TOXMAP:
A GIS Information Portal to Environmental Health Databases

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Abstract

The National Library of Medicine (NLM) has an extensive collection of environmental health information, including bibliographic and factual data on hazardous chemical substances in its TOXNET databases. TOXNET also provides access to the EPA Toxic Release Inventory (TRI) data, which covers air, water, and land releases, as reported by industrial facilities around the United States. Built using ArcIMS, NLM has developed a web-based system, TOXMAP, in which users can dynamically create maps that show where TRI chemicals are released and directly link to the appropriate chemical data records in TOXNET. By extracting the associated regional geographic terms from the displayed map (e.g., rivers, towns, county, state), TOXMAP (http://toxmap.nlm.nih.gov/) also provides customized chemical and/or region-specific searches to NLM's bibliographic bio-medical databases resources. This paper will focus on the design concepts, implementation strategy, challenges, and feedback from users. It will also address issues associated with data accuracy, the risk of data misinterpretation, and future directions.

Background

The National Library of Medicine (NLM)[1] is part of the National Institutes of Health (NIH), which is one of the organizations within the Department of Health & Human Services[2]. NLM is the world's largest medical library and is a leader in the selection, acquisition, organization, and provision of medically related literature and data. Within NLM, the Specialized Information Services Division (SIS) is responsible for a collection of databases and related information on environmental health. In the 1960s there was a growing recognition of the harmful effects of certain chemicals in food, water, and the environment. In 1960, following a NIH study regarding the effects of environmental chemical contaminants, the President's Science Advisory Committee recommended formation of a computer-based file of toxicological information[3]. Responsibility for implementation was assigned to the National Library of Medicine, resulting in formation of the Toxicology Information Program, now called the Toxicology and Environmental Health Information Program (TEHIP)[4], at NLM. Over the years, the TEHIP program has evolved from a handful of databases oriented for use by researchers to a broad array of products and services serving researchers, industry, students, and the general public.

As a part of TEHIP, and prior to the popularity of the Internet, NLM collaborated with the Environment Protection Agency (EPA) in making their Toxic Release Inventory (TRI) database accessible to on-line computer subscribers for a fee. TRI contains information on the annual estimated releases of toxic chemicals to the environment. Mandated by the Superfund legislation, TRI's data covers air, water, land, and underground injection releases, as well as transfers to waste sites, and waste treatment methods and efficiency, as reported by industrial facilities around the United States.

With the advent of the Internet, EPA and others were able to publish TRI directly to the web. EPA offers comprehensive information about its TRI program on their web site, and a report[5] released in May 2003 discusses the different ways in which the TRI data are being used by citizens, government, business and academia.[6] As a service to the NLM users, TEHIP has continued to provide the TRI data (from 1987 to present) to its community through an easy-to-use multi-database web application, TOXNET. Recently, NLM has introduced a GIS-based application to integrate information on TRI sites with relevant bibliographic and factual data on hazardous chemicals via "TOXMAP"[7].

TOXMAP: Introduction

With a strategic goal to "facilitate and encourage use of high-quality information,"[8] NLM has an interest in exploring new ways to facilitate more effective understanding of its database contents, including investigation of new data presentation techniques and integration of data from different health data sources. TOXNET is an extensive collection of toxicology and environmental health research bibliographic information, as well as a rich resource of factual data on hazardous chemical substances. Within TOXNET, TRI is the only database in which each record has discrete geospatial data fields (e.g., latitude/longitude, street address, city/state, zip code), and thus is a viable candidate for applying GIS technology (i.e. to visualize the facility sites on a map).

To examine this approach, SIS developed a GIS system called TOXMAP. This application uses maps of the United States to show TRI[9] locations where companies are releasing specific chemicals. TOXMAP integrates the map display with access to other relevant bibliographic and factual data on hazardous chemicals of interest, thus providing a GIS-based portal to these resources.

TOXMAP Objectives:

- Show the distribution of releases by chemical and not solely by the locations of release
- Show how chemical releases have changed over time
- Use chemical and geographic terms from the displayed map to search bibliographic files
- Link to chemical information in TOXNET's Hazardous Substances Databank (HSDB)[10] and other authoritative resources
- Integrate geographically coded data from other sources
- Provide general information about GIS, data quality, and map interpretation
- Make easy to navigate and understandable to those unfamiliar with GIS

Development

The TOXMAP development process applied a “build a little, test a little” iterative approach. An advantage of using an iterative lifecycle model is its focus on involving users more intimately throughout the development cycle. As developers deliver functional subsets of the overall system, end users help to validate the requirements and refine the user interface.

To avoid duplicating an existing GIS application and to learn about other technologies, a first step was to review the significant features and capabilities of current web-based environment health GIS applications such as US Environmental Protection Agency’s (EPA) ”EPA’s “Window To My Environment”[11] and the U.S. Geological Survey’s (USGS) NationalAtlas.gov[12]. Three key findings were determined from this review. First, only the user knows what unique combinations of data they want to compare, and so the ability for the user to be able to ‘mix and match’ data layers is desirable. Second, current applications map toxicology and environmental health data, but do not identify studies that may correlate to them, nor do they link to related information about the

particular chemicals released from a TRI site. Finally, while several of the sites do map the locations of TRI facilities, they do not provide a map that shows distribution of specified chemical releases and how they have changed over time.

With this in mind, in 2002 a proof-of-concept prototype was mocked up and demonstrated to candidate users, who endorsed the concept. The prototype was used to gather and refine requirements. Over a two-year development cycle, evolving versions of TOXMAP have been subjected to informal usability testing combined with more structured focus group feedback sessions. For example, two informal focus groups with selected members of the environmental health community were held via teleconference to discuss the beta release (October, 2003). To familiarize themselves with TOXMAP's current capabilities and with some possible future features, participants were asked to complete some brief, web-based tasks prior to the teleconference. User feedback has resulted in significant improvements in the user interface and the product's functionality, as well as NLM's knowledge of GIS technology. A key lesson learned from this process was that the chemical-centric approach to display of the TRI data is a unique capability, and building on this feature would provide the most value to the user community.

Another lesson learned was that users may not be experienced in reading maps or understanding map data. To address this, TOXMAP currently uses a well-known approach to help address some of these issues - Frequently Asked Questions (FAQ). Like most FAQ, those in TOXMAP seek to provide a centralized source of authoritative information. The FAQ provide questions/answers to supplement the user's ability to understand the map displays and data. They also attempt to provide information about topics many users would not necessarily know to ask about. The initial release of TOXMAP includes questions from "What is GIS?" and "What is TOXMAP?" to "How accurate is TRI Data?" and "What are some tips for reading maps critically?"

User Scenarios

As mentioned earlier, TOXMAP allows users to create nationwide or local area maps that show where chemicals are released into the air, water, and ground, and also provides region-specific links to chemical and bibliographic information. While any number of user scenarios can be supported by TOXMAP, a few examples help to illustrate the resource's capabilities.

Scenario 1: Facilities

A family is preparing to move to a new city (Los Angeles, CA). The parents want to learn more about the health of the environment in the area. They create a map of all TRI facilities in the area. When they choose several of the facilities in the area, they are presented with information about each toxins released by that facility. For a consumer-oriented information resource, they click to "learn more" about the chemicals in ATSDR's ToxFAQs; for "professional strength" information about Health Effects of toxins, they select the link to HSDB.

19. **XERXES CORP.** — EPA Facility Number: 92807XRXSC1210N

1210 NORTH TUSTIN AVENUE, ANAHEIM, CA 92807

Emissions Estimates:
(lbs. for all years)

Chemical	lbs./all years
STYRENE	3,066,329
ACETONE	51,000
TOTAL	3,117,329

All chemicals reported by this facility

20. **POLY PAK AMERICA INC.** — EPA Facility Number: 90023PLYPK2935E

2935 E WASHINGTON BLVD, LOS ANGELES, CA 90023

Emissions Estimates:
(lbs. for all years)

Chemical	lbs./all years
1,1,1-TRICHLOROETHANE	2,995,808
N-BUTYL ALCOHOL	29,434
TOTAL	3,029,342

All chemicals reported by this facility

ATSDR

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Matching Categories	Summary
ToxFAQs and Public Health Statements	1 - 5 (8 Total)

ToxFAQs and Public Health Statements

(at first page) | Next Page

1: Public Health Statement: 1,1,1-Trichloroethane

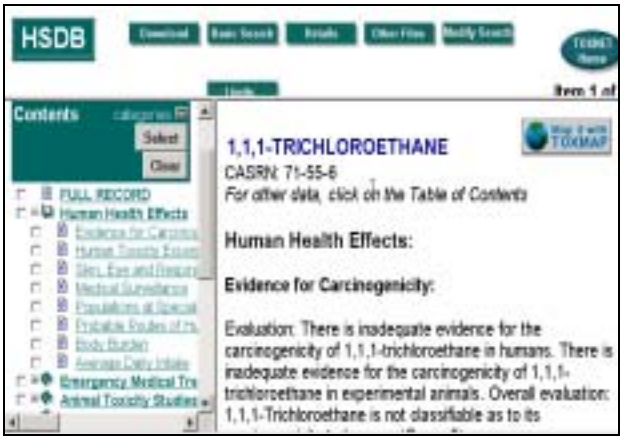
1,1,1-Trichloroethane is a synthetic chemical that does not occur naturally in the environment. It is also known as methylchloroform, methyltrichloromethane, trichloromethylmethane, and a-trichloromethane. Its registered trade names are chlorothene NU® and Aerothene TT®. It is a colorless liquid with a sweet, sharp odor. 1,1,1-Trichloroethane dissolves slightly in water. The liquid evaporates quickly and becomes a vapor in the air. Most people begin to smell 1,1,1-trichloroethane in the air when levels reach 120 to 180 parts of 1,1,1-trichloroethane per one million parts of air (ppm). If the chemical makes up 8 to 10.5% (80,000 to 105,000 ppm) of the air, 1,1,1-trichloroethane can burn easily when it comes in contact with a spark or flame. If the vapor burns at high temperatures such as those produced during welding operations, it can produce a poisonous gas known as phosgene. Because of its tendency to evaporate easily, the vapor form is most commonly found in the environment. 1,1,1-Trichloroethane also can be found in soil and water, particularly at hazardous waste sites.

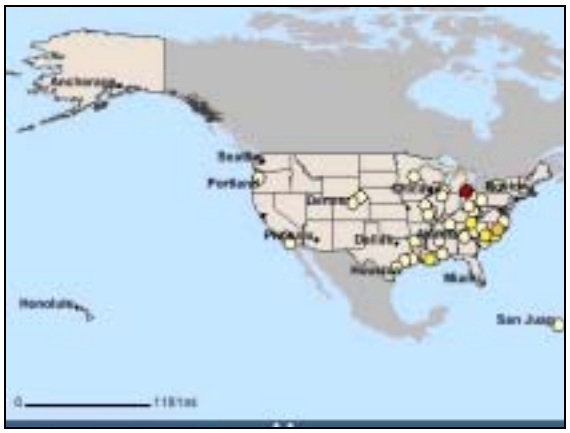
Score: 980, Size: 36822 bytes

2: Public Health Statement: 1,1,2-Trichloroethane

Scenario 2: Releases

A concerned citizen is reading about a particular chemical in HSDB (Dioxane) and wants to see where it was released throughout the United States. A map is generated showing all the facilities releasing Dioxane in the United States. She zooms in on an area showing a high concentration of the chemical (sites are color-coded by amount released.) Finally, she clicks a particular facility with high release concentration of Dioxane to learn more about that TRI facility.





4. EQ RESOURCE RECOVERY INC. **EPA Facility Number:** 48174MCHGN36345

36345 VAN BORN ROAD, ROMULUS, MI 48174

Emissions Estimates:
1,4-DIOXANE

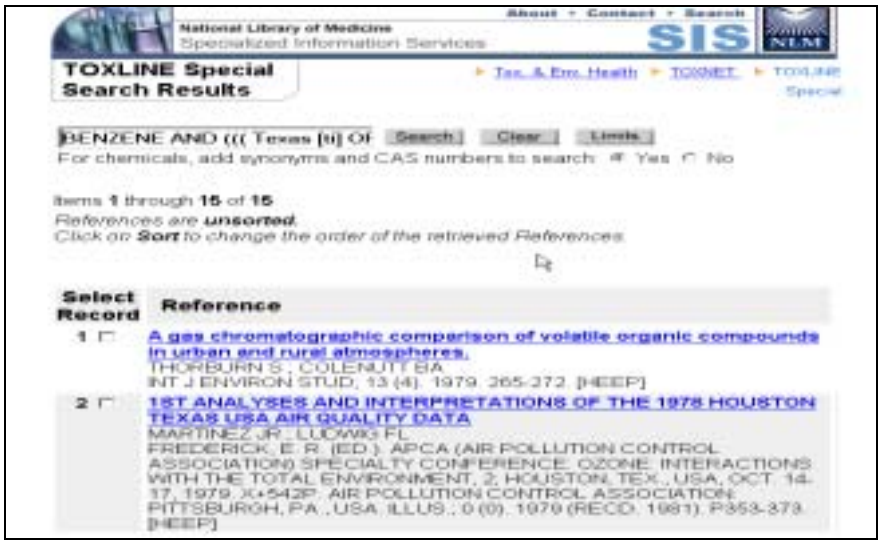
Environmental Medium	(lbs./rep yr. 2001)
Air	75
TOTAL	75

Details about this release

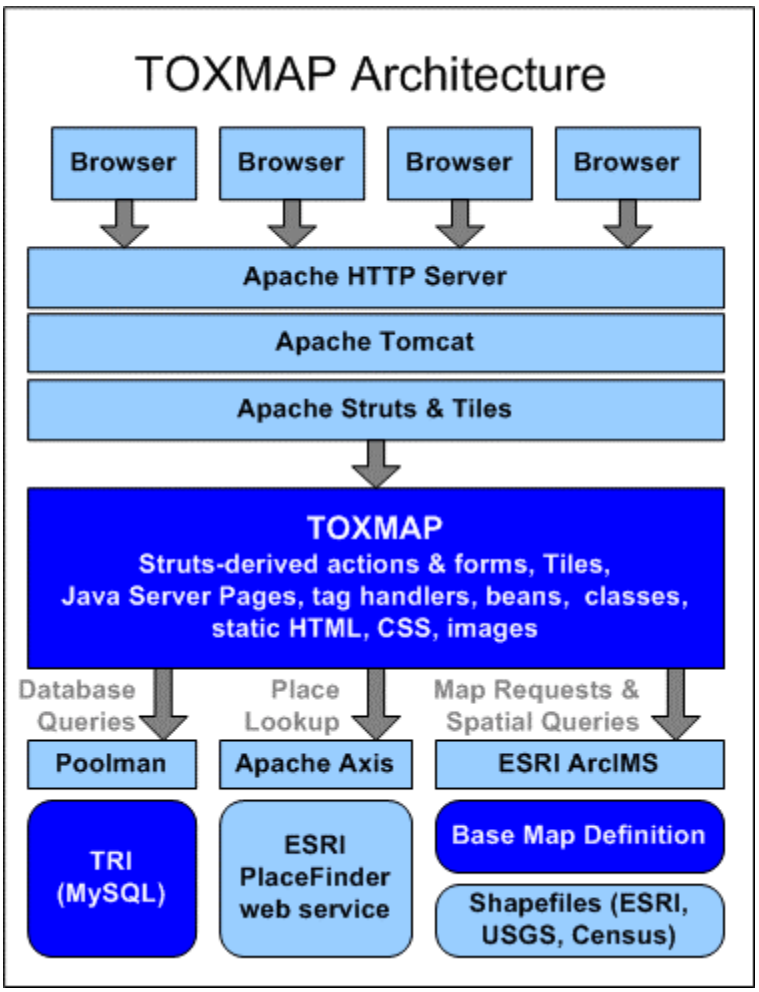
All chemicals reported by this facility

Scenario 3: Trends

A researcher is aware that a specific area of the United States (Houston, Texas) is known to contain high concentrations of a particular chemical (benzene). She uses TOXMAP to generate a map of that area which shows current released volumes of benzene, as reported in TRI. After studying the map, she asks to see how volume of releases has changed over time, and a new map is generated. Last, she is interested in seeing what research studies may have been published relating to benzene in the area displayed in the map. Results from a search of the bibliographic file, TOXLINE, are displayed.



TOXMAP Architecture: Overview



This diagram shows the architecture, or high-level design view, of TOXMAP. The lightly-shaded boxes are tools and services from third parties, such as Apache[13] and ESRI[14], and the darkly-shaded boxes are those built by NLM.

TOXMAP is designed and built with Java on top of ArcIMS[15], the Place Finder ArcWeb Service[16], and open source software tools from the Apache organization and MySQL[17]. The user only needs a standard web browser. The TOXMAP server is built to run on Windows, Linux, or Solaris operating systems.

Future architectural changes to TOXMAP will take greater advantage of functionality available in ArcIMS. NLM also plans to work closely with ESRI to overcome issues running ArcIMS on Linux servers. And in addition, NLM will continue to encourage ESRI to integrate its tools with those from the open source community (such as ArcSDE[18] and MySQL).

Implementation Details Scenario

As a means of describing implementation details, this section walks through a typical query and set of maps.

The user begins by visiting the TOXMAP site. Like all TOXMAP pages, the main page is a combination of static and dynamic content created from a set of templates (header, left navigation, body, etc). Static content such as fixed images and cascading style sheets are served by Apache HTTP Server. Dynamic content (i.e. generated by Java on the server) is served by Apache Tomcat[19], though this could be any container compatible with the Servlet 2.4 and JSP 2.0 specifications[20]. Templates ease the separation of content while retaining a frameless window for the user, and are implemented with Apache Tiles[21].

When the user types a chemical name and city, state, or zip in the “Quick Search” form, several things happen. As with all requests, the Quick Search is first handled by

Apache Struts[22] and a series of TOXMAP "actions" that carry out the request. Using the Struts framework simplifies the task of separating the logic necessary to execute queries, create maps, and so forth from the formatting code that presents the results to the user.

A configuration file directs Struts on the chain of Java "action" classes to use. In the Quick Search case, one action determines the kind of map to create, another conducts a database search, and so on. TOXMAP grabs a connection to MySQL from a pool managed by PoolMan[23], and uses the chemical criterion to search the TOXMAP database. Due to the volume of data (47,000 facilities with 1.2 million chemical releases), indexes are used to strategically speed searches. City state and zip search are conducted with ESRI's Place Finder ArcWeb web service. TOXMAP uses Apache Axis[24] to simplify the consumption of this service.

If multiple results are found, TOXMAP stores the chemical and place results as server-side collections, and the configuration file directs control to a tile that assembles a web page to ask the user to resolve the ambiguity. The tile uses a combination of HTML, JavaServer page scriptlets and expressions, tag files, tag handlers, images, and Cascading Style Sheets to format the result. TOXMAP also generates a small amount of Javascript to help the browser connect the various forms and controls together while retaining a clean presentation.

Once the user makes their final selection, a map can be created. The same Struts framework is used to manage this request. TOXMAP queries MySQL for the point data necessary to render the thematic layer of map (latitude, longitude, related attributes) and generates an acetate layer in AXL as part of a larger GET_IMAGE request. The request is sent to ArcIMS which generates the map image. ArcIMS overlays the acetate layer on TOXMAP's base map, which is built on a variety of shapefiles from the U.S. Geological Survey, ESRI's data CDs, the U.S. Census, and other sources. TOXMAP uses distinct layers, scale-dependent rendering, and generalized map layers to control map detail and improve runtime performance. A tile combines the generated map image with summary information, a legend, related links, application toolbars and map controls.

TOXMAP allows the user to identify data on the map by walking through features in increments of ten pages. MySQL's LIMIT feature handles paging requests and calculation of total map features, while custom tags format a summary list to the right of the map and the detailed list below (keeping the summary list "above the fold"). The detailed list features attributes arranged in tables with links to further information in the TOXNET site. Importantly, TOXMAP integrates page position, map envelope, and other data in HTML forms returned to the browser. This permits the user to navigate with the browser "back" button and zoom in, for example, without loss of context.

Some of the related links in TOXMAP use geographic terms (city names, river names, etc) as part of their search criteria. To accomplish this, TOXMAP submits a number of spatial queries to ArcIMS using bounding coordinates from the current map. Queries are executed on the most significant layers first (e.g. large cities), and then executed on subsequent layers until a system-configurable maximum is reached.

Content, such as TOXMAP's Frequently Asked Questions, are maintained in a simple web-based content management tool built with PHP and MySQL. Using the tool allows all team members, technical and non-technical alike, to contribute and review content without concern for formatting. TOXMAP routines pull content from MySQL at build time and integrate statically for fast access.

Other NLM systems serve as entry points into TOXMAP, allowing the user to create context-sensitive maps. As an example, while reading reference information on a suspected asthma-related chemical, the user could create a map showing locations in the U.S. that release that chemical into the environment. TOXMAP's Struts actions use interface decoration to designate actions as entry points to the application.

Data Accuracy

When a government organization disseminates information, a prime responsibility is to ensure a high quality data product. In the case of TOXMAP, all the data from the National Library of Medicine is authoritative, reviewed information (e.g., the HSDB chemical substance records are peer reviewed by a panel of science experts). The EPA is the collector of the TRI data. Facilities are required by law[25] to self report the amount of releases of the hazardous chemicals defined in the legislation, if the release amount is over a specified threshold. EPA readily addresses the question of data accuracy.[26] Their data entry process and validation process has built-in checks for data errors and procedures for facilities to revise their chemical reports if they discover errors. EPA regularly conducts a Three Percent Data Quality Review of TRI data, during which a random sample of input forms are compared to the database, and the results are reassuring – e.g., in the reporting year 1995, both data entry accuracy rate and release value accuracy rate were over 99%.

Regarding accuracy of the geospatial data in the TRI data, visually mapping the facility locations based on the reported latitude and longitude provided a 'quick view' assessment. When the TRI data was initially mapped in TOXMAP, some of the sites appeared to be located in the ocean, or to have other obvious errors. A closer examination was made of a random sampling of such sites, and in these cases the facility's latitude and/or longitude were found to be incorrect, causing us to question the precision of the TRI location values.

For a better understanding of coordinate accuracy, a simple assessment was conducted – a comparison of each facility's reported zip code with its latitude/longitude coordinates. Allowing for a reasonable margin of error (i.e., counting as 'suspect' only those facilities with latitude/longitude coordinates that fall outside a region defined by the first 3 numbers of the zip code), we found 0.89% (419 facilities of 47,080 TRI facilities) of the TRI records to be 'location suspects.' Prior to the ease of being able to map these facilities in a GIS application, it is unlikely that many TRI users would have picked up on this discrepancy by reading the text latitude/longitude in the TRI record.

The EPA is currently aware of the location discrepancies, and their new interactive data entry application (TRI-ME)[27] will identify this type of error in current and future data collections. However, cleaning up the historic TRI data is an onerous task. EPA plans to tackle this data clean-up over a period of time, and recommended that NLM use a

different, more location-accurate EPA source, the Facility Registry System (FRS)[28], for mapping the TRI facility sites. TOXMAP now checks the FRS latitude/longitude against the zip code; if a discrepancy outside a reasonable threshold is found, an "accuracy suspect" icon is displayed with the facility identification information. This alerts users to the discrepancy in location data, and provides a link to more information about data accuracy.

Data Interpretation

Maps are a powerful way of visualizing data. However, a key concern when presenting data in a geospatial view is the potential for misinterpretation. As Mark Monmonier points out in his book "How to Lie with Maps"[29], maps not only point the way and provide information, they can mislead. For example, in TOXMAP, the amount of a facility's total chemical release is visually depicted by a gradation in color of the circle depicting the facility location. As the level of release increases, the color changes from pale yellow to orange to red. This information reflects the facility's estimate for the total release of the chemical over the full reporting year. From the map data, the user would not know if all the release occurred in a short period of time (day, week or month) or was released in smaller quantities on a continual basis throughout the year.

The casual viewer of this map might also infer that an area showing a higher release of a chemical is an indicator of a heightened threat to human health or the environment. However, the level of a chemical's toxicity, how quickly it dissipates in the environment and other factors must be considered in any risk assessment. Hence, a smaller release of one chemical may be a more serious threat than a large release amount of another.

TOXMAP has the option to view how releases of a particular chemical have changed over time. The formula for determining the trend is to compare the total environmental release amount for the most recent year of TRI data to the average of all previous years. If lower, the trend is downward and a green-shaded 'down' arrow is mapped on the facility location. If higher, the trend is upward, and a red-shaded 'up' arrow is used. If the overall trend is downward but there's an increase in chemical release between any two years, this is mapped as a fluctuation.

While this technique gives a general indicator of an area's release history, it has the potential to be misleading. For example, trends in release data may reflect expansion of TRI's chemical and industry coverage or other modifications in reporting requirements over the course of the years, and not be a true indicator of the release amount increasing or decreasing. To reduce the potential for misunderstanding, the trending algorithm will be improved and EPA baseline years will be used in trend computations. TOXMAP also provides links to additional NLM resources/information, such as HSDB's "Environmental Fate and Exposure," and ATSDR's "ToxFAQs and Public Health Statements."[30]

Data Layer Complexity

Given quality data that has a geospatial identity, GIS empowers an application with the capability to integrate and overlay disparate data sets. This is a powerful technique for building hypotheses (i.e., is there a potential link between data?) and quickly visualizing

spatial relationships across different data sets. The concern arises when a viewer infers a relationship in data overlays incorrectly. In the environmental health area, relationships between disease, illness, and environment factors/triggers are extremely complex. For this reason, how much and what data to integrate in TOXMAP can be an issue.

For example, if cancer mortality death data is overlaid with TRI site facility locations, the results might show an interesting disease/chemical correlation, which would be useful for a scientist to consider in his/her cancer research. The concern comes from the possibility of the casual user inferring from the map that a certain cancer was being caused by a chemical released from a specific TRI facility. The amount of information to provide for data overlay within TOXMAP is still under consideration. Guidance and feedback will come from the biomedical research community, as well as from the public.

Visualization Design Challenge

As the number and types of data layers are increased, there is also an increase in the challenge of keeping the visualization readable and understandable. Factors such as a viewer's workstation platform, screen resolution, connectivity to the Internet, browser versions, and user's map/reading aptitude are all contributors to the complexity of visualization. In Edward Tufte's book "Visual Explanations"[31] he discusses the importance of an information design representing the integrity of the content displayed. Tufte suggests system designers ask the following questions:

- *Is the data revealing the truth?*
- *Is the representation accurate?*
- *Are the data carefully documented?*
- *Do the methods of display avoid spurious readings of the data?*
- *Are appropriate comparisons and context shown?*

As decisions are made about what data to include in TOXMAP and what display design/techniques to use, Tufte's questions will be applied.

Future Directions

Based on feedback from users of the TOXMAP beta release, several additional system features were suggested and are candidates for future releases, such as:

- Multiple chemicals displayed on a single map
- Maps showing releases of one or more types - air, water, land, and/or underground injection
- Tables and graphs of release data (bar charts & pie charts with percentages)
- Updated and expanded U.S. Census demographics (population, race, age, income)
- "Local view" feature to visualize a specific state or county.

To further enhance capability, users have suggested addition of many different types of data to overlay with the TRI release data. In addition to more demographic data, recommendations have been received to add health statistics, floodplain data, landfill

sites, water quality data, land use imagery, school and neighborhood sites. Users have also requested demographics data at a more granular level (e.g. Census tract). Added information that assists users in using and 'interpreting' maps is also being considered for future versions of TOXMAP.

Another possible extension for TOXMAP would be to include and map international chemical data about pollutant releases. The United State's TRI program is one of several similar programs established, or being established, by countries around the world. The term used internationally for these TRI-like systems is Pollutant Release and Transfer Register (PRTR), and the EPA web site offers information about the international efforts.[32] One of the challenges in displaying international data comes from the differences in the measurement and reporting standards, which might lead to misinterpretation, i.e., comparing ‘apples’ to ‘oranges.’ To help reduce this problem in North America, the governments of the U.S., Canada and Mexico are working together to improve the ability to compare data from their three PRTR systems.

Future architectural changes to TOXMAP will take greater advantage of functionality available in ArcIMS and related tools, as appropriate. Of greatest significance is the desire to run the server components on the Linux platform. The first release of ArcIMS 4.0 for Linux saw exponentially greater parse times for large acetate layers on similar Intel hardware when compared to Microsoft Windows. While ESRI has since discouraged use of large acetate layers, the TOXMAP team is curious whether plugging in a faster parser might solve the Linux issue. For the long term, the NLM is interested in seeing an integration of ArcSDE and an open source database, such as MySQL or PostgreSQL.

As TOXMAP grows to integrate more data from external sources, and share its resources with others, it will look to appropriate Open GIS Consortium web service standards. TOXMAP will also use improved ArcWeb services as they become available.

In addition, the TOXMAP team plans to use the ArcIMS Java Connector over the original AppServerLink solution.

Conclusion

The National Library of Medicine (NLM) has developed the GIS system, TOXMAP, to learn if a tool which integrates its environmental health information with mapping technology would be of interest and value to environmental health scientists, concerned citizens, businesses, educators, public health departments and others. TOXMAP provides a useful visual resource for quickly identifying where TRI facilities are located in the United States, combined with a chemical orientation focused on identifying which facilities are releasing specific chemicals. TOXMAP also provides the user with interactive links to more detailed information about the chemicals. With user feedback as a guide, future versions will introduce new ways of viewing the TRI data, integrate additional data sets, and add relevant links to other non-geospatial chemical and environmental health information.

Acknowledgements

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