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Research Article

Who's Watching Your Food? A Flexible Framework for Public Health Monitoring[1]

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Abstract
By responding to potentially life-threatening emergencies such as foodborne illnesses and water contamination, U.S. public health agencies play a vital role in promoting human health and protecting the environment. Local, state, and federal partners must collaborate to strategically plan initiatives, allocate resources, and evaluate emergency response activities. These collaborative decision-making processes can be improved by using web-based mapping applications for visualization and analysis. We developed a web-based GIS framework which is applied to public health data for North Carolina's (NC) Department of Health and Human Services. The application visualizes all state-regulated food service facilities and supports query and analysis tools crucial for food recalls or radiation contamination tracking. Built with PostgreSQL/PostGIS, GeoServer, and a customized GeoExplorer map viewer, the framework delivers a web-based mapping tool that is flexible and Open Source. The flexibility of the framework is an important dimension of its scalability, allowing it

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to be customizable, modular, and portable so that it is easily configurable to support additional research and education initiatives. This approach reverses a trend toward application-specific web mapping development in Open Source GIS. To demonstrate flexibility, we configured an additional website for forest landowner management to be used by another state agency, the NC Forest Service.

1 Introduction

Public health organizations use technology and public education to safeguard lives, promote human health, and protect the environment from physical, chemical, and biological threats. Devastating food contamination instances such as the 2006 E. coli outbreak in the eastern United States and the 2010 E. coli outbreak in Europe underline the vitality of rapid information sharing for public health agencies that respond to public health dangers. Protecting public health necessitates rapid response to emergencies such as food contamination, floods, fires, chemical spills, earthquakes and illness related to environmental factors. In these events, timely web delivery of large geospatial databases is essential for disaster intervention and control (Croner 2003). It also is imperative that local, state, and federal partners collaborate to strategically plan initiatives, allocate resources, and evaluate emergency response activities. Unfortunately, many public health agencies' data repositories only contain physical addresses and they lack any direct means for geographic visualization or analysis. This article discusses the development of a web-based mapping framework and application for the Division of Public Health (DPH) within North Carolina's (NC) Department of Health and Human Services.

The assessment and control of environmental factors is essential for creating health-supportive environments and preventing disease. Decisions pertaining to potentially life-threatening emergencies such as foodborne illnesses and water contamination fall to U.S. public health agencies. These agencies play a vital role in food safety, as they are instrumental in developing standards, reviewing plans and monitoring enforcement of food-handling facilities and lodging establishments. The identification and quantification of patterns related to food- or water-borne illness can provide the first steps toward control of these illnesses. Spatial analysis also improves surveillance by providing opportunities to reveal undetected patterns by linking previously disparate datasets.

Geographic Information Systems (GIS) provide well-established tools for visualization and spatial analysis. GIS technology is increasingly being used by public health agencies at all levels of government and by the partners that support them, such as universities and consultants. Considering that an estimated 80–90% of all government databases contain georeferenced information (data can be tied to a specific location or place such as area code, latitude and longitude, street address, or political boundary), public health organizations are poised to capitalize on the benefits of GIS (Federal Geographic Data Committee 2002). There is a growing recognition at the highest levels of policy-making that the cost-effective development of, and access to, geospatial information systems is essential to the successful operation of the U.S. Government and the nation (Cahan 2000).

At the same time, emerging technologies are providing more effective ways for diverse user groups to have access to GIS. As the Internet continues to change our perception and use of geographic information, web-based mapping and geoprocessing services are becoming pervasive across many domains (Dragićević et al. 2011). There is a burgeoning demand for web-based mapping of public health data because geospatial factors are important for decision-making in this domain and web-based maps can deliver geospatial analysis to distributed and diverse groups of public health decision-makers (Dragićević et al. 2011). In fact, in the more general domain of public health, web-based GIS are already routinely being used to model and assess public health-related data (Cinnamon et al. 2009, Kamadjeu and Tolentino 2006, MacEachren et al. 2008, Maclachlan et al. 2007, Moreno-Sanchez et al. 2007, Tiwari and Rushton 2010).

The NC DPH collects and stores permitting, enforcement, inspection, and complaint data from all 86 local health departments within the state. Existing tools for accessing these data do not provide any geographic context. Incorporating geographic location and the ability to analyze data distributions into decision-making will greatly enhance emergency response capabilities. This article describes a web-based GIS framework conceived by the IT/GIS Branch of the NC Department of Environment and Natural Resources to support their data visualization and sharing objectives. Many health departments around the country have similar needs, but they also have severe budgetary issues; therefore, we wanted to create a reusable solution that other groups could deploy in their own departments with minimal startup time and cost. This goal informed the system design and software choices. Beyond public health needs, this reusable framework can be extended to accomplish a variety of web-based GIS objectives for various departments within a large organization. It is this flexibility of the framework that makes it both innovative and significant.

The remainder of this article is organized as follows. Section 2 discusses related work in more detail. Section 3 describes the system design and Section 4 presents the DPH website built on this framework. To demonstrate the flexibility of the framework, it is used in Section 5 to build a website for the NC Forest Service. Section 6 presents conclusions.

2 Background and Related Work

There is a growing need for access to geospatial information among public health professionals, policy makers, managers, researchers, students and the general public (Maclachlan et al. 2007). Beyond access, the ability to easily query, organize, combine, overlay, and plot health data also is needed. Because public health data are integral to surveillance, response, management, mitigation, and prevention of adverse human health events and conditions, timely delivery and analysis of geospatial health data, for routine and crisis circumstances, must be viewed as high public health and national priorities (Croner, 2003). Despite growing concern surrounding the cost of acute and chronic care, insufficient attention has been given to the role that public health data could have on strategies to reduce the burden of disease (Najafabadi and Pourhassan 2009). Recently, a number of applications have been developed to address various aspects of public health, including those related to disease surveillance (Robertson and Nelson 2010). Still, many government organizations lack spatially enabled decision support systems.

The need for GIS in public health is clearly illustrated by a public health emergency that occurred within the jurisdiction of NC DPH in June 2008 in the City of Greenville, NC. City officials detected the presence of fecal coliform bacteria contamination in the city water supply during routine sampling. Due to an inability to locate the precise locus of contamination, approximately 600 facilities supplied by the city's water service, such as restaurants, meat markets, child care centers, nursing homes, hospital facilities, and university food service facilities, were required to close. The logistics associated with responding to an event of this magnitude required timely notification via the broadcast media, by telephone, and by site visits. At that time, the regulatory system lacked a geospatial component and therefore, response activities were commensurately lacking in efficiency. A GIS enabled with spatial data layers such as the water supply system network, geocoded facility addresses, utility department service call records, reports of malfunctions, and contaminated water sampling results could have been employed for improved outcomes. A GIS implementation could have provided an efficient plan for deploying the most geographically appropriate response personnel using the most effective trip routing. If the precise locus of bacterial contamination had been identified, components of the city's water network could have been used to isolate and cease water service only to affected sections of the system. The remainder of the city's water customers would have remained unaffected by the Boil Water and Closure Orders. This would have greatly lessened the economic, social, and psychological effects of the contamination event.

GIS are powerful communication tools for public health. However, using GIS often requires considerable expert knowledge. Still, many government and private sector organizations are seeking ways to capitalize on the benefits of GIS to improve the health of the public, while contolling for cost. With these goals in mind, the Internet and use of georeferenced public health information is an important development for the nation's public health departments (Najafabadi and Pourhassan 2009). Web-based GIS has emerged as a solution for the problems of access and expertise in that a wider audience with varied computer and GIS knowledge can participate (Cromley 2003, Croner 2003). More specifically, web-based GIS provides opportunities to analyze complex geospatial data, solve problems, and present data in a graphical format that public health decision makers and the public can easily see and understand (Croner 2003). Web-based maps have become omnipresent in recent years, mirroring the advancement of desktop GIS and information technology in general (Cinnamon et al. 2009). The publication and distribution of spatial data are also becoming increasingly important activities enabling organizations to share maps as images over the Internet (Kamadjeu and Tolentino 2006). Global trends in Internet use, along with innovative technology for creating and sharing geographic information through pioneering and often collaborative applications have led to the rapid development of web-based mapping and geographic information (Haklay et al. 2008).

Implementing proprietary solutions may be a limiting factor in the adoption of a public health GIS in a resource-constrained environment (Kamadjeu and Tolentino 2006). Open Source software (OSS) solutions are desirable for health departments who in many cases lack resources for GIS hardware and software as well as other related GIS investments such as training or staff expertise (Richards et al. 1999). OSS components eliminate the need for project developers to pay initially for proprietary software, as well as the reccurring licensing fees associated with many of the products, and therefore they increase the potential for adoption and re-use by other agencies. Other benefits of employing OSS include multidirectional development and support, smooth learning curves which make them accessible to more novice developers, and the fact that they do not require high-end computers to perform at a satisfactory level (Moreno-Sanchez et al. 2007). The advancement of OSS allowed for the development of several web-based mapping applications in the public health domain, supporting the notion that there is growing interest in OSS solutions for public health problems. Using OpenGISconformant technology, Boulos and Honda (2006) give a step-by-step tutorial explaining how interested readers can publish their own health maps with Web Mapping Services (WMS) layer adding ability. Driedger et al. (2007) employed participatory design techniques to develop a web-based mapping tool to assist a non-profit (public) health sector organization in improving child developmental health. Kamadjeu and Tolentino (2006) is another example where the authors demonstrated the potential for free and OSS; in their instance, for the dissemination of immunization information to a broad internet audience through interactive maps.

Other public health applications of OSS web-based GIS include cross-border health issues, cancer and injury atlases and disease burden modeling. Moreno-Sanchez et al. (2007) designed a web-based multimedia GIS system for dengue fever monitoring across the U.S.–Mexico border, which uses raster images provided by distributed WMS. MacEachren et al. (2008) develop a web-based cancer atlas to support government cancer-control activities. Another atlas example by Rinner et al. (2011) discussed the data processing and cartographic requirements to integrate publicly accessible map services and protected data layers for a comprehensive look at injury rates and demographic risk factors. Tiwari and Rushton (2010) have developed an environmental health surveillance system that can visualize the spatial patterns of disease outcomes from individual-level data and automatically link environmental data, environmental models, and GIS tasks like geocoding for the purposes of estimating individual exposures to environmental contaminants. Each of these prototypes addresses a different aspect of public health and they all argue the merits of developing OSS interactive online geovisualization tools for public health.

These applications would not be possible without advances in geospatial interoperability, geospatial data transmission, and automated conflation of geospatial databases. Open Geospatial Consortium standards, such as WMS and Keyhole Markup Language (KML), can be used so that the system will have the interoperability required to consume and display mapping services and data from the widest possible variety of sources. OSS web-based GIS have reached a stage of maturity, sophistication, robustness and stability, and user friendliness rivaling that of commercial, proprietary GIS and web-based GIS server products (Boulos and Honda 2006). However, the selection of application implementation tools, such as map server software, can determine the data handling and analytical capabilities available to decision-makers (Rinner et al. 2011). The next section discusses the application choices made in developing this framework and the requirements driving those decisions.

3 Methodology and Design

3.1 System Requirements

Our web-based public health information system is designed to give local, state, and federal public health officials and partnering organizations distributed access to centralized well-maintained, current datasets. It will provide users with the tools for spatially informed planning, analysis, and emergency response. Working with public health specialists and through study of related work, we identified the following functional requirements:

- **Connect** to tabular and spatial database information;

- **View/visualize** public health data along with other geographic features to provide locational context;
- **Examine** public health data attribute values;
- **Communicate** public health data by creating customized views to store and share for collaboration and emergency response;
- **Explore** public health data for detecting points which have common attributes, such as selling a flagged product, or identifying points that are geographically proximate;
- **Spatial analysis** for determining geographic coordinates, returning views of specified regions, finding addresses, and generating routes; and
- **Manipulate** data by placing new public health data points on a geographic display or moving existing ones.

This list outlines a set of basic data access and analysis tools that address the current usage needs; however, future demands on this system are likely to necessitate additional functionality. A well designed system should be reusable and extensible. The following design decisions are added to support this goal:

- Functionality must be readily configurable. A system administrator can add or remove functionality as desired;
- Preferred use of OSS components. OSS not only relieves the agencies of recurring license fees, it also reveals the source code giving users the ability to modify and supplement the functionality; and
- Support for varied geographic data type display.

3.2 System Design

To meet the functionality requirements specified above, a reusable template or framework was created from which a specific GIS application was developed for pertinent public health data. The components of this system were desired to be OSS due to several issues related to using commercial software to deliver geographic data and provide geo-processing functionality. Anderson and Moreno-Sanchez (2003) highlight the expense and steep learning curve of commercial products. When choosing a back-end GIS application server, ArcGIS Server, arguably the most well-known commercial GIS Application Server, has licenses fees that range from $20k to $40k (depending on functionality level), which are out of reach for many agencies. Additionally, contacts within DPH speak to the fact that a map viewer itself should be a self-contained application, which is not dependent on compiled or proprietary software, to maximize the potential for reuse.

Mindful of the preference for OSS, a framework was created to store, manage, serve, and display data with an interface supportive of analysis. The core software components are a database management system, a web mapping server application, and data viewer/analysis system. For these we use PostgreSQL/PostGIS, GeoServer, and GeoExplorer. PostgreSQL extended with PostGIS provides a spatial database management system to support spatial public health data. Other databases such as Oracle and SQL Server can be loosely coupled with the system as well. GeoServer, a Java-based, community developed application, and Mapserver, a C-based application developed at the University of Minnesota, are two popular OSS web mapping servers. Both applications have strengths and weaknesses and are continuously evolving. Our framework uses GeoServer, which provides a web-based administration tool for easy configuration and integrates well with the Agency's other Java-based enterprise application framework, which also runs on the Tomcat servlet container. For visualization and user interface development, we used GeoExplorer, a basic data viewer, which focuses on the display and management of layers (either from a WMS or Web Feature Service), the ability to query and search across these layers, and the display of results. Figure 1 shows the system architecture of these core software components consisting of the database, application, and web presentation tiers.

To develop the map client viewer framework for the presentation tier, we built upon the existing code base provided by GeoExplorer. GeoExplorer is a map viewer application that comes packaged with the OpenGeoSuite Community Edition distribution. GeoExt, Ext, and OpenLayers functionality as well as print preview capability are bundled with the installation of GeoExplorer (Figure 2). GeoExplorer is a modern looking Ajax viewer based on OpenLayers and GeoExt that is not dependent upon proprietary software components that many other modern looking map viewers employ, such as Flash, Flex, or Silverlight. GeoExplorer is entirely Javascript-based. This is more desirable because most government agencies have some in-house Javascript programmers who will be able to maintain and extend the map viewer. Because GeoExplorer is based on OpenLayers, a great many tools have already been developed and are readily available for re-use in the OpenLayers Sandbox (http://dev.openlayers.org/sandbox/). A growing number of other map viewer applications also use OpenLayers (MapFish, GeoMoose, etc.) and tools developed for them can often be re-purposed, as needed.

Tool functionality not included with the preconfigured GeoExplorer external libraries can be added into the code base (Figure 2). For example, the desire for a tool which could select features within a given distance of a certain point required the addtion of the Mapstraction Library. Other desired functionality such as geocoding, routing (including multiple stops) and Google Earth view was implemented by inserting and calling additional JavaScript libraries. Additional components added within the GeoExplorer code base include the homepage which calls the appropriate libraries, configuration files to allow for different application functionality and appearance, and files which specify

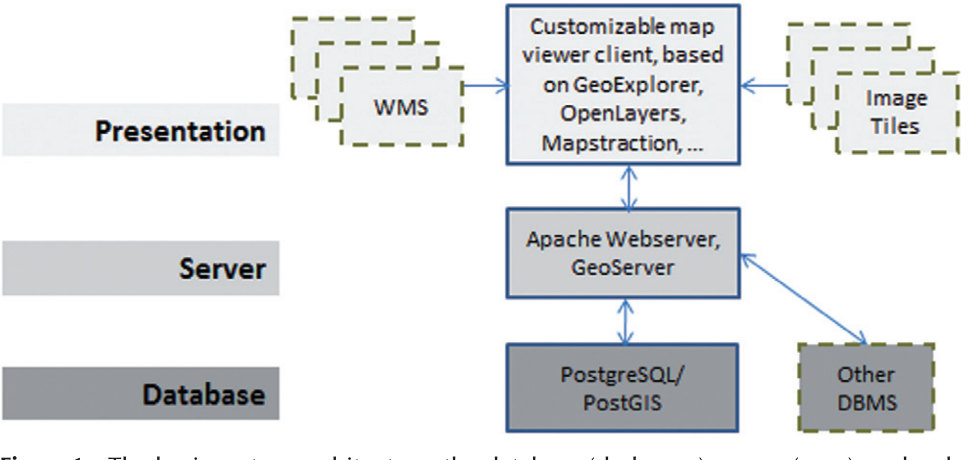

Figure 1 The basic system architecture: the database (dark grey), server (grey), and web presentation (light grey) tiers, composed of core system components (solid lines) and external resources (dashed lines)

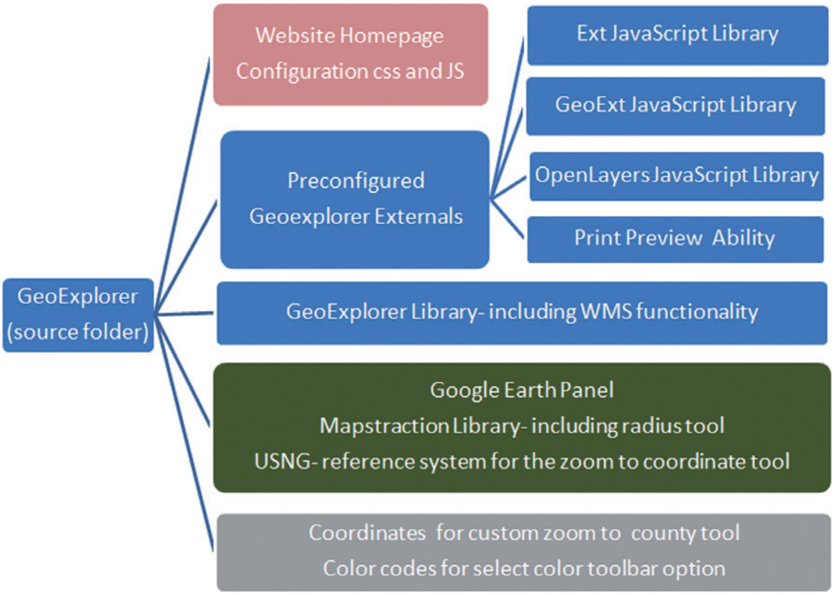

Figure 2 The map client viewer framework components for the presentation tier: GeoExplorer code base (blue), additional functionality called from files or libraries (green), files specific to configuration instance (grey), and the home page and configuration files (pink)

tool-related options such as the centroids for each of the 100 counties needed for a zoom to county tool or color options for highlighting features upon selection.

The configuration files are of particular importance to the modularity and portability of the framework. When the need for a new web mapping instance arises or an existing web mapping application needs to be augmented, the maintainers of the web-mapping framework can address these desires by recreating or editing these files. This functionality allows for the framework to be used in multiple differently "branded" instances of map viewers which can be run on the same server at the same time. Specifically, the self-contained JavaScript configuration file controls what analysis and visualization tools will appear along the top of the map, what data sources will be used to populate the base maps and overlay data, and the display and security provisions employed to protect specific information from being viewed and edited. The desired tools can be chosen from an established list of tools. The ability to customize the "visual branding" on each instance of the client viewer by specifying different colors, graphics, text, overview map, tool choices and toolbar location is controlled by the cascading style sheet (css) configuration file. Editing either configuration file can be accomplished in a standard text editor with no additional code development necessary. If additional tools are required for specific analysis needs, they can be added to the source code bundle and incorporated into the JavaScript configuration file by the developer.

4 Prototype Development and Use

To demonstrate the capabilities of our web-mapping framework, we created the Best Environmental Health Technology System Map (BETSMap) for NC's DPH. Within

DPH the Food Protection Program (FPP) has many responsibilities related to North Carolina's retail food protection and other sanitation programs. First, it enforces the state's food safety statutes for a diverse collection of facilities, including restaurants, food stands, mobile food units, push carts, public and private school cafeterias, hospitals, nursing homes, and child care centers. Second, it works with local public health department specialists who inspect retail food and respond in emergencies. Third, it assists local programs with preparedness as well as response and recovery actions when food-related emergencies occur. Finally, in addition to the local health departments, FPP collaborates closely with other state agencies and federal partners, such as the U.S. Food and Drug Administration, to coordinate response and recovery at all levels of government.

To comply with these responsibilities, FPP maintains a data repository of current and historical information related to facilities and establishments under their jurisdiction. Public health specialists enter inspection scores, violations, and complaint reports for food and lodging facilities, institutions, centers, swimming pools, and tattoo artists in this database. Complaints include illness, adulterated food, improper hygiene, contamination of food or surfaces, undercooked food, unsanitary conditions, water quality, wastewater handling, facility fires, and illegal operation. Originally designed as a tabular data repository, with facility mailing addresses serving as the only location components, our framework addresses the need for improved trend analysis, more rapid threat identification, and geographically focused emergency response capabilities, a need which has become increasingly evident in light of recent serious food-related emergencies affecting both the nation and North Carolina.

Built with an OSS framework, BETSMap is designed to allow users to track and visualize this database of FPP-regulated facilities with the associated inspections and complaints. BETSMap is designed for use by DPH and their local, state, and federal partners to provide users with the tools for spatially informed planning, analysis and emergency response. Additionally, BETSMap can be used to verify database facility location information. To create the spatial database, tabular data had been geocoded; this data may have had incomplete or incorrect addresses which could lead to errors in the geocoded locations. The BETSMap application allows users to move and save data points as needed to correct these errors when identified.

To demonstrate additional BETSMap functionality, we describe two usage scenarios:

Scenario 1: The Shearon Harris Nuclear Generating Station is a nuclear power plant located 22 miles southwest of Raleigh, NC. If the plant were to be damaged somehow, radiation and radioactive particles could be released. Exposing food to radiation does not always make it harmful to human health; however, food products that contain radioactive nuclei can be toxic and/or carcinogenic. While persons occupying food serving facilities will be evacuated by first responders, food at those facilities could have prolonged exposure. To identify potentially affected food for assessment and/or disposal, BETSMap allows users to find all facilities within a given radius of the plant. Figure 3 shows the mapped and tabular findings for this scenario.

Scenario 2: A wide variety of canned goods are recalled nationally for the potential of Clostridium Botulinum contamination. Suppose, for example, there is a recall on all products packaged in #10 cans, the large cans typically found in institutions such as hospitals kitchens, nursing home kitchens, and school cafeterias. These products must be removed immediately from service to prevent severe illnesses from occurring. Thus, specific facilities must be identified, based upon type (e.g. hospital kitchen, school

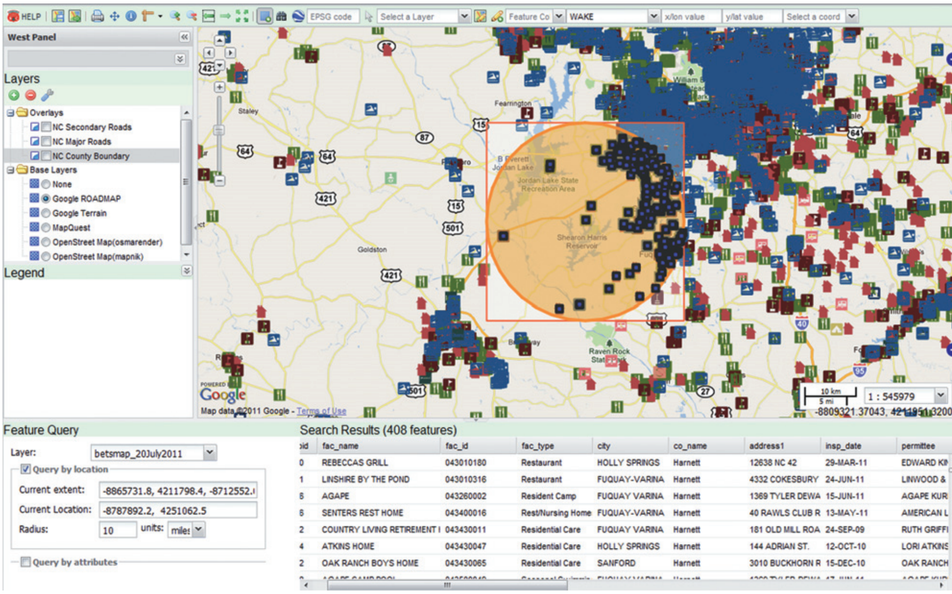

Figure 3 Identifying facilities (highlighted in blue and listed in the search results table) within a 10 mile radius of the Shearon Harris Nuclear Generating Station

cafeteria, etc.) and visited as soon as possible by FPP personnel. Facilities potentially offering this product can be spatially identified using BETSMap by querying facility type, establishment name, category type, county, city, etc. Additionally, local officials can use BETSMap to identify routes for efficient and timely enforcement of recalls and Google Earth to get a ground view of each facility, as shown in Figure 4.

The developed toolset provides the basic functionality desired by FPP. Existing tools can be extended to provide enhanced analysis, for example, a polygon select tool could extend the radius query for more customized boundary selection and the routing tool could implement Dijkstra's shortest path algorithm for more sophisticated routing. The framework is designed to accommodate modifications to the toolset. The next section demonstrates this functionality.

5 Customizable Framework

Designing an application framework which is customizable, modular, and portable and which can easily be configured to support a diverse range of functionality is both practical and economical, particularly for wide distribution within a large organization. One motivation for building a flexible framework is to be able to reuse the framework for different applications in research and education initiatives beyond the environmental health domain. To test the framework's customizability, we configured an additional application. This web-based mapping tool, called ForestMap, is designed for use by the NC Forest Service, a division of the NC Department of Agriculture and Consumer Services, as part of the NC Forest Service Forest Management E-Plan.

NC has over 700,000 non-industrial forest, private landowners, many of whom are in need of forest management advice and services. The NC Division of Forest Resources,

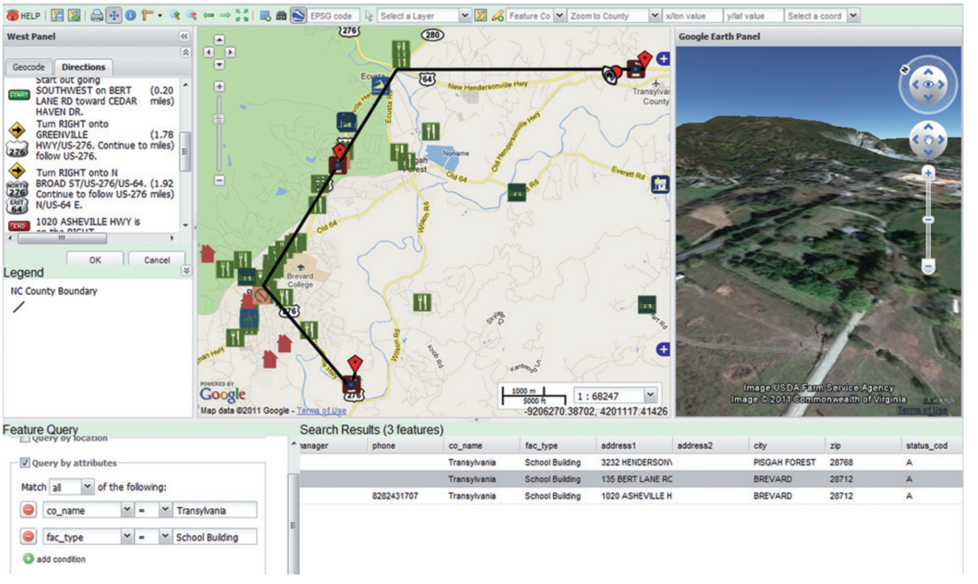

Figure 4 Finding school facilities that could potentially serve cafeteria food prepared with recalled products: in the Feature Query panel, a compound query, finds all school buildings in Transylvania County, NC; the Directions tool finds the route for visiting the facilities, using MapQuest functionality; and a 3D tool displays the scenery near the facility, using Google Earth functionality

NC Wildlife Resources Commission, NC Division of Soil and Water, NCSU Forestry Extension, and other agencies, as well as private consulting foresters and others natural resources professionals are not able to service this great need effectively. Most landowners live in cities and towns and are unable to coordinate meeting with a forester or natural resource professional. Some North Carolina landowners live in other states and rarely visit their property. The NC Forest Service Forest Management E-Plan website is a way to reach these landowners and provide them with relevant forestry information to help them make informed decisions about their land management.

On the website, landowners can develop a forest management plan by specifying information about their property, such as the stand types (yellow pine, white pine, upland oak, etc.) and age (seedling, sapling, timber, etc.), management objectives (financial/income, wildlife and fisheries habitat improvement, forest protection, etc.), and so forth. Based on this input, the site provides information about management practices for achieving the landowner's objectives and generates a Forest Management E-Plan, which can be the basis for remote consultation with foresters or other natural resource professionals. ForestMap provides a tool for mapping the owner's forest stands, so that the map can be included in the management plan.

ForestMap allows landowners to identify the forested areas they wish to inventory or manage by drawing and editing polygon features to represent forest stands (Figure 5). After management areas are digitized, the application captures a high-quality map for their management plan. The management areas are saved in a spatial database (as vector polygons) for later recall by the landowner and can be redisplayed and edited on return visits to the site, in case corrections or modifications are needed.

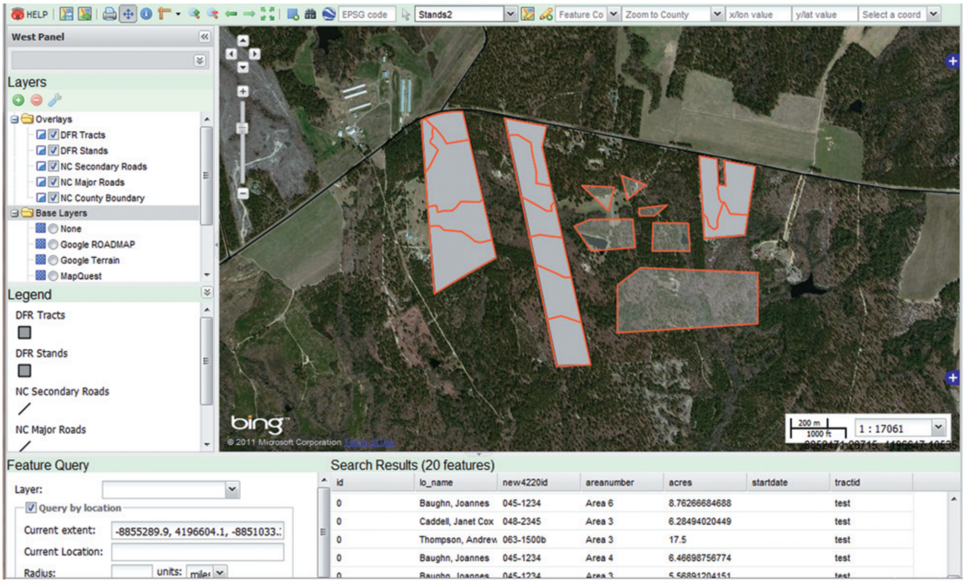

Figure 5 ForestMap: A private landowner can identify the forest stands she manages by drawing polygons

Professional forest managers within the forest service can also access the information if landowner assistance is required at a later time and forest managers can view the managed stands to gauge the effectiveness of the E-Plan at reaching landowners across the state.

The requirements for forestry that differ from those of DPH include:

1. Addressing a non-expert (typically less computer-savvy) user base, which requires "hiding" unnecessary tools to avoid confusion. (No location, routing, query, or 3D tools).
2. Offering measurement options including feet, chains, and acres (conventional units of measurement in forestry).
3. Displaying tracks and management areas/stands (not FPP facilities).
4. Drawing polygons to represent forest management areas/stands and saving these features to PostgreSQL.
5. Editing forest management area/stand polygons.
6. For a given user, only displaying that user's forest management areas/stands.
7. Capturing an image of the mapped stands to be included in the forest management plan when editing is complete.

These requirements were met by either making small modifications to a configuration file, by adding code to the file responsible for defining tools, or by adding applications to the flexible architecture. To address the first requirement, we were able simply to remove undesired tools from the tool list in a configuration file. For the second requirement, we modified the existing measurement tool to include the desired measurement units. For the third requirement, we simply changed the list of overlay layers in the configuration file. The next three requirements are closely related. Users need to be able to draw forest management areas on the map and return to view and modify only those stands they generated. This problem is essentially the same as the facility editing functionality implemented for the BETSMap application, but for this application, it involves editing polygons instead of points. Modifying the list of editable layers in the configuration file fulfilled requirements four and five. When the geometry of the editable layer is polygonal, the editing tool allows the user to add polygons to that layer. The sixth requirement is handled just as point location is handled for the BETSMap application. For the seventh requirement, QGIS was added to the system. Landowners can save the map using the MapFish print functionality of the core framework, but adding QGIS and Common Gateway Interface (CGI) scripts allows the application to automatically generate and store the landowner map. When the user completes the map, a CGI script is triggered to render and capture the scene in QGIS on the website server.

The system architecture customized to accommodate the ForestMap requirements as well as the BETSMap requirements (Figure 6), has few differences from the basic framework architecture of Figure 1. Figure 6 shows the specific web mapping services (WMS) and image tiles being used by the application tier. The addition of QGIS called by CGI scripts in the server tier was discussed above. In the database tier, other databases are included in addition to the PostgreSQL/PostGIS core component. BETS data is housed in an Oracle Locator database, served by GeoServer. The Forestry Stewardship data belongs to a SQL Server database which communicates landowner identification to the ForestMap through the Forest Management E-Plan site. An instance of PostgreSQL that has both Esri's ArcSDE spatial middleware and the PostGIS spatial extension is used so that a single spatial database repository can accommodate both Open Source GIS and Esri GIS applications. Even though no Esri applications were included in this project, this illustrates that PostGIS and ArcSDE can be used for the same spatial database, thus avoiding duplication of the spatial data layers to support two different application approaches. This makes the system more flexible for other state and county departments who may be using ArcGIS on the

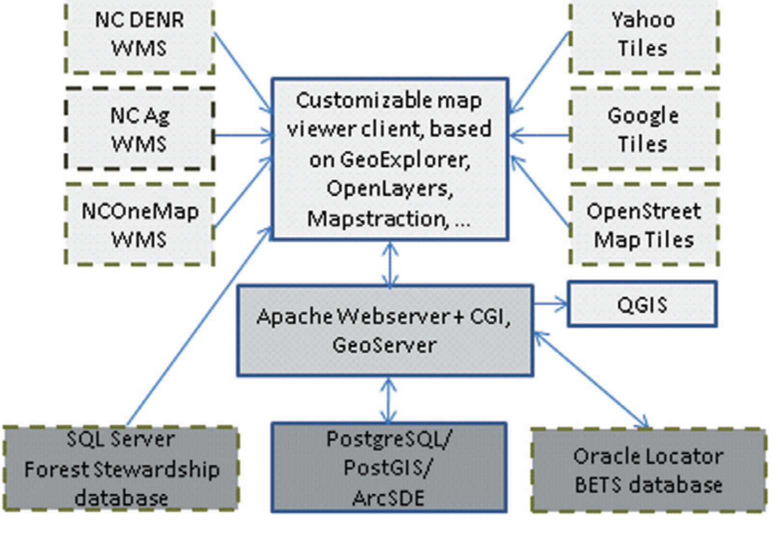

Figure 6 The system architecture configured for both BETSMap and ForestMap

desktop to maintain data. Replacing Esri applications and substituting GIS OSS may not always be the most cost effective approach for these agencies. By using a "hybrid" spatial database, agencies can maximize established investments in desktop GIS licenses and staff training without having to purchase additional ArcGIS Server software to have web mapping capability.

Customizing the framework for both the BETSMap and the ForestMap sites demonstrates the flexibility of this economical, reusable template for creating web mapping applications. Preliminary feedback is positive; project managers from the Natural Heritage, Waste Management, Parks and Recreation, and Water Quality programs of North Carolina have expressed interest in adopting the framework for their own web mapping needs. Additional configurations of this framework are being used in academic research endeavors at North Carolina State University, including research in tourism trend evaluation and park location decision-making.

6 Conclusions

The utility of web mapping applications in the public health arena is clear. Geospatial analysis is an important aspect of public health decision-making, a process which is often a collaborative effort across multiple agencies. Web-based mapping provides a means for distributing data, visualizing it, and facilitating analysis tools.

In this research, an OSS web-based framework has been configured and implemented by two different divisions within NC's State Government for two distinct objectives. One web mapping application handles the vital needs for contamination tracking and emergency response scenarios, with query and analysis tools to support these tasks for the Division of Public Health within NC's Department of Health and Human Services. The other web mapping application for the NC Forest Service within NC's Department of Agriculture and Consumer Services allows landowners to identify the forested areas they wish to inventory or manage by drawing and editing polygon features. These two examples of framework deployment demonstrate how diverse objectives can be accomplished with minimal administrative effort, allowing for future web mapping needs to be addressed with minimal startup time and expense. Therefore, organizations with very specific web mapping application needs and budgetary restraints can employ a system that can be easily installed and maintained, and which requires little or no training to operate.

This flexible framework will support future development of web mapping instances as they arise, allowing for tailoring of each new application for specific audiences and analysis objectives. Other NC government divisions including Natural Heritage, Waste Management, Parks and Recreation, and Water Quality have programs which have identified similar needs for web mapping functionality and have expressed interest in adapting this framework. The idea of a framework to support diverse web mapping objectives is far from novel; the team at OpenGeo has pioneered this effort by creating a powerful web mapping software suite that is in itself a flexible framework ("OpenGeo Suite" 2011). Still, despite the ubiquitous nature of web mapping applications, most of those described in the literature are designed for a singular purpose. This effort reverses that trend by deploying a framework that is easily moved and customized to meet specific mapping objectives that serve selected audiences. That is, if an objective cannot be met from the pool of current tool options, additional tools can be developed at the administrators' expense. Additional extensions of the framework will be used in multiple university GIS research initiatives as well as in student education, where the rapid growth of web-based mapping requires increased attention. We view this framework not only as a dynamic application that will grow with user contributions, but also as an effective option to serve the web mapping needs of large and small, private and public organizations.

Note

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