime contractor in fulfilling GIS-related requirements for EH applications. Esri is prepared to provide all necessary documentation, including assigned staff and their resumés, as well as a reference site.

Esri is also prepared to provide specific pricing for both software and professional services required for requests for proposal. Contact Esri Professional Services for further information or assistance at esri.com.

In addition to the white papers, demos, and other resources described above for staff of EH agencies, systems integrators and developers should also consider the following:

- Many people belong to the Esri Developer Network (EDN℠), a cost-effective way to use and leverage ArcGIS products and technologies in applications and systems they design and build.

- Many people attend the Esri Developer Summit, an opportunity for them to connect with Esri staff and software developers from around the world to explore trends, tips, and best practices for effective GIS development.

# Appendix A: Terms and Abbreviations

- **automate—**To convert data to a digital format that can be displayed on a computer as a map. This can be accomplished through geocoding address information, digitizing, scanning, reading coordinate information text files, or direct keyboard input.

- **CAD—**Acronym for *computer-aided design*. A computer-based system for the design, drafting, and display of graphical information. Also known as computer-aided drafting, such systems are most commonly used to support engineering, planning, and illustrating activities.

- **client—**An application, computer, or device in a client/server model that makes requests to a server. Although client/server architecture can exist on one computer, it is more relevant to network systems that distribute applications over computers to different locations.

- **confounding—**A relationship between the effects of two or more causal factors as observed in a set of data such that it is not logically possible to separate the contribution that any single causal factor has made to an effect.[45]

- **enterprise GIS—**A geographic information system that is integrated through an entire organization so that a large number of users can manage, share, and use spatial data and related information to address a variety of needs, including data creation, modification, visualization, analysis, and dissemination.

- **Environmental Public Health Tracking (EPHT)—**The ongoing collection, integration, analysis, and interpretation of data about (1) environmental hazards, (2) exposure to environmental hazards, and (3) health effects potentially related to exposure to environmental hazards.[46]

- **epidemiologist—**An investigator who studies the occurrence of disease or other health-related conditions or events in defined populations.[47]

- **epidemiology—**The study of the distribution and determinants of health-related states or events in specified populations and the application of this study to control health problems.[48]

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[45] Last, J. *A Dictionary of Epidemiology*, Fourth Edition. New York: Oxford University Press, 2001.
[46] Centers for Disease Control and Prevention. National Environmental Public Health Tracking Program: Glossary. Retrieved June 1, 2009, http://www.cdc.gov/nceh/tracking/lib/glossary.htm.
[47] Last, J. *A Dictionary of Epidemiology*, Fourth Edition. New York: Oxford University Press, 2001.
[48] Ibid.

- **exposure assessment—**The process of estimating concentration or intensity, duration, and frequency of exposure to an agent that can affect health.[49]

- **feature—**The representation of a geographic feature that has both a spatial representation (referred to as a shape) and a set of attributes. Features can be represented as points, lines, polygons, or grids.

- **geocode—**A code representing the location of an object, such as an address; a census tract; a postal code; or x,y coordinates.

- **geocoding—**A GIS operation for converting street addresses into spatial data that can be displayed as features on a map, usually by referencing address information from a street segment data layer.

- **geodatabase—**A collection of geographic datasets for use by ArcGIS. There are many types of geographic datasets including feature classes, attribute tables, raster datasets, network datasets, and topologies.

- **geographic information system—**An integrated collection of computer software and data used to view and manage information connected with specific locations, analyze spatial relationships, and model spatial processes.

- **Health Insurance Portability and Accountability Act of 1996 (HIPAA)—**Public Law 104-191 resulted in new privacy standards for health information in the United States. HIPAA's goals include improving portability and continuity of health insurance coverage in the group and individual markets; combating waste, fraud, and abuse in health insurance and health care delivery; and simplifying the administration of health insurance, among other purposes.[50]

- **Health Level 7 (HL7)—**One of several American National Standards Institute (ANSI)-accredited standards developing organizations (SDOs) operating in the health care arena. HL7 produces standards (sometimes called specifications or protocols) for the particular health care domain of clinical and administrative data.[51]

- **interoperability—**The capability of components or systems to exchange data with other components or systems or to perform in multiple environments.

- **kriging—**An interpolation technique in which the surrounding measured values are weighted to derive a predicted value for an unmeasured location.

- **personal digital assistant (PDA)—**A handheld computer.

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[49] Ibid.
[50] United States Congress. *Health Insurance Portability and Accountability Act of 1996*. Retrieve December 18, 2008, http://www.cms.hhs.gov/HIPAAGenInfo/Downloads/HIPAALaw.pdf.
[51] Health Level Seven. *What Is HL7?* Retrieved December 17, 2008, http://www.hl7.org/.

- **PHIN (Public Health Information Network)—**A national initiative sponsored by the US Centers for Disease Control and Prevention to improve the capacity of public health to use and exchange information electronically by promoting the use of standards and defining functional and technical requirements.

- **Rapid Inquiry Facility (RIF)—**An automated tool that provides an extension to Esri ArcGIS functions and uses both database and GIS technologies. Its purpose is to rapidly address epidemiological and public health questions using routinely collected health and population data.[52]

- **raster—**A spatial data model that defines space as an array of equally sized cells arranged in rows and columns and composed of single or multiple bands. Each cell contains an attribute value and location coordinates. Unlike a vector structure, which stores coordinates explicitly, raster coordinates are contained in the ordering of the matrix. Groups of cells that share the same value represent the same type of geographic feature.

- **server—**A computer that manages shared resources, such as disks, printers, and databases, on a network or software that provides services or functionality to client software. For example, a web server is software that sends web pages to browsers.

- **service-oriented architecture (SOA)—**An architecture in which core business capabilities are encapsulated within independent software services, and these services are leveraged by various front-end applications to fulfill business requirements.[53]

- **spatial modeling—**Analytic procedures applied with GIS. There are three categories of spatial modeling functions that can be applied to geographic features within a GIS: (1) geometric models such as calculating the Euclidean distance between features, generating buffers, and calculating areas and perimeters; (2) coincidence models such as topological overlay; and (3) adjacency models such as pathfinding, redistricting, and allocation. All three model categories support operations on spatial data such as points, lines, polygons, and grids.

- **systems integrator—**An entity that builds solutions from diverse components. With increasing IT complexity, more organizations want complete solutions incorporating hardware, software, and networking expertise in a multivendor environment.

- **vector (GIS context)—**A coordinate-based data model that represents geographic features as points, lines, and polygons. Each point feature is represented as a single coordinate pair, while line and polygon features are

[52] Small Area Health Statistics Unit (Imperial College London). "Rapid Inquiry Facility (RIF): A Tool for Environmental Health Tracking." SAHSU Related Studies. Retrieved June 1, 2009, http://www.sahsu.org/related_studies.php. Also see http://www.ehponline.org/members/2008/10816/10816.html.

[53] Kawamoto, Kensaku, and David Lobach. "Proposal for Fulfilling Strategic Objectives of the U.S. Roadmap for National Action on Decision Support through a Service-Oriented Architecture Leveraging HL7 Services," *Journal of the American Medical Information Association* (2007): 146–155.

represented as ordered lists of vertices. Attributes are associated with each vector feature, as opposed to a raster data model, which associates attributes with grid cells.

- **vector (public health context)—**In infectious disease epidemiology, an insect or living carrier that transports an infectious agent from an infected individual (or its wastes) to a susceptible individual or its food or immediate surroundings. The organism may or may not pass through a developmental cycle within the vector.[54]

- **web service—**A software component accessible over the web for use in other applications. Web services are built using industry standards, such as XML and SOAP, and thus are not dependent on any particular operating system or programming language, allowing access to them through a wide range of applications.

[54] Last, J. *A Dictionary of Epidemiology*, Fourth Edition. New York: Oxford University Press, 2001.

# Appendix B: Esri Solutions for Environmental Health

Below are selected Esri solutions for environmental health. For a full list of Esri products, visit esri.com/products/index.html.

## ArcGIS Desktop

ArcGIS Desktop is a powerful tool for the management, display, query, and analysis of spatial information. ArcGIS software's extensible architecture has enabled Esri to develop optional plug-in modules, dramatically extending the software's functional capabilities. ArcGIS links traditional data analysis tools, such as spreadsheets, databases, and business graphics, with maps for a completely integrated analysis system. By integrating an EH organization's data geographically with ArcGIS, new patterns can be uncovered and new insights gained. Recent developments for ArcGIS Desktop relevant to EH organizations include capabilities to

- Create, manage, and visualize time-aware data for more in-depth analysis.
- Increase collaboration via tight integration with ArcGIS℠ Online search and share capabilities.
- Link maps, graphs, charts, and scatterplots to perform exploratory spatial data analysis (ESDA).
- Take advantage of new analysis tools such as fuzzy overlay and location-allocation, as well as a model-building tool that facilitates iterative modeling capabilities.
- Perform in 3D virtually everything you can do in a 2D environment: modeling, editing, visualization, and analysis.
- Automate common tasks and analyses with Python scripting.
- Take advantage of increased support for PDF documents (e.g., users can author a map document and export it in PDF for wide distribution while passing along the ability for increased end-user interaction with the document beyond simple viewing).
- Use the spatial statistics toolbox, featuring tools for spatial autocorrelation, analyzing spatial patterns (i.e., clustering or dispersion), and assessing spatial distributions.

## ArcGIS Server

ArcGIS Server connects people with geographic information via web applications and services. Organizations use ArcGIS Server to distribute maps and GIS capabilities over the web to improve internal workflows, communicate vital issues, and engage stakeholders. By providing key technologies and supporting interoperability with standards such as .NET 2.0; Enterprise JavaBeans; Web Services Interoperability Organization (WS-I)-compliant web services; and Open Geospatial Consortium, Inc. (OGC), services out of the box, the ArcGIS Server technology platform is ideally suited to SOA deployment. With ArcGIS Server, EH organizations can

- Improve decisions and productivity with web mapping services and applications that can be delivered to web, desktop, and mobile workforces.
- Leverage existing EH IT architecture by integrating a GIS server and spatial data with other enterprise systems, such as customer relationship management (CRM) or enterprise resource planning (ERP) systems.
- Rapidly meet specialized demand for focused EH applications by mashing up geographic content with GIS functionality.
- Take control of EH spatial data through centralized management of data, applications, and services.
- Discover and organize geographic data throughout the enterprise via the new search service in ArcGIS Server.
- Provide fast access to large volumes of imagery using image services, with the option for dynamic mosaicking and on-the-fly processing, reducing storage costs and data processing overhead.

## ArcGIS Mobile

ArcGIS Mobile helps EH organizations deliver GIS capabilities and data from centralized servers to a range of mobile devices. EH organizations can use ArcGIS Mobile to deploy intuitive and productive mobile GIS applications to increase the accuracy and improve the currency of data throughout the EH organization. Easy-to-use ArcGIS Mobile applications enable field staff who do not necessarily have any GIS experience to do mapping, spatial query, sketching, GPS integration, and GIS editing. With ArcGIS Mobile, EH organizations can

- Extend mobile projects to tablet-based PCs using the ArcGIS Mobile customizable, ready-to-deploy application (view a video demonstration).
- Simplify ArcGIS Mobile deployments using the new Mobile Project Center.
- Leverage streaming GPS, photo attachments, and location tracking.
- Access a new iPhone mapping application directly from the Apple iTunes App Store.
- Build iPhone applications using ArcGIS API for iPhone (view a video demonstration).

## ArcPad

ArcPad® is designed for GIS professionals who require GIS capabilities in the field. It gives field-based personnel the ability to capture, edit, analyze, and display geographic information easily and efficiently. With ArcPad, EH organizations can

- Perform reliable, accurate, and validated field data collection.
- Integrate GPS, range finders, and digital cameras into a GIS data collection.
- Share enterprise data with field-workers for updating and decision making.
- Improve the productivity of a GIS data collection.
- Improve the accuracy of the GIS database and make it more up to date.

## GeoCollector

GeoCollector™ is the ideal solution for collecting and maintaining the accuracy of GIS data. Esri, the leading GIS software vendor, has partnered with Trimble, the leading GPS vendor, to exclusively offer the GeoCollector series. For more information, visit esri.com/software/arcgis/geocollector/index.html.

## Geostatistical Analyst

ArcGIS Geostatistical Analyst is an extension to ArcGIS Desktop that provides a powerful suite of tools for spatial data exploration and surface generation. It effectively bridges the gap between geostatistics and GIS analysis by enabling EH organizations to model spatial phenomena, assess risk, and accurately predict values within study areas. With ArcGIS Geostatistical Analyst, EH agencies and researchers can create surfaces from data measurements taken over areas where collecting information for every location would be impossible or cost prohibitive. Users can fully examine sample data, evaluate uncertainties, generate unique insights, and create customized interpolation surfaces for more informed decision making. With ArcGIS Geostatistical Analyst, EH agencies and researchers can

- Visualize, model, and predict spatial relationships.
- Link data, graphs, and maps dynamically.
- Perform deterministic and geostatistical interpolation.
- Evaluate models and predictions probabilistically to assess risks.

## Spatial Analyst

ArcGIS Spatial Analyst brings sophisticated raster and vector data analysis to the desktop. It seamlessly integrates raster-based spatial analysis with ArcGIS software's vector-based mapping and analysis. This powerful combination brings unprecedented power for mapping, visualization, modeling, and analysis to EH organizations in an affordable desktop package. ArcGIS Spatial Analyst provides the tools needed to support a broad range of spatial modeling and application requirements. With ArcGIS Spatial Analyst, an EH organization can perform capability, sensitivity, predictive, and site suitability modeling; site location analysis; demographic analysis; and much more.

## ArcGIS Network Analyst

This powerful extension provides network-based spatial analysis including routing, travel directions, and closest facility and service area analysis. ArcGIS Network Analyst enables EH organizations to dynamically model realistic network conditions, including turn restrictions, speed limits, height restrictions, and traffic conditions, at different times of the day. With ArcGIS Network Analyst, EH organization can conduct

- Drive-time analysis
- Point-to-point routing
- Route directions
- Service area definition
- Shortest path analysis
- Optimum route analysis
- Closest facility analysis
- Origin-destination analysis

## ArcLogistics

ArcLogistics™ is a complete desktop solution for creating optimized routes and solving scheduling problems. Create dynamic routes and schedules that cut fuel costs and improve customer service using ArcLogistics. From a small fleet operation to a large multiuser environment, ArcLogistics provides a quick and significant return on investment. With ArcLogistics, EH organizations will

- Create routes and schedules in less time.
- Meet commitments and improve service.
- Save money, use less fuel, and reduce emissions.

## Esri Data

Esri's business, consumer spending, and demographic data encompasses a wide variety of datasets that help agencies, companies, and organizations analyze markets, profile customers, evaluate competitors, and more. Esri data is available as part of Esri Business Analyst™, Esri Business Analyst Server, or Business Analyst Online™ (BAO℠) or as individual databases. EH organizations can use Esri data to

- Analyze and describe a community or service area.
- Identify new sites for facilities or programs.
- Profile constituents.
- Forecast demand for services.

## Hardware

Esri offers many hardware packages that may be of interest to EH agencies. For more information, visit esri.com/hardware.

## Developer Tools

Esri also offers a number of developer tools, which are described in the Vendors, Systems Integrators, and Developers section.

# Appendix C: Outdoor Air Quality: GIS Presentations and Publications

The recently released HealthyPeople 2020 goals for the United States include an objective for outdoor air quality, broken down into three subcategories: air quality index, alternative modes of transportation, and airborne toxins. Below are selected GIS references.

Baccarelli, A., et al. 2009. Living Near Major Traffic Roads and Risk of Deep Vein Thrombosis. *Circulation* 119: 3118–3124. http://circ.ahajournals.org/cgi/content/abstract/119/24/3118.

Baxter, L. K., J. E. Clougherty, C. J. Paciorek, R. Wright, and J. I. Levy. 2007. Predicting Residential Indoor Concentrations of Nitrogen Dioxide, Fine Particulate Matter, and Elemental Carbon Using Questionnaire and Geographic Information System Based Data. *Atmospheric Environment* 41:6561–6571. http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2760735/.

Berlow, J. 2008. The Correlation between Air Pollution and Poverty Indicators. Presented at the Esri Health GIS Conference. http://proceedings.esri.com/library/userconf/health08/docs/tuesday/air_pollution_poverty.pdf.

Clougherty, J. E., E. Houseman, and J. I. Levy. 2009. Examining Intra-urban Variation in Fine Particle Mass Constituents Using GIS and Constrained Factor Analysis. *Atmospheric Environment* 43 (November) (34): 5545–5555.

Clougherty, J. E., R. J. Wright, L. K. Baxter, and J. I. Levy. 2008. Land Use Regression Modeling of Intra-urban Residential Variability in Multiple Traffic-Related Air Pollutants. *Environmental Health* 7:17. http://www.ncbi.nlm.nih.gov/pubmed/18485201.

Clougherty, J. E., J. I. Levy, L. D. Kubzansky, P. B. Ryan, S. F. Suglia, M. J. Canner, and R. J. Wright. 2007. Synergistic Effects of Traffic-Related Air Pollution and Exposure to Violence on Urban Asthma Etiology. *Environmental Health Perspectives* 115:1140–1146. http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1940095/.

Cradock, A. L., P. J. Troped, B. Fields, S. J. Melly, S. V. Simms, F. Gimmler, and M. Fowler. 2008. Factors Associated with Federal Transportation Funding for Local Pedestrian and Bicycle Programming and Facilities. *Journal of Public Health Policy* 30:S38–S72. http://www.ncbi.nlm.nih.gov/pubmed/19190583.

Environmental Systems Research Institute. 2007. GIS Best Practices: *GIS for Air Quality*. http://www.esri.com/library/bestpractices/air-quality.pdf.

Environmental Systems Research Institute. 2005–2006. Colorado's North Front Range Metropolitan Planning Organization Makes Ride Sharing Easier with GIS. *ArcNews* (Winter).

http://www.esri.com/news/arcnews/winter0506articles/colorados-north-front.html.

Friis, R., et al. 2008. Health Effects Associated with Goods Movement in the Los Angeles Basin. Presented at the American Public Health Association annual meeting. http://apha.confex.com/apha/136am/webprogram/Paper175363.html.

Greco, S. L., A. M. Wilson, S. R. Hanna, and J. I. Levy. 2007. Factors Influencing Mobile Source Particulate Matter Emissions-to-Exposure Relationships in the Boston Urban Area. *Environ Sci Technol* 41:7675–7682. http://www.ncbi.nlm.nih.gov/pubmed/18075073.

Gumusay, A., et al. 2008. Use of Geographical Information Systems in Analyzing Vehicle Emissions: Istanbul as a Case Study. Presented at the International Society for Photogrammetry and Remote Sensing Congress (Beijing, China). http://www.isprs.org/congresses/beijing2008/proceedings/1_pdf/171.pdf.

Hwang, B., and J. Jaakkola. 2008. Ozone and Other Air Pollutants and the Risk of Oral Clefts. *Environmental Health Perspectives* 116 (October): 10. http://www.ehponline.org/members/2008/11311/11311.html.

Kim, J., et al. 2008. Residential Traffic and Children's Respiratory Health. *Environmental Health Perspectives.* 116 (September) (9): 1274–1279. http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=2535634&tool=pmcentrez.

Liao, D., et al. 2006. GIS Approaches for the Estimation of Residential-Level Ambient PM Concentrations. *Environmental Health Perspectives* 114 (September) (9). http://www.ehponline.org/members/2006/9169/9169.html#meth.

Littlejohn, M., and J. Lwebuga-Mukasa. 2007. Spatial Distribution of Ultrafine Particles on Buffalo's West Side. Presented at the Esri Health GIS Conference. http://proceedings.esri.com/library/userconf/health07/docs/spatial_distribution.pdf.

Medina-Ramón, M., et al. 2008. Residential Exposure to Traffic-Related Air Pollution and Survival after Heart Failure. *Environmental Health Perspectives* 116 (April) (4). http://www.ehponline.org/members/2008/10918/10918.html.

Park, S., et al. 2008. Air Pollution and Heart Rate Variability Effect Modification by Chronic Lead Exposure. *Epidemiology* 19 (January) (1): 111–120. http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=2671065&tool=pmcentrez.

Poulstrop, A., and H. Hansen. 2004. Use of GIS and Exposure Modeling as Tools in a Study of Cancer Incidence in a Population Exposed to Airborne Dioxin. *Environmental Health Perspectives*: annual review issue 112 (June) (9). http://www.ehponline.org/members/2004/6739/6739.html.

Setton, E., et al. 2008. Spatial Variations in Estimated Chronic Exposure to Traffic-Related Air Pollution in Working Populations: A Simulation. *Int J Health Geogr* 7:39. http://www.ij-healthgeographics.com/content/7/1/39/abstract/.

Stuart, A., et al. 2006. Investigation of Health Disparities Due to Localized Air Pollution Exposures in Tampa, FL. Presentation at the American Public Health Association annual meeting. http://apha.confex.com/apha/134am/techprogram/paper_134309.htm.

Texcalac, J. L., et al. 2008. Exposure Assessment of PM2.5 Using Spatial Analysis Model in Mexico City. Epidemiology 19 (January) (1): S218–S219. http://www.ehponline.org/docs/1997/105-6/innov.html.

Tonne, C., S. Melly, M. Mittleman, B. Coull, R. Goldberg, and J. Schwartz. 2007. A Case–Control Analysis of Exposure to Traffic and Acute Myocardial Infarction. *Environmental Health Perspectives* 115:53–57. http://ehp03.niehs.nih.gov/article/fetchArticle.action?articleURI=info%3Adoi%2F10.1289%2Fehp.9587.

Wilhelm, M., et al. 2008. Environmental Public Health Tracking of Childhood Asthma Using California Health Interview Survey, Traffic, and Outdoor Air Pollution Data. *Environmental Health Perspectives* 116 (September) (9). http://www.ehponline.org/members/2008/10945/10945.html.

Wilhelm, M., and B. Ritz. 2003. Residential Proximity to Traffic and Adverse Birth Outcomes in Los Angeles County, California. *Environmental Health Perspectives*: 111 (February) (2): 1994–1996. http://ehp.niehs.nih.gov/members/2003/5688/5688.html.

Zhou, Y., and J. Levy. 2007. Factors Influencing the Spatial Extent of Mobile Source Air Pollution Impacts: A Meta-analysis. *BMC Public Health*: 7:89. http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=1890281.

# Appendix D—Water Quality: GIS Presentations and Publications

The HealthyPeople 2020 goals for the United States include an objective for water quality, broken down into subcategories including safe drinking water, waterborne disease outbreaks, per capita domestic water withdrawls, and beach closings. Below are selected GIS references:

Aschengrau, A., et al. 2008. Prenatal Exposure to Tetrachloroethylene-Contaminated Drinking Water and the Risk of Adverse Birth Outcomes. *Environmental Health Perspectives* 116 (June) (6): 814–820. http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=2430239&tool=pmcentrez.

Bastrup, R., et al. 2008. Arsenic in Drinking-Water and Risk for Cancer in Denmark. *Environmental Health Perspectives* 116 (February) (2): 231–237. http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=2235208&tool=pmcentrez.

Brody, J., et al. 2006. Breast Cancer Risk and Drinking Water Contaminated by Wastewater: A Case Control Study. *Environmental Health*: 5:28. http://www.ehjournal.net/content/5/1/28.

DeWeese, A., et al. 2007. Reducing Risks to the Anishinaabe from Methylmercury: A GIS-Based Fish Consumption Advisory Program for Walleye. Presented at the American Public Health Association annual meeting. http://apha.confex.com/apha/135am/techprogram/paper_153890.htm.

Fischer, T. 2006. Developing an Underground Storage Tank Inspection Prioritization Tool Using GIS. Presented at the Esri International User Conference. http://proceedings.esri.com/library/userconf/proc06/papers/abstracts/a1673.html.

Fleming, H., and H. Harding. 2007. Groundwater Arsenic Concentrations and Cancer Incidence Rates: A Regional Comparison in Oregon. Presented at the American Public Health Association annual meeting. http://apha.confex.com/apha/135am/techprogram/paper_153271.htm.

Gordon, L. 2009. Assessing the Risks to Public Health from Contamination in Potable Wells Using the Geographic Information Systems (GIS). Presented at the NEHA conference. www.neha.org.

Hughes, S., et al. 2004. Using a Geographical Information System to Investigate the Relationship between Reported Cryptosporidiosis and Water Supply. *Int J Health Geogr* 3:15. http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=506784&tool=pmcentrez.

Jacob, B., et al. 2008. Hydrological Modeling of Geophysical Parameters of Arboviral and Protozoan Disease Vectors in Internally Displaced People Camps in

Gulu, Uganda. *Int J Health Geogr* 7:11. http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=2275725&tool=pmcentrez.

Januleuwicz, P., et al. 2008. Risk of Learning and Behavioral Disorders Following Prenatal and Early Postnatal Exposure to Tetrachloroethylene (PCE)-Contaminated Drinking Water. *Neurotoxicology and Teratology* 30 (3): 175–185. http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=2494864&tool=pmcentrez.

Jones, M. 2009. Mapping Water Sources in Rwanda Helps Effort to Reduce Child Mortality. *HealthyGIS* (Summer). http://www.esri.com/library/newsletters/healthygis/healthygis-summer09.pdf.

Kurakina, N. 2008. Analyzing the Environmental Impact of Water Bodies in Russia: River Pollutants Monitored with GIS. *ArcNews* (Summer). http://www.esri.com/news/arcnews/summer08articles/river-pollutants.html.

Meliker, J., et al. 2008. Validity of Spatial Models of Arsenic Concentrations in Private Well Water. *Environmental Research* 106 (January) (1): 42–50. http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=2271042&tool=pmcentrez.

Mitchell, R. A Social Map of the Gulf Oil Spill. *Computerworld*. http://blogs.computerworld.com/16078/a_social_map_of_the_gulf_oil_spill.

Osei, F., and A. Duker. 2008. Spatial and Demographic Patterns of Cholera in Ashanti Region—Ghana. *Int J Health Geogr* 7:44. http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=2533654&tool=pmcentrez.

Osei, F., and A. Duker. 2008. Spatial Dependency of *V. cholera* Prevalence on Open Space Refuse Dumps in Kumasi, Ghana: A Spatial Statistical Modeling. *Int J Health Geogr* 7:62. http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=2628349&tool=pmcentrez.

Simental, L., and J. Martinez-Urtaza. 2008. Climate Patterns Governing the Presence and Permanence of Salmonellae in Coastal Areas of Bahia de Todos Santos, Mexico. *Appl Environ Microbiol* 74 (October) (19): 5918–5924. http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=2565968&tool=pmcentrez.

Wang, X., et al. 2008. Bayesian Spatio-Temporal Modeling of *Schistosoma japonicum* Prevalence Data in the Absence of a Diagnostic 'Gold' Standard. *PLoS Negl Trop Dis*. 2 (June) (6): e250. http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=2405951&tool=pmcentrez.

# Appendix E—Toxics and Waste: GIS Presentations and Publications

The HealthyPeople 2020 goals for the United States include addressing toxics and waste, broken down into subcategories including blood lead levels in children, risks posed by hazardous sites, pesticide exposures resulting in visits to health care facilities, toxic pollutants, and recycling of municipal waste. Below are selected GIS references:

Burch, J., et al. 2006. Radio Frequency Nonionizing Radiation in a Community Exposed to Radio and Television Broadcasting. *Environmental Health Perspectives* 114 (February) (2). http://www.ehponline.org/members/2005/8237/8237.html.

Carney, R. M., S. Husted, S. Jean, C. Glaser, and V. Kramer. 2008. Efficacy of Aerial Spraying of Mosquito Adulticide in Reducing Incidence of West Nile Virus, California, 2005. *Emerging Infectious Diseases* serial on the Internet (May). http://www.cdc.gov/EID/content/14/5/747.htm.

Chen, H., et al. 2006. Spatial Interpolation for Identifying Soil Contamination Area. Presented at the Esri International User Conference. http://proceedings.esri.com/library/userconf/proc06/papers/papers/pap_1094.pdf.

Choi, A., et al. 2006. Does Living Near a Superfund Site Contribute to Higher Polychlorinated Biphenyl (PCB) Exposure? *Environmental Health Perspectives* 114 (July) (7). http://ehp.niehs.nih.gov/members/2006/8827/8827.html.

Harris, W., et al. 2008. Crossing County Agency Administrative Borders and Using GIS to Effectively Target High Risk Dwellings for a Lead Abatement Program: Riverside County, California. Presented at the American Public Health Association annual conference.
http://apha.confex.com/apha/136am/webprogram/Paper177950.html.

Hauptman, M. 2008. Geographic Distribution of the Burden of Lead Poisoning in Rhode Island: Using Spatial Analysis to Identify High-Risk Areas. Presented at the American Public Health Association annual meeting.
http://apha.confex.com/apha/136am/webprogram/Paper186122.html.

Hewitt, C., et al. 2007. Environmental Assessment of Uranium with Geotechnologies. Presented at the Esri Health GIS Conference.
http://proceedings.esri.com/library/userconf/health07/docs/environmental_assessment
.pdf.

Kim, D. 2007. Can GIS Help Save Money: Using GIS to Direct Targeted Screening for Childhood Lead Poisoning in North Carolina. Presented at the Esri Health GIS Conference.
http://proceedings.esri.com/library/userconf/health06/docs/lead_poisoning.pdf.

Lutgendorf, C. 2007. Prostate Cancer Aggressiveness, Race and Pesticides in North Carolina: The PCaP Geographic Information Study (PCaP-GIS). Presented at the American Public Health Association annual meeting.
http://apha.confex.com/apha/135am/techprogram/paper_161570.htm.

Norton, J. 2007. Race, Wealth, and Solid Waste Facilities in North Carolina. *Environmental Health Perspectives* 115 (September) (9).
http://ehp.niehs.nih.gov/members/2007/10161/10161.html.

Payton, M., et al. 2008. GIS Technology and Lead Poisoning Prevention in Mississippi. Presented at the American Public Health Association annual meeting.
http://apha.confex.com/apha/136am/webprogram/Paper186939.html.

Roberts, E., et al. 2007. Maternal Residence Near Agricultural Pesticide Applications and Autism Spectrum Disorders among Children in the California Central Valley. *Environmental Health Perspectives* 115 (October) (10).
http://www.ehponline.org/members/2007/10168/10168.html.

Sasser. H. 2007 Neighborhood Characteristics of Poisoning. Presented at the American Public Health Association annual meeting.
http://apha.confex.com/apha/135am/techprogram/paper_157883.htm.

Shea, J. 2007. Disparate Solid Waste Processing Facility Impact: Control through GIS Evaluation and Regulation. Presented at the National Association of County and City Health Officials' annual conference.
http://www.naccho.org/conferences/NACCHOannual07/documents/NA07%20Conference%20Guide%20-%20FINAL%20for%20Web.pdf.

Smith, R. 2007. ArcGIS Application for Managing of Chemical Risk and Transportation Routes of Hazardous Materials: The Case of Medellin Metropolitan Area. Presented at the Esri International User Conference.
http://proceedings.esri.com/library/userconf/proc07/papers/papers/pap_1346.pdf.

Vaidyanathan, A., et al. 2007. Neighborhood Level Risk Analysis of Childhood Lead Poisoning in the City of Atlanta. Presented at the Esri Health GIS Conference.
http://proceedings.esri.com/library/userconf/health07/docs/neighborhood.pdf.

Vinceti, M., et al. 2009. Risk of Congenital Anomalies around a Municipal Solid Waste Incinerator: A GIS-Based Case-Control Study. *Int J Health Geogr* 8:8.
http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=2652434&tool=pmcentrez.

Wilson, S., et al. 2002. Environmental Injustice and the Mississippi Hog Industry. *Environmental Health Perspectives Supplements* 110 (April) (S2).
http://www.ehponline.org/members/2002/suppl-2/195-201wilson/wilson-full.html.
Wilson, S., et al. 2007. Community Levels of Atmospheric Ammonia near Industrial Hog Operations. Presented at the American Public Health Association annual meeting. http://apha.confex.com/apha/135am/techprogram/paper_156352.htm.

# Appendix F: Healthy Homes and Healthy Communities: GIS Presentations and Publications

The HealthyPeople 2020 goals for the United States include an objective for healthy homes and healthy communities, broken down into subcategories including indoor allergen levels, radon mitigation systems in homes, radon-reducing new home construction, school policies to promote healthy and safe environments, home test for lead-based paint, and housing units with physical problems. Below are selected GIS references:

Christensen, L., and J. Rigby. 1995. GIS Applications to Radon Hazard Studies—An Example from Nevada. Presented at the Esri International User Conference. http://proceedings.esri.com/library/userconf/proc95/to150/p142.html.

Cradock, A. L., S. J. Melly, J. G. Allen, J. S. Morris, and S. L. Gortmaker. 2007. Characteristics of School Campuses and Physical Activity Among Youth." *Am. J. Prev. Medicine* 33 (2):106–113. http://www.ncbi.nlm.nih.gov/pubmed/17673097.

Corburn, C., et al. 2006. Urban Asthma and the Neighbourhood Environment in New York City. *Health & Place* 12 (June) (2): 167–179.

Coley, R., et al. 2007. Developing a Tool for Conducting Assessments of the Built Environment. Presented at the American Public Health Association annual meeting. http://apha.confex.com/apha/135am/techprogram/paper_162987.htm.

Foong, H., and B. Robertson. 2007. GIS Modeling for Healthy Parks, Healthy Communities: Using ModelBuilder to Determine Community Park Needs. Presented at the Esri Health GIS Conference. http://proceedings.esri.com/library/userconf/health07/docs/community_park_needs.pdf.

Gustafson, A., et al. 2008. Understanding the Local Food Environment through a Community Food System Assessment. Presented at the American Public Health Association annual meeting. http://apha.confex.com/apha/136am/webprogram/Paper178861.html.

Gustat, J., et al. 2008. Within Walking Distance: Characteristics of Individuals Who Say They Can Walk to Local Features. Presented at the American Public Health Association annual meeting. http://apha.confex.com/apha/136am/webprogram/Paper180153.html.

Gruber, D. 2006. New Jersey Hippocrates Situational Awareness System. Presented at the Esri Health GIS Conference. http://proceedings.esri.com/library/userconf/health07/docs/hippocrates_new_jerseys.pdf.

Hamdi, H. 2008. In the Absence of Garden of Eden, Where Do Newark's Southward Residents Purchase Fresh Produce? Presented at the American Public Health Association annual meeting. http://apha.confex.com/apha/136am/webprogram/Paper180344.html.

Kim, D., et al. 2008. A Framework for Widespread Replication of a Highly Spatially Resolved Childhood Lead Exposure Risk Model. *Environmental Health Perspectives* 116 (December) (12): 1735–1739. http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=2599772&tool=pmcentrez.

Kwan, D. 2007. Childhood Obesity and the Built Environment in Los Angeles County. Presented at the Esri Health GIS Conference. http://proceedings.esri.com/library/userconf/health07/docs/childhood_obesity.pdf.

Magzamen, S., and I. Tager. 2006. Exploring Asthma Prevalence and Sociodemographic Factors in an Urban Community. Presented at the Esri Health GIS Conference. http://proceedings.esri.com/library/userconf/health06/docs/urban_asthma.pdf.

Myatt, M., et al. 2007. Application of GIS to Estimate Public Health Benefits of Whole House In-Duct Air Cleaning. Presented at the Esri Health GIS Conference. http://proceedings.esri.com/library/userconf/health07/docs/application_of_gis.pdf.

Naphtali, Z., et al. 2008. Maps Expand Asthma Hazards Awareness: GIS Helps Policymakers See Where Childhood Asthma, Schools, and Pollution Sources Collide. *HealthyGIS* (Winter). Reprint available at http://www.esri.com/industries/health/pdf/healthygis_asthma.pdf.

Plunkett, K. 2006. Secure Real Time Collaborative Mapping and Analysis (Ohio Public Health Analysis Network). Presented at the Esri Health GIS Conference. http://proceedings.esri.com/library/userconf/health06/docs/secure_realtime.pdf.

Santana, P., et al. 2009. Walkable Urban Green Spaces: Health Impact Assessment in Amadora, Portugal. Presented at the 14th International Conference on Urban Planning and Regional Development in the Information Society in Sitges, Spain. http://programm.corp.at/cdrom2009/papers2009/CORP2009_40.pdf.

Seto E., A. Holt, T. Rivard, and R. Bhatia. 2007. Spatial Distribution of Traffic Induced Noise Exposures in a US City: An Analytic Tool for Assessing the Health Impacts of Urban Planning Decisions. *International Journal of Health Geographies* 6 (24). http://www.ij-healthgeographics.com/content/6/1/24.

# Appendix G: EH Infrastructure and Surveillance: GIS Presentations and Publications

HealthyPeople 2020 goals for the United States include EH infrastructure and surveillance, broken down into subcategories including exposure to environmental chemicals, information systems used for EH, monitoring diseases caused by exposure to environmental hazards, and schools located near highways. Below are selected GIS references:

Alfred, B., et al. 2006. Leveraging GIS Technologies in Public Health Departments: Best Practices. Presented at the American Public Health Association annual meeting. http://apha.confex.com/apha/134am/techprogram/paper_131287.htm.

Allpress, J., et al. 2008. A GIS-Based Method for Household Recruitment in a Prospective Pesticide Exposure Study. *International Journal of Health Geographics* 7:18. http://www.ij-healthgeographics.com/content/7/1/18/abstract.

Beale, L. 2007. Environmental Public Health: A Disease Mapping and Risk Analysis Tool. Presented at the Esri International User Conference. http://proceedings.esri.com/library/userconf/proc07/papers/papers/pap_1125.pdf.

Farhang, L., R. Bhatia, C. C. Scully, J. Corburn, M. Gaydos, and S. Malekafzali. 2008. Creating Tools for Healthy Development: Case Study of San Francisco's Eastern Neighborhoods Community Health Impact Assessment. *Journal of Public Health Management and Practice* 14 (3).

Francis, S. 2007. Integrating GIS into the El Dorado County Public Health Department: A Practical Review of GIS Implementation and Tools for a Local Health Department. Presented at the Esri Health Conference. http://proceedings.esri.com/library/userconf/health07/docs/integrating_el_dorado.pdf.

Geraghty E., P. Franks, and D. Soule. 2008. Daily Pollen Levels and Emergency Room Visits/Hospitalizations in California. Presented at the Esri Health GIS Conference. http://proceedings.esri.com/library/userconf/health08/docs/Tuesday/pollen_levels.pdf.

Hadjichristodoulou, C., et al. 2005. Methodological Aspects of a GIS-Based Environmental Health Inspection Program Used in the Athens 2004 Olympic and Para Olympic Games. *BMC Public Health* 5:93. http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=1232856.

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Kroeger, R. 2007. GIS to Help Manage Public Environmental Health. Presented at the Colorado Public Health Association annual conference. http://emaps.dphe.state.co.us/gis/documents/CPHA07_WPHA_GIS.pdf.

Li, H. 2007. Developing a Surveillance System to Track Disease and Pollution." Presented at the Esri Health GIS Conference. http://proceedings.esri.com/library/userconf/health07/docs/developing_a_surveillance.pdf.

Liu, H., et al. 2008. Spatio-temporal Analysis of the Relationship between WNV Dissemination and Environmental Variables in Indianapolis, USA. *Int J Health Geogr* 7:66. http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=2615761&tool=pmcentrez.

Miranda, M. L., et. al. 2005. Building Geographic Information Systems Capacity in Local Health Departments: Lessons Learned from a North Carolina Project. *American Journal of Public Health* 95: 2180–2185.

Noor, A., et al. 2007. Increasing Coverage and Decreasing Inequity in Insecticide-Treated Bed Net Use among Rural Kenyan Children. *PLoS Med* 4 (August) (8): e255. http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=1949846&tool=pmcentrez.

Powell, R., and A. Venner. 2008. National Environmental Public Health Tracking Network: Crossing Borders with Data. Presented at the American Public Health Association annual meeting. http://apha.confex.com/apha/136am/webprogram/Paper186407.html.

Rácz, E. 2007. Environmental Factors Affecting Host-Seeking *Ixodes scapularis* Ticks in the United States. Presented at the Esri Health GIS Conference. http://proceedings.esri.com/library/userconf/health07/docs/environmental_factors.pdf.

Sharma, R., et al. 2006. Spatial Data Analytical Tools for Linking Environmental Surveillance Data to Health Outcomes: Application to Data from a Local Health Department. Presented at the American Public Health Association annual meeting. http://apha.confex.com/apha/134am/techprogram/paper_144033.htm.

Shoultz, J. 2007. Server-Based GIS and Spatial Leveraging of Public Health Data." Presented at the Esri Health GIS User Conference. http://proceedings.esri.com/library/userconf/health07/docs/plenary/pdf/dhec.pdf.

Vozenilek, V. 2008. Impact of Climate Change on the Incidence of Tick-borne Encephalitis and Lyme Disease in the Czech Republic. Presented at the Esri Health GIS User Conference. http://proceedings.esri.com/library/userconf/health08/docs/mapgallery/c0000523.pdf.

Wiafe, S., et al. 2008. Rapid Needs Evaluations Using Geographic Information Technologies for Vector Control Surveillance in San Bernardino County. Presented at the American Public Health Association annual meeting. http://apha.confex.com/apha/136am/webprogram/Paper181123.html.

# Appendix H: Global Environmental Health: GIS Presentations and Publications

The HealthyPeople 2020 goals for the United States include global environmental health. Below are selected GIS references:

Aramayo, C., et al. 2009. Diarrhea and Parasitosis in Salta, Argentina. J Infect Developing Countries 3 (2): 105–111. http://www.jidc.org/index.php/journal/article/viewFile/57/39.

Ingraham, J. 2005. The Republic of Zambia: 5 Year Potable Water Delivery and Training Program. Presented at the Esri International User Conference. http://proceedings.esri.com/library/userconf/proc05/papers/pap2399.pdf.

Osei, F., and A. Duker. 2008. Spatial and Demographic Patterns of Cholera in Ashanti Region—Ghana. *Int J Health Geogr* 7:44. http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=2533654&tool=pmcentrez.

Osei, F., and A. Duker. 2008. Spatial Dependency of *V. cholera* Prevalence on Open Space Refuse Dumps in Kumasi, Ghana: A Spatial Statistical Modeling. *Int J Health Geogr* 7:62. http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=2628349&tool=pmcentrez.

Sasaki, S., et al. 2008. Spatial Analysis of Risk Factor of Cholera Outbreak for 2003–2004 in a Peri-urban Area of Lusaka, Zambia. *Am. J. Trop Med Hyg* 79 (3): 414–421.

Southwest Consortium for Environmental Research and Policy. Posters from the Binational GIS Summit. http://mapper.nmsu.edu/scerp%5F2006summit/poster.html.

Simental, L., and J. Martinez-Urtaza. 2008. Climate Patterns Governing the Presence and Permanence of Salmonellae in Coastal Areas of Bahia de Todos Santos, Mexico. *Appl Environ Microbiol* 74 (October) (19): 5918–5924. http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=2565968&tool=pmcentrez.

Wang, X., et al. 2008. Bayesian Spatio-Temporal Modeling of *Schistosoma japonicum* Prevalence Data in the Absence of a Diagnostic 'Gold' Standard. *PLoS Negl Trop Dis* 2 (October) (6): e250. http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=2405951&tool=pmcentrez.

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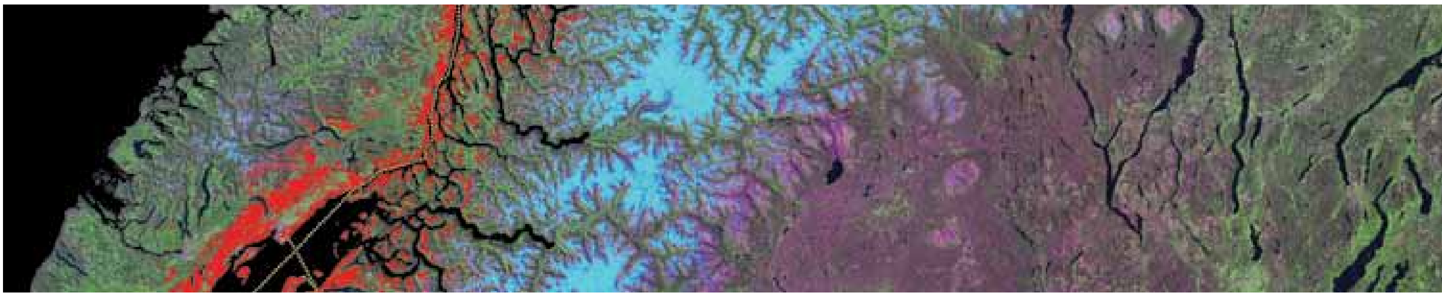

## About Esri Australia

Esri Australia is the nation's leading Geographic Information System (GIS) specialist. From humble beginnings in 1977 – a single office based in Perth – we have expanded into seven capital cities and have the capacity to service clients across the country. In our 34 years, we have worked with thousands of clients, across a diverse range of sectors.

GIS employs the science of geography to map and analyse information. As market leaders in this space, we use cutting-edge technology to deliver valuable location-based intelligence to our clients – a process that helps them to see more and do more with their information.

## Our Focus

Underpinning our market position is a genuine passion for what we do. We are committed to making a difference – in the corporate world and wider community. This passion for the science behind GIS and considered, insightful approach enables us to deliver exceptional results.

Collaboration is also central to the way we operate – with every assignment we bring our extensive experience and expertise. We've been an integral part of some of the most exciting GIS projects on Australian shores and work with the nation's most progressive geo-enabled enterprises.

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