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# An Investigation Into the Development of a Practical Gis Mapping tool Supporting Emissions Inventory Information

Elizabeth J. Davis-Noland  
*Regis University*

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## **Abstract**

Environmental Protection Agency (EPA) regulations call for States to submit for EPA review and approval State Implementation Plans (SIPs) which establish goals and emission reduction strategies for improving air quality in national parks and wilderness areas. State and tribe air quality analysts therefore need the ability to display and analyze emissions inventory data in relation to geographic locations. However, due to budget and other constraints, traditional Graphical Information Systems (GIS) tools are often not available. Today, traditional GIS are being challenged in various domains by a variety of free or low-cost internet accessible services. Leveraging the availability of the Google Maps web service and published API combined with the built-in spatial capabilities of Oracle Database, this paper presents the research, design, development, instantiation and evaluation of an easy-to-use and feature-rich yet economical GIS mapping tool for the presentation of emissions inventory data.

## **Acknowledgements**

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## **Chapter 1 - Introduction**

### **1.1 Statement of Problem**

The Environmental Protection Agency's (EPA) 1999 regional haze regulations calls for States to submit for EPA review and approval State Implementation Plans (SIPs) which establish goals and emission reduction strategies for improving air quality in national parks and wilderness areas. Because the pollutants that lead to regional haze can originate from sources located across broad geographic areas, EPA has encouraged States and Tribes to address visibility impairment from a regional perspective. These Regional Planning Organizations (RPOs) evaluate emissions inventory and other air quality data to better understand how their States and Tribes impact national park and wilderness areas within their regions and across the country. A primary goal of one RPO, the Western Regional Air Partnership (WRAP), is to provide access, visualization, analysis, and retrieval of technical data and analytical results prepared using a regional approach to support the air quality planning needs of the states and tribes within the region. Included in this goal is a "fully functional" internet GIS tool (Western Governors' Association, 2003). However, due to budget and other constraints, a traditional GIS tool has not been developed. In addition, a review of web sites maintained by other RPOs, and some of their constituent states, finds no such tools.

### **1.2 Statement of Goals and Objectives**

Today, traditional GIS is being challenged in various domains by a variety of free or low-cost internet accessible services and tools such as the Google Maps and Google

Earth application programming interfaces (APIs) and Shape2Earth, a tool for converting shape files to Keyhole Markup Language (KML). Given the need for web-enabled graphical information systems (GIS) that provide air quality analysts with the ability to display and analyze data that is related to a geographic location, how can a GIS mapping tool be developed which utilizes today's available technology? Combined with the built-in spatial capabilities of Oracle Database (including the free Oracle Express Edition), the goal of this project has been to design, develop, implement, and evaluate an easy-to-use and feature-rich yet economical GIS mapping tool for the presentation of emissions inventory data.

## Chapter 2 - Review of Literature and Research

For this project, a review of literature was undertaken to meet several objectives. First, the researcher needed to understand the basic characteristics of effective GIS mapping tools in general and specifically for displaying environmental data. Second, the research required an examination of Internet GIS including the web services available and the methods used to leverage these services. Next, the researcher reviewed existing web sites and articles discussing existing web sites to confirm that the implementation of effective GIS mapping tools using these services is indeed feasible. Then, it was necessary to confirm the shortage of such tools for displaying environmental data and, therefore, verify the problem statement. These aspects of the research are presented in sections 2.1 through 2.5. The research then led to investigating how to design and test a specific solution and is presented in sections 2.6 through 2.9.

### 2.1 Data Visualization

In the simplest of terms, *data visualization* is the process of graphically presenting data in a way that will provide meaningful information to someone. The earliest samples of graphically depicting data extend as far back as the 10<sup>th</sup> century (Friendly, 2008, p. 90). Given the volume and complexity of data in the world today, how to effectively present data to facilitate knowledge and support decision making is one of the primary goals of computer information systems. According to Chen, et al., “The importance of software for producing graphics is incontrovertible” (2008, p. 7). A large body of research literature exists regarding the challenges of designing these systems. Zhu asserts there is a lack of consistency in defining effective data visualization and how that

effectiveness is measured (2007). Some have faulted poor computer graphics for the bad decision that led to the Challenger space shuttle disaster (Freedman & Shah, 2002). Still, the benefits of data visualization are apparent as evidenced by the vast array of examples in all areas of our daily lives.

Various methods and techniques for designing data visualizations have been developed. Some designers take a data-centric view and assert that “the structure of a visualization should match the structure of the data” while others “take a task-centric view and believe that the effectiveness of visualization is task specific” (Y. Zhu, 2007). Taking the task-centric method a step further, Fry (2008) states that it is most important to know specifically what questions need to be answered by the visualization and that too often designers focus on the huge amounts of data that have been collected; “[R]ather than thinking about the data that was collected, think about how it will be used and work backward to what was collected”. As noted above, how data visualizations are used often involve interpretation and analysis by the reader and subsequent decision-making. Beyond simply presenting results, these types of data visualizations are termed “exploratory” (Chen, et al., 2008) and are best offered through user-interfaces that provide interactive capabilities (Friendly, 2008).

## **2.2 Data Visualization and GIS**

When decision-making involves management of the earth and its resources, geographic information systems (GIS) have become a primary tool for providing the relevant data visualizations by mapping the location-based data (Goodchild, 2008). Therefore, GIS based decision support systems (DSS) are extremely valuable to the

environmental sciences community. Air quality management decisions are especially based on spatial information (Where does pollution occur? What is the source of the pollution?). Lindley and Crabbe (2004) site several specific uses for GIS in air quality management including “assisting with the identification of pollution hotspots” , “illustration of changes in spatial patterns of pollution from policy or other interventions”, and “provide(s) tools for testing various emission scenarios and assessing their impact on air quality in a spatial as well as quantitative way”. Further, GIS is an important QA tool as functionality such as address mapping, or geocoding, can “highlight the spatial errors in the data” (Alexis, 2002).

A significant aspect of GIS is the ability to map various layers of information either individually or combined with other layers. Typically, GIS contain two types of underlying geographic data that compose layers; the primary data being the originally collected data and secondary data being external, previously compiled data (LeGates, 2005). In this project, the primary data are the point and area source annual emissions. Key secondary layers identified by the WRAP include boundaries (polygons) for various geographic areas such as county, state, tribal reservation, country, class I area and other federal lands and lines such as roads and railroads (Western Governors' Association, 2003). Additional layers could also prove useful to this project. For example, LeGates (2005) mentions the use of U.S. Census Bureau data in many projects regarding public policy.

As a DSS, interactive functionality of GIS maps is also important and includes “pan, zoom, query layer information, ability to add/remove multiple layers of data, point

and click, measure distances, buffer, print multiple sizes of maps, and select map features by line, rectangle, or polygon” (Western Governors' Association, 2003). Commercial GIS software packages, such as those developed by ESRI, are capable of providing these types of functionality and are often used in the development of air quality data sets such as emissions inventories and dispersion models (Elbir, 2004). There are multiple costs associated with these products for special hardware, licenses, specific database versions and licenses, training, and support. Exact costs depend on the specific requirements of the GIS application; however, the cost of just a single-use license for ArcView Desktop is \$1500. Many examples, such as “A Study of Air Quality Impacts on Upper Respiratory Tract Diseases” where a commercial GIS was developed to combine cancer death rate data with pollution data to study the association between the two data sets, state that funding was provided (in this case by the National Science Council of Tawain) but do not specify costs (Hsieh, Hwang, Cheng, & Wang, 2007).

### **2.3 Internet GIS**

Traditionally, GIS have been developed as client/server applications where the spatial database and end-user application exist on the same local area network (LAN) which “lets users instantaneously transfer large amounts of data between the spatial database and the visualization module” (Brabec & Samet, 2007). Typically these systems consist of “proprietary and all-encompassing GIS software programs and data models” (Moretz, 2008) and are obviously limited to local users or require remote access to a local computer. In contrast, Internet GIS relies on the Internet to allow users to share data and applications developed using “standards-based components with specialized functions



that can interface with other components and GIS service providers” (Moretz, 2008). The air quality planners of an RPO are widely dispersed. However, it is beneficial they have access over the internet to shared data sets and GIS tools that “provide a means for users to select data that is of importance to them and display the data in a fashion that is easily understood” (Western Governors' Association, 2003) .

## **2.4 Map Mashups**

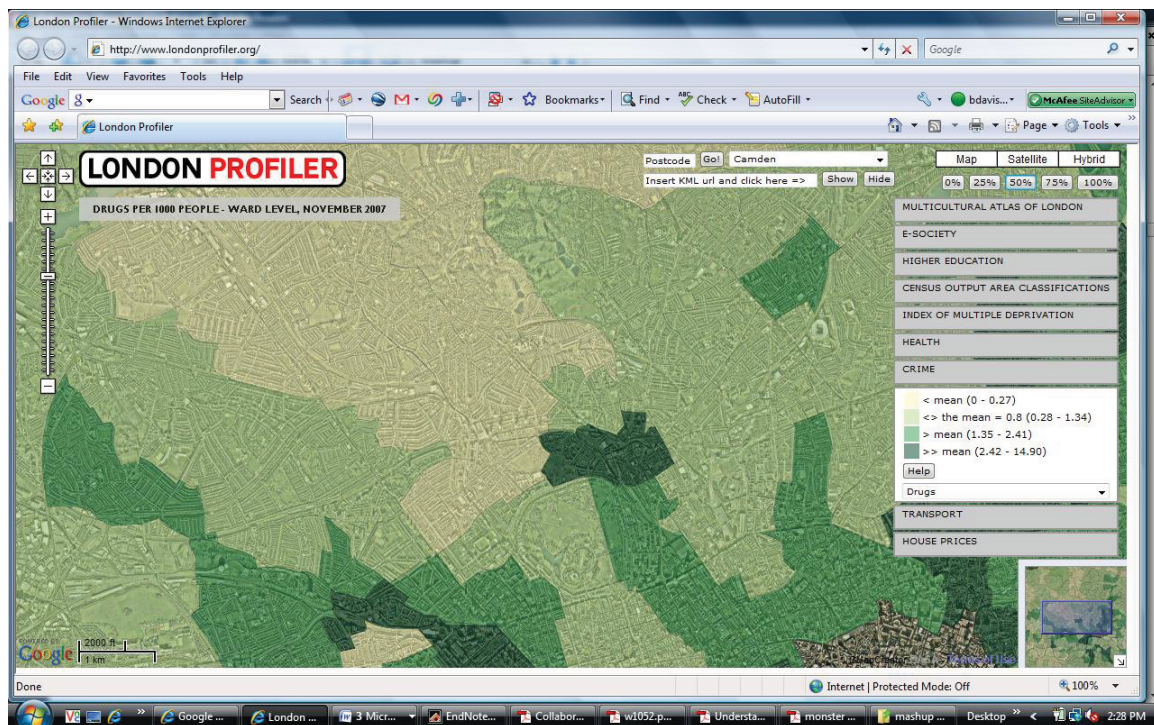
Although distributed, Internet GIS still relies on client/server architecture and the standard data, logic, and presentation tiers. Inherent challenges include how to “limit the data flow between the database (server) and the visualization unit (client) to get timely responses from the system” while maintaining a functionally rich interactive user-interface (Brabec & Samet, 2007). One solution is to develop a “mashup”, a web application “generated by combining content, presentation, or application functionality from disparate Web sources” (Yu, Benatallah, Casati, & Daniel, 2008). A map mashup uses a web mapping service, such as Google maps, to provide the base map data and interface functionality thereby distributing the data and logic tiers between servers and the logic tier between server and client (Moretz, 2008).

There are numerous examples of map mashups on the internet today, a few of which are listed in Table 1. One excellent example, The London Profiler, available at [www.londonprofiler.org](http://www.londonprofiler.org), combines the Google Maps application programming interface (API) with a tool called the GMap Creator which can “read and then project shapefiles onto a thematic map layer based on a field attribute from a table” as raster image tiles in different levels of transparency (Gibin, 2008). Figure 1 shows the London Profiler

focused on the Camden borough and displaying the number of drug-related crimes per 1000 people in November 2007 (Gibin, 2008).

**Table 1. Recent Internet Map Mashups (from Google Maps Mania, April 2, 2009).**

Name	Purpose	url
Pacific Institute Sea Level Map	Impacts of Sea Level Rise on the California	<a href="http://www.pacinst.org/reports/sea_level_rise/gmap.html">http://www.pacinst.org/reports/sea_level_rise/gmap.html</a>
World Volcano Browser	Locations and information on 1550 volcanos	<a href="http://www.geocodezip.com/v2_volcanoBrowser.asp">http://www.geocodezip.com/v2_volcanoBrowser.asp</a>
Nighttime Map	Night time satellite image showing the light pollution	<a href="http://www.cc.gatech.edu/~pesti/night/">http://www.cc.gatech.edu/~pesti/night/</a>



**Figure 1. The London Profiler Map Mashup.**

Mashups are also an attractive *economic* alternative to ESRI and other commercial products for presenting spatial data. The freely availability Google Maps API “has encouraged a very considerable number of users with intermediate and advanced programming knowledge to build their own applications, using Google Maps data as a visualization interface” (Gibin, 2008). In addition, the open source community is providing numerous developer tools that package the Google Maps API classes within common programming language controls, such as the Google Maps .NET control available from Reimers.dk (Reimers). The prevailing attitude in the development community is summed up by this paragraph from a Google Maps “how-to” book:

“You don’t need an expensive development kit to use Google Maps API. You don’t need a computer science degree, or even a lot of experience. You just need a feel for what’s important data and an idea of what you can do to present it in a visually persuasive way” (Purvis, 2006).

The phrase “visually persuasive” is not quite accurate for this application. Rather, the point is to provide a tool that is visually informative, one that allows the user to interact with the tool in order to see information from the available data in different ways, to “further explore data sets and to draw out specific information for complementary air quality management tasks” (Lindley & Crabbe, 2004).

Map mashups are not limited to using the Google Maps API. Alternatives include Yahoo!Maps, Microsoft Virtual Earth, and MapQuest. Geller (2007) provides a comparison and notes similarities in function, guidelines, registration requirements and that each API is implemented through JavaScript. In addition, the four can be compared

side-by-side at RockStarApps.com (Buffone, 2009). This researcher prefers Google Maps primarily due to the exceptional clarity of all types of maps and the intuitive and easy-to-use controls. In addition, the clear leader is Google Maps according to Programmable Web as shown in Figure 2 (Musser, 2009). Further, Google now offers a Google Earth plug-in and API that “let you embed Google Earth, a true 3D digital globe, into your web pages” (Google Earth, 2009).

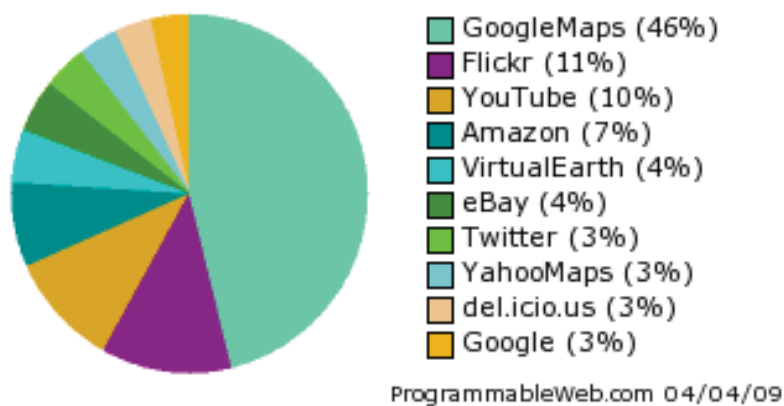


Figure 2. Programmable Web's Top 10 APIs of All Time.

## 2.5 Interactive Environmental Data Maps on the Internet

A search for interactive maps on the internet presenting environmental data was made and is summarized in Table 2. In addition, The Environmental Protection Agency (EPA) has provided a KML file containing a subset of data from the National Emissions Inventory (NEI). However, use of this file requires the user to download and install the Google Earth client application. The end result of this search indicates a surprising lack of interactive mapping tools capable of effectively displaying environmental data.

**Table 2. Interactive Environmental Data Maps (April, 2009).**

<b>Web Site Name</b>	<b>url</b>	<b>Comments</b>
Map of U.S. Toxic Air Emissions	<a href="http://www.dotgov.wa.gov/wsd/emap.php">http://www.dotgov.wa.gov/wsd/emap.php</a>	Can't access - link results in a fatal error.
Locus Technologies	<a href="http://www.locustec.com/ePortal.asp">http://www.locustec.com/ePortal.asp</a>	A Google Maps mashup. Customers must purchase access.
EnviroMapper – EPA	<a href="http://www.epa.gov/enviro/wme/">http://www.epa.gov/enviro/wme/</a>	Maps water and air monitoring locations and facilities but no collected data. Built on the ESRI Portal Toolkit. Interface is cumbersome and slow.
GEO Data Portal – United Nations	<a href="http://geodata.grid.unep.ch/">http://geodata.grid.unep.ch/</a>	Search for and select a variety of data sets and choose map display. Low resolution data, interactive capabilities very limited.
State of Hawaii Dept. of Health	<a href="http://hawaii.gov/doh/air-quality/index.html">http://hawaii.gov/doh/air-quality/index.html</a>	Maps monitoring locations and graphs current levels of SO <sub>2</sub> and other gaseous pollutants. Requires Java runtime libraries. Non-interactive.
AirData Reports & Maps - EPA	<a href="http://www.epa.gov/oar/data/geosel.html">http://www.epa.gov/oar/data/geosel.html</a>	Allows selection of a geographic area from a map and generates an emissions map for an user selected pollutant. Interactive is limited to mouseover showing emissions for the mouseover area (such as county) and zoom in/out.

## 2.6 Spatial Database

A GIS tool is not possible without spatial data. Spatial data can be stored in a variety of ways; simply as latitude and longitude coordinates, as Graphic Markup Language (GML) documents, as Key Markup Language (KML) documents, or in relational databases using special data types such as Oracle's SDO\_GEOMETRY. Since

one of the main goals of this research was to discover an economical solution, the capabilities of Oracle Locator were investigated as part of the solution. Available in every version of Oracle, including the freely licensed Oracle XE, Oracle Locator, “provides native data management, query, and analysis of location data, accessible through standard SQL” (Oracle Corporation, 2005). There are also published methods for storing GML in Oracle (F. Zhu, Guan, Zhou, & Zhou, 2006) and assertions that KML output can be achieved through open source technologies such as GeoServer:

“By providing basic connectivity to Oracle Locator/Oracle Spatial feature tables in Oracle Database, GeoServer can perform simple Oracle Spatial bounding box queries (primary-filter queries), transform the results into KML, and provide the KML output as a service for Goggle Earth to render on a map. This is an attractive, low-cost solution for simple geospatial queries” (Lokitz, 2007).

In addition, the existing relational data of this project is currently housed in an Oracle 10g Release 2 Standard Edition database.

## **2.7 Design and Development Framework**

The rapid-prototyping life-cycle model as described by Schach (2007, pp. 53-54) and Whitten, et al. (2001, pp. 98-99) and illustrated in Figure 3 was used for this project. Relatively small in scope, low in risk, and developed solely by the researcher, the goal was to quickly determine if a low-cost but effective task-oriented GIS mapping tool could be realized. The requirements for achieving this goal were somewhat vague, therefore a

prototype was developed and made available because “the users know what they want when they see it working” (Whitten, et al., 2001, p. 98) and “the users will clarify requirements, identify new requirements, and provide feedback on design (e.g., ease of learning, ease of use) for the next iteration through the design-by-prototyping loop” (Whitten, et al., 2001, p. 99). More details on how this method was utilized are provided in section 3.6.

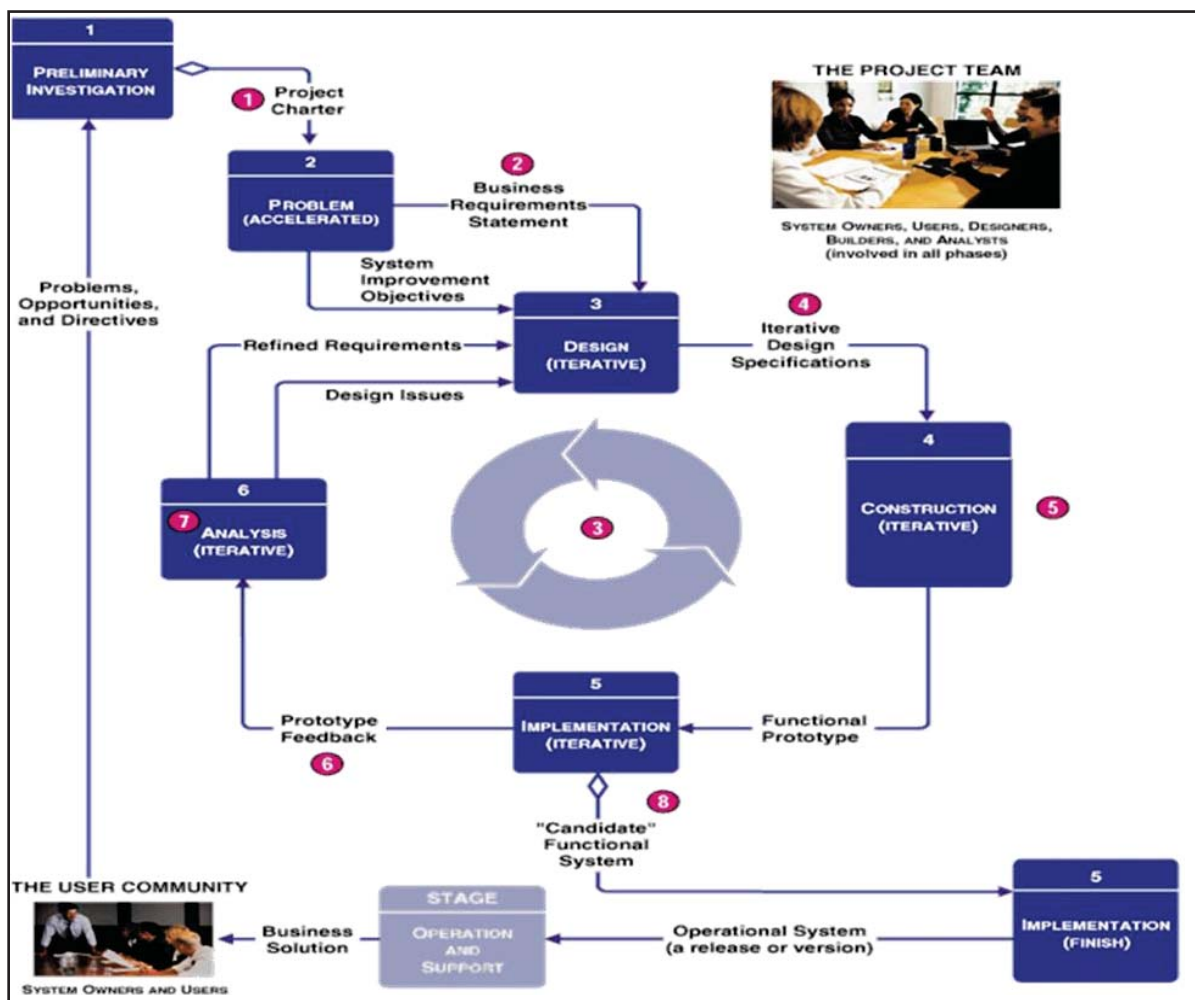


Figure 3. Rapid Application Development (Whitten, et al., 2001, p. 99)

## 2.8 Google Maps .NET Controls

The Google Maps application programming interface (API) is implemented by embedding JavaScript in web pages. The prototype was added to an existing web site developed with Visual Studio 2008 and the VB.NET programming language. Therefore, to facilitate production of robust JavaScript code through the Visual Studio environment a third-party Google Maps .NET control was utilized. From the result of internet searches three possible controls were investigated and are summarized in Table 3. The Subgurim control was chosen for its greater likelihood of good support and availability of source code if needed in the future.

**Table 3. Review of Google Maps .NET Controls.**

<b>Developer</b>	<b>url</b>	<b>Comments</b>
Bill Pierce	<a href="http://www.codeproject.com/KB/custom-controls/LatLaysFlat-Part4.aspx">http://www.codeproject.com/KB/custom-controls/LatLaysFlat-Part4.aspx</a>	Open source, free. Referenced from several developer forums and blogs with good reviews. However, does not work as-is with the latest version of Google Maps.
Jacob Reimers	<a href="http://www.reimers.dk">www.reimers.dk</a>	Open source, free and licensed versions. Few references from developer sites, lack of documentation.
Subgurim	<a href="http://en.googlemaps.subgurim.net/">http://en.googlemaps.subgurim.net/</a>	\$40 server license required for commercial applications. Source code license also available. Fairly good documentation in several languages. Many positive references from developer forums and blogs.



## **2.9 Oracle Database Connectivity**

A variety of methods exist for .NET applications to connect to Oracle databases. However, the spatial data types in Oracle cannot be directly accessed by them. Fortunately, Oracle's latest version of the Oracle Data Provider for .NET provides support for Oracle User Defined data types, which is how the spatial objects are implemented, and Oracle provides a tutorial and sample files for accomplishing the task (Oracle Corporation, 2009c).

## Chapter 3 - Methodology

Design-science research methods were used for this project and followed the general methodology outlined by Vaishnavi and Kuechler (2008); awareness of problem, suggestion, development, evaluation, and conclusion. During the research process, some of the research patterns (“a formalized way of recording experience”) asserted by these authors were identified, utilized, and evaluated within each phase of the research. Details are provided in sections 3.1 through 3.4. In addition, the researcher has attempted to follow the guidelines presented in “Design Science in Information Systems Research” published March 2004 in MIS Quarterly (Hevner, March, Park, & Ram, 2004). These guidelines and their influence on the project are presented in section 3.5. The design and development methodology followed are discussed in the remaining sections of the chapter.

### 3.1 Awareness of Problem Phase

The awareness of problem process began prior to preparation of the thesis proposal and continued through the early stages of the project. Problem selection and development patterns were used during this stage. These patterns included the “Familiarization with New Area” and “Industry and Practice Awareness” patterns (Vaishnavi, 2008) in the literature search process to review literature, gather information about current web-enabled GIS applications and affirm the lack of an existing web-enabled mapping tool for presentation of emissions inventory data. For example, the “Familiarization with New Area” pattern led to a search for general information on data visualization and GIS while the “Industry and Practice Awareness” pattern was used to

investigate the “programming languages, database systems, design methodologies and other systems and tools currently used in practice” (Vaishnavi, 2008, p. 116).

Next, the “Problem Formulation” pattern (Vaishnavi, 2008, p. 87) served as a foundation for solidifying the issues and questions surrounding the problem and for developing the problem statement. Finally, the “Leveraging Expertise” pattern was utilized to build on the researchers experience developing web-enabled database applications for the environmental sciences and to identify a problem “that has the best chances of successful completion based on one’s current strengths” (Vaishnavi, 2008, p. 90).

### **3.2 Suggestion and Development Phases**

Of the patterns used in the suggestion and development phases of this project, the most important was the “Problem Space Tools and Techniques” pattern. This pattern leads the researcher to “choose tools and techniques that one thinks are appropriate to the solution of the research problem without being directly influenced by the traditions of the relevant research community” (Vaishnavi, 2008, p. 126). In this case, the pattern led to the suggestion to use the Google Maps API as a primary component of the solution instead of more traditional GIS tools. In addition, the “Integrating Techniques” pattern (Vaishnavi, 2008, p. 154) was used to combine the capabilities of Oracle Locator spatial objects, ASP.NET, and the Subgurim .NET Google Maps control with the Google Maps API to develop the solution.

### **3.3 Evaluation and Validation Phase**

“Demonstration” is the sole pattern used in the evaluation and validation phase. According to Vaishvavi, demonstration typically entails “the construction of a prototype for the solution and the prototype should “demonstrate that the constructed solution is reasonable for a set of predefined situations” (2008, p. 160). For this project, use case scenarios served as the predefined situations and were demonstrated to and evaluated by several primary users of the tool. To supplement this evaluation, the researcher solicited feedback via a survey from co-workers and acquaintances.

### **3.4 Conclusion Phase**

This paper is the result of the conclusion phase and two patterns were utilized for its production. First, the “Style Exemplars” pattern was used to study examples of other papers submitted in the Regis MSCIT and other information technology degree programs to “help one to write a paper in a manner that is likely to be well received by the referees of the paper and thus accepted by them” (Vaishnavi, 2008, p. 178). Second, the researcher has attempted to employ the “Novelty and Significance” pattern to demonstrate the novel approach to this problem and the significance the solution will have to its users and others looking for solutions to similar problems.

### **3.5 Design-Science Research Guidelines**

Hevner, et al., (2004) states that the results of design-science research should be a “purposeful IT artifact created to address an important organizational problem.” Therefore, the top two guidelines asserted by Hevner are “Design as an IT Artifact” and

“Problem Relevance”, meaning that research should provide “technology-based solutions to important and relevant business problems”. For this project, problem relevance is established in Chapter 1 while the resulting IT artifact of the research is presented extensively in Chapter 4.

The “Design as a Search Process” guideline is expressed throughout Chapter 2. Most importantly, the “Design Evaluation” guideline has been utilized in this project to assess the “utility, quality, and efficacy of a design artifact” (Hevner, et al., 2004). As mentioned above, the prototype has been evaluated through a demonstrations process to allow users the opportunity to evaluate the prototype’s functionality and supplemented by survey responses from the researcher’s co-workers and acquaintances. The survey responses and researcher’s interpretations are summarized in Chapter 4.

The final guideline, “Communication of Research”, states that “[D]esign-science research must be presented effectively both to technology-oriented as well as management-oriented audiences.” The author has tried to follow this guideline by providing an appropriate level of technical detail while preserving the patterns discussed in section 3.4.

### **3.6 Design and Development Methodology**

As discussed in section 2.7, the rapid-prototyping life-cycle model was used for this project. To define the problem, use cases and scenarios were created. Further, the concept of *persona* was used to better define each scenario. An element of the Unified Process, each use case identifies an actor and a specific interaction between the actor and the software (Eriksson, Penker, Lyons, & Fado, 2004). The use case typically provides a

brief description of the role of the actor in the business model; a customer, an employee, a manager, etc. From the use case statements, normal and alternative scenarios are developed to document how each use case might play out in reality. Each scenario is an instance of the use case. However, the scenario provides no instantiation of the actor or actor's role in the scenario. The persona concept has been used to fill this gap. According to himself, Alan Cooper (2004) was the first to use the term persona in relation to software development in his book, "The Inmates are Running the Asylum". For Cooper, the personas concept evolved as a way to inspire interface design teams to think about the software they were creating from the points of view of very specific users. Cooper defines a persona as "a precise description of our user and what he wishes to accomplish".

Next, the initial system design was determined by studying the scenarios and included construction of a class model, a database entity relationship diagram and process flow diagrams. The functional prototype was then constructed from these design documents. The persona description, use cases and scenarios, and design documents are provided in Chapter 4.

## Chapter 4 - Results

The project results consist of details on the constructed prototype and include the written documentation and diagrams comprising the design artifact, steps for setting up the development and deployment environments, examples (screen shots) from the instantiated prototype and an evaluation summary of the prototype demonstration and survey responses.

### 4.1 User Persona

A primary user persona was developed to help clarify use cases and use case scenarios and to design the user-interface. The primary persona was given the name Karen and described as an air quality specialist by the Colorado Department of Public Health and Environment, Air Pollution Control Division, Technical Services Program. Her duties include:

- Preparing emissions inventories.
- Preparing technical documents related to the state's air quality programs such as state implementation plans which describe how a state will meet or maintain a certain air quality level or specialized analyses for the permit of a new or modified emissions source (e.g., power plant, manufacturing facility).
- Preparing an analysis of air quality not tied specifically to a state or federal statute.

Karen has moderate computer skills and moderate experience with a large ESRI-based GIS system and other mapping software. She has a high understanding of

emissions data and has helped prepare the state's emissions inventories which include point, area and mobile sources. However, she does not understand the details of how biogenic and fire inventories were developed. These latter inventories are largely modeled or based on data that the state does not control. She also has an understanding of regional meteorology. Karen's goals for using this system include:

- Quality assurance: Verifying that emissions from point sources (and to a lesser extent other sources) appear where they should geographically, and that their magnitude of emissions are correct.
- Investigating how close specific sources (usually point) are from geographic landmarks (often protected environments such as Class I areas). There are federal regulations that govern how close emitters of specified levels can be to protected areas.
- Understanding regional patterns of emissions that affect the state.
- Understanding the state's emissions in terms of potential to impact other states.

## 4.2 Use Cases

Goal-driven Use Cases and Scenarios for this system include:

### **View Emissions Data**

The user positions the map to display a specific map area, selects a boundary type or facilities, inventory version, sector, and pollutant, then clicks a button.

### **View Boundaries**



The user selects to display boundaries. The system retrieves the boundary polygons and displays them. The polygons are assigned a color based on the emissions data value. The emissions data for each polygon is displayed or made available for display when an event is triggered (such as mouse-over or click).

### Scenario

Karen wants to view the mobile source carbon monoxide (CO) emissions data for all counties in Colorado. She positions the map in order to see all of Colorado, selects inventory 13 (2002 version 4), county boundaries, on-road mobile sources, and CO from the selection lists, then clicks a button to trigger the request. The system queries the database and retrieves the spatial data for each county within the viewable map area. For each county, the system generates a polygon representing the county boundaries, then retrieves the total annual tons of CO emissions for inventory 13, on-road mobile sources for the county. The emissions value is compared to a table that stores ranges of levels for each combination of area type (county), source type (on-road mobile), and pollutant (CO). If pre-defined levels are not found, the system calculates the bin levels and stores them for future use. The county polygon is assigned a color based on the level the CO emissions value lies within. If no emissions value is found for a county, the polygon remains transparent. The meta data and the CO emissions value for the county is associated with the polygon. The map is displayed with the polygon overlay. A key defining the meaning of the polygon colors is also displayed. When Karen clicks a polygon, the meta data and emissions value are displayed.

### **View Facility Locations**

The user positions the map to display a specific map area, selects to display facilities and an inventory version, sector, and pollutant, then clicks a button. The system retrieves the facility locations and displays markers indicating the locations. The marker images are of various colors based on the emissions data value. The data for each marker is made available for display when an event is triggered (such as mouse-over or click).

### Scenario

Karen wants to view facility locations and associated Nitrogen Oxides (NO<sub>x</sub>) emissions values in Weld County, Colorado. She positions the map in order to see all of Weld County, selects inventory 13 (2002 version 4), facilities and NO<sub>x</sub> from selection lists, then clicks a button to trigger the request. The system queries the database and retrieves the spatial data for each facility within the viewable map area. For each facility, the system retrieves the annual tons of NO<sub>x</sub> emissions. The emissions value is compared to a database table that stores ranges of levels for each combination of area type (facility), source type (point) and pollutant (NO<sub>x</sub>). If pre-defined levels are not found, the system calculates the bin levels and stores them for future use. The system generates a location marker using an icon, the color of which is determined by the level the NO<sub>x</sub> emissions value lies within. The meta data and the NO<sub>x</sub> emissions value for the facility are associated with the marker. The map is displayed with the marker overlay. A key defining the meaning of the icon colors is also displayed. When Karen clicks a marker, the meta data and emissions value are displayed.

### **View Filtered Facility Locations**

The user provides further criteria for facility display. The system then displays only those facilities meeting the criteria (for the selected inventory and pollutant).

### Scenario

Karen has requested a map that displays facilities in Weld County and their associated NOx emissions values. There are numerous facilities and she wants to be able to more easily identify those with high emissions values. She checks a box that indicates she wants to apply this criterion. The system prompts her for a value and she enter 30,000 then clicks a button to trigger the request. The system removes or hides the markers from the map for facilities with less than 30,000 annual tons on NOx.

### **View Wilderness Boundaries**

The user checks a box indicating they want to see Class I Wilderness boundaries on the map.

### **Calculate Distances**

The user indicates they want to calculate distance (via some event such as button click or box check), then clicks two points on the map. The system labels the point A and B and draws a line between the points, then calculates and displays the distance in km.

Additional distances are calculated for each two points clicked.

### Scenario

Karen has requested a map that displays facilities in Weld County and their associated NOx emissions values where the emissions are greater than or equal 30,000 tons. Now

she wants to see how far it is from one of these facilities to the Class I Wilderness boundary in Rocky Mountain National Park. She positions the map to view both the facility of interest and the wilderness boundary. She indicates by clicking a button that she wants to calculate the distance. She clicks the facility marker. The system changes the facility marker to one labeled “A”. Karen clicks a point somewhere within the Class I Wilderness boundary. The system labels this Point “B”, draws a line between the two points and displays the calculated distance in kilometers. Karen calculates additional distances between facilities and the wilderness by following the same process.

### **Stop Calculating Distances**

The user indicates they want to discontinue calculating distances (via some event). The system stops calculating distances.

### **Draw Circles**

The user indicates they want to draw a circle on the map (via some event). The system prompts the user to enter a radius value. The user enters the radius value then clicks a point on the map. The system draws a colored circle on the map using the radius value and point. The radius value can be modified and additional circles drawn for each point clicked on the map.

### Scenario

Karen wants to identify all facility locations with high NO<sub>x</sub> values within 50 kilometers of the Class I Wilderness area in Rocky Mountain National Park. She has positioned the map to be centered over the wilderness area at a zoom level that will include 50 km all

around and has requested a display of facilities for inventory 13 (2002 version 4), where NOx is greater than or equal 30,000 tons. She indicates by clicking a button that she wants to draw a circle on the map. The system prompts her for a radius value. She enters 50 then clicks a point within the wilderness area. The system draws a circle with the given radius. Additional circles can be drawn by clicking on other points on the map.

### **Stop Drawing Circles**

The user indicates they want to discontinue drawing circles (via some event). The system stops drawing circles.

### Scenario

After displaying a circle on the map as described in the previous scenario, Karen sees that there are 5 facilities within a 50 km radius of the wilderness. She now wants to see the facility meta data and emissions values for these facilities. However, if she clicks a facility marker, the system will assume she wants to draw a circle with the marker as the center point. Therefore, she indicates to the system that she wants to stop drawing circles by toggling off the draw circles button.

### **Clear Map**

The user indicates they want to clear the map of all markers, boundaries, etc. (via some event). The system clears the map.

### Scenario

Karen has completed a task and wants to start a new one on a clean map surface. She indicates this by clicking a button and the system clears the map of all boundaries, markers, lines, and circles.

### **4.3 Classes, Data Entities, and Process Flows**

Classes and data entities for the prototype were determined by studying the use case scenarios. The classes, their attributes, methods and associations are shown in Figure 4. An entity relationship diagram (ERD) is presented in Figure 5. The ERD indicates the new entities and those already existing in the Emissions Data Management System (EDMS) database. Process Flow Charts for the primary scenarios are presented in Figures 6 through 9.

# GIS Mapping Tool

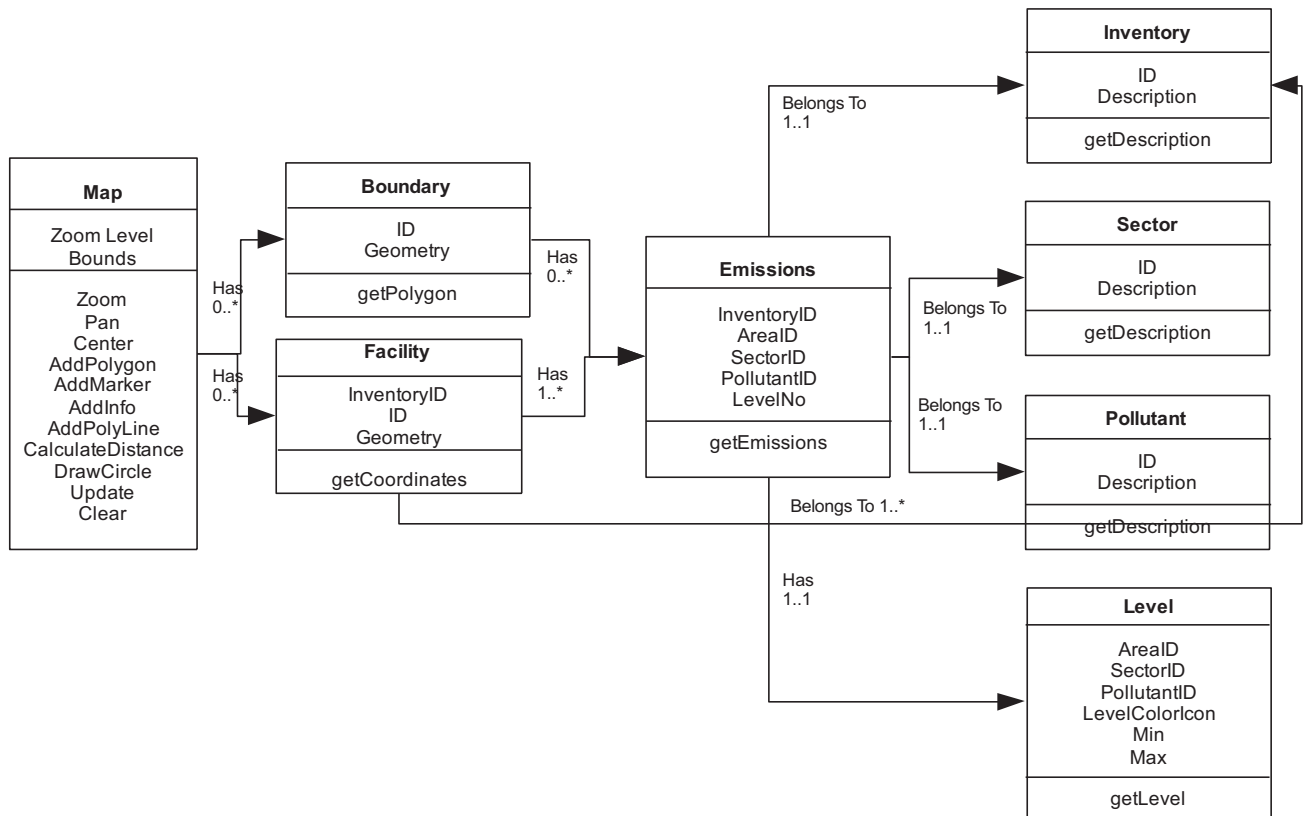


Figure 4. Class Diagram.

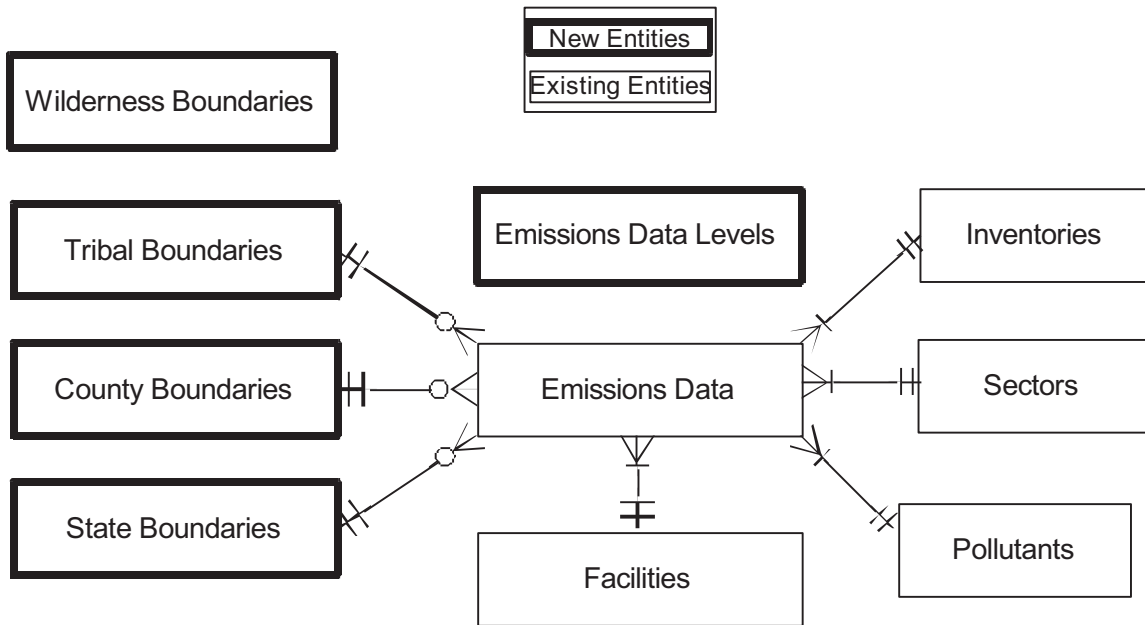


Figure 5. Entity Relationship Diagram.

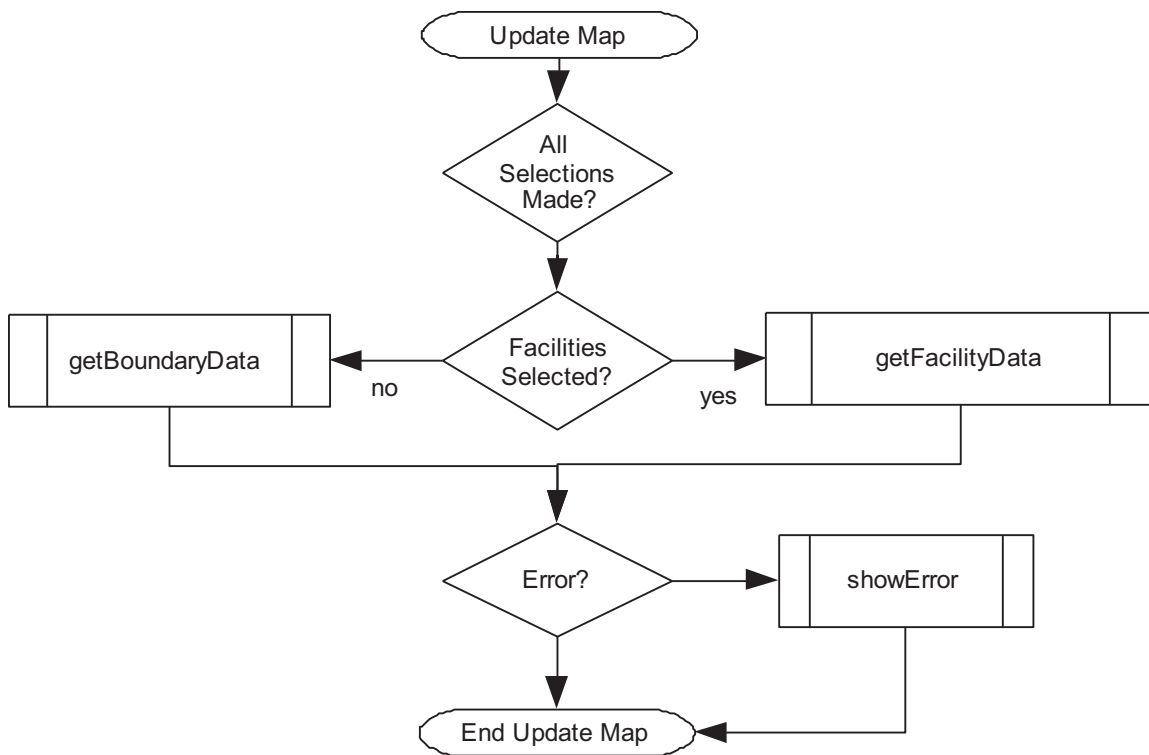


Figure 6. View Emissions Data Process Flow Chart.



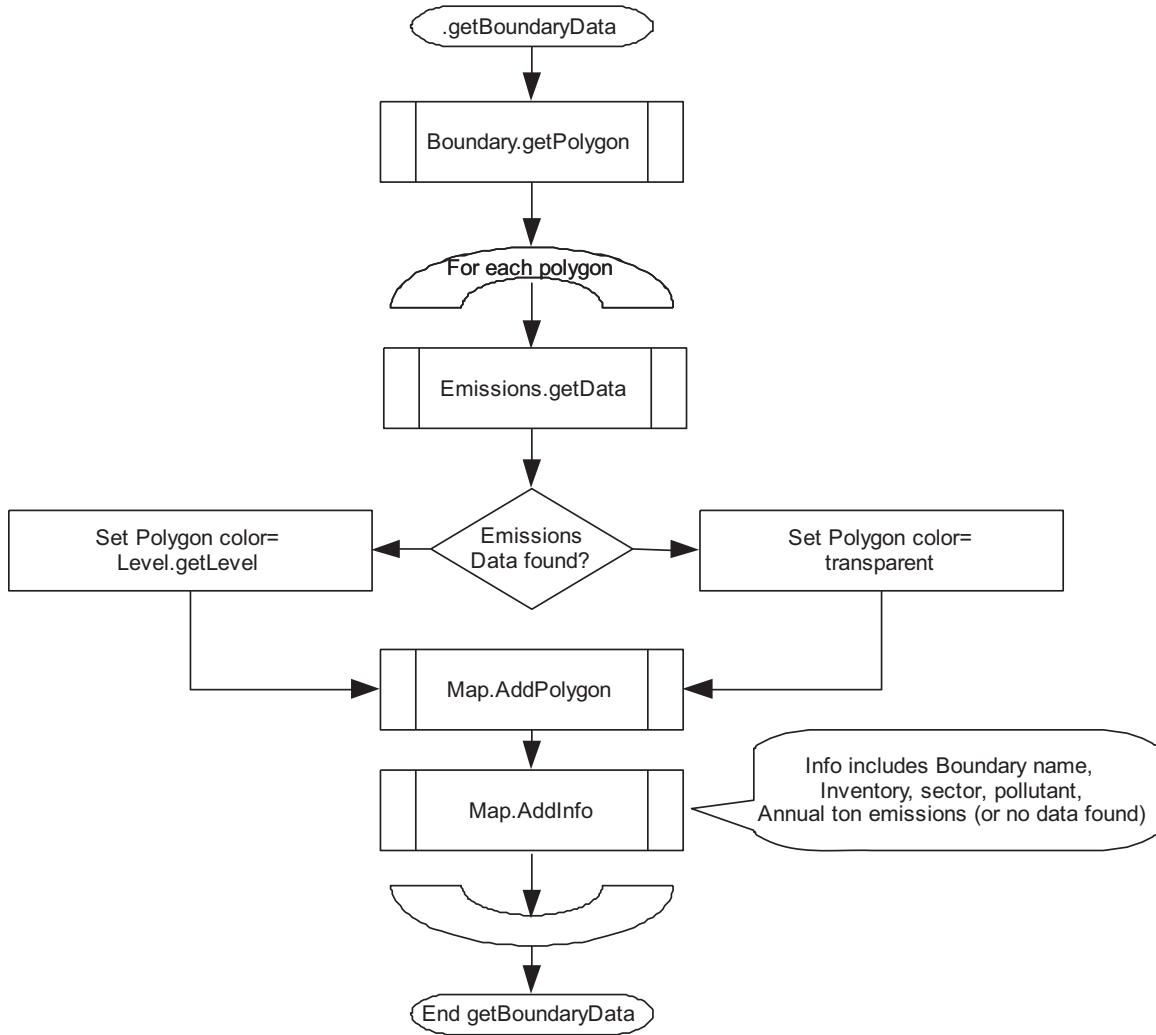
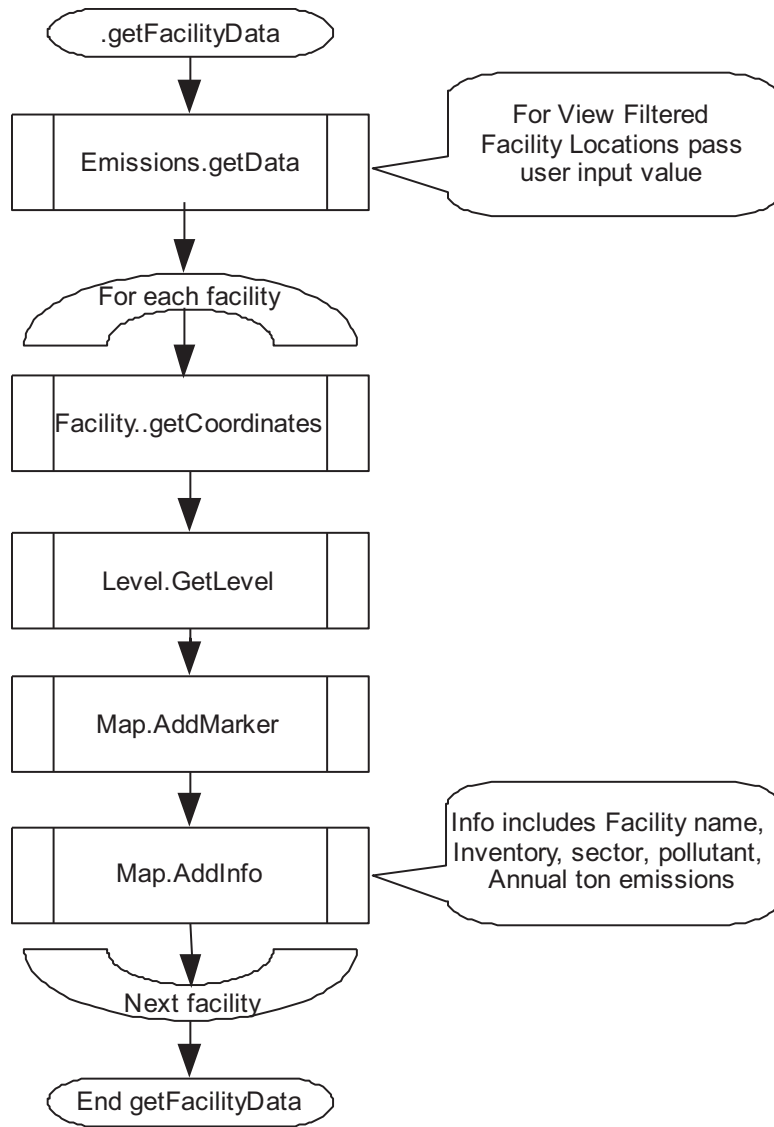
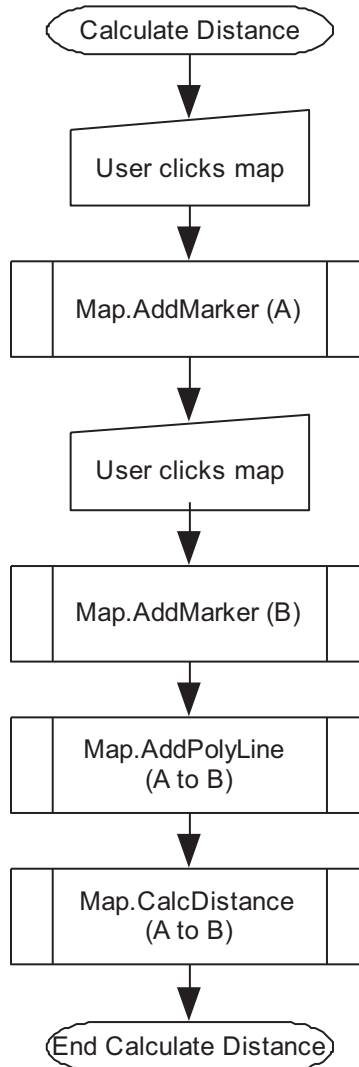


Figure 7. View Boundaries Process Flow Chart.



**Figure 8. View Facility Locations Process Flow Chart.**



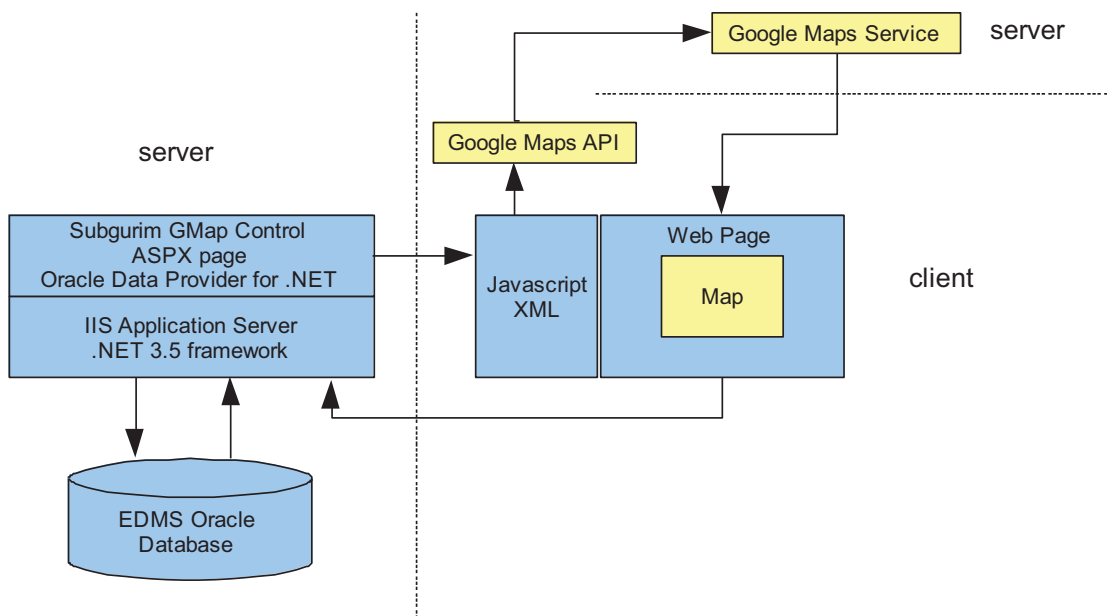
**Figure 9. Calculate Distance Process Flow Chart.**

#### **4.4 Implementation**

This GIS mapping tool will become a feature of an existing web site. Therefore the implementation design was influenced by a combination of the research and the existing infrastructure consisting primarily of an Oracle database and ASP.Net web site application. The application was developed with Visual Studio (VS) 2008 running on

Internet Information Server. An overview is provided here with more details in the following subsections.

As shown in Figure 10, the tool is designed to leverage the extensive capabilities of the Google Maps web service. This service provides the base map data in a variety of views (such as road map, satellite, and hybrid), navigation controls (such as pan and zoom), the ability to add overlays (such as polygons and markers), and methods for programmatically customizing map events (such as what happens when the map is clicked).



**Figure 10. Components of the GIS Mapping Tool.**

The Google Maps service API is implemented through JavaScript. To facilitate production of robust JavaScript code through the VS development environment, the .Net control provided by Subgurim has been utilized. This control encapsulates the required JavaScript in a .Net class library and allows the control to be added to an ASP web page.

The map's properties, methods, and events can then be referenced in code behind files like any other control. The ASP application utilizes additional class libraries and controls to query the Oracle database and retrieve the data required.

#### 4.4.1 Visual Studio and the Subgurim Control Setup

To setup the VS development environment to use the Subgurim control the following steps were taken:

1. Opened the web site project in Visual Studio and added a web page.
2. Downloaded the Subgurim control from the Subgurim web site (Subgurim, 2009). Decompressed the file and put the GMaps.dll in the \bin folder of the web site project.
3. Added the control to the VS toolbox.
4. Acquired a Google Maps key from the Google Maps API web site (Google Maps, 2009).
5. Added this key to the web site application web.config file as follows:

```
<appSettings>
```

```
<add key="googlemaps.subgurim.net"
```

```
value="ABQIAAAAmHc_2NiQmNEndmM3na5MIRRQfr
```

```
h4zNYaVywcg-
```

```
wxAZ4M3EUi2RRJRekSECKCXw5PPP1hAmoy6ZdaqA
```

```
</>
```

```
</appSettings>
```

6. Added “Imports Subgurim.Controls” to the code behind file for the web page.

From this point, the Subgurim Google Map Control (GMap) could be selected from the VS toolbox, dragged to the asp page and its properties accessed through the properties view. In addition, the properties and methods could be accessed through the class view and VS *Intellisense*, providing easy language reference to the properties and methods in the code behind page.

#### *4.4.2 Spatial Data and Database Structures*

Spatial data required for this system includes state, county, tribe, and wilderness area boundaries and facility location coordinates. This section describes how these data were acquired, the database structures created or modified to store the data, and how the data were loaded into the structures.

#### **Boundary Geometries**

First, shape files containing state, county and American Indian Area boundaries were acquired from the United States Census Bureau web site (US Census Bureau, 2009). Shape files containing Class I Wilderness Area boundaries were acquired from the National Park Service, United States Forest Service, and Fish and Wildlife Service.

Next, a utility program called the “shape to sdo converter” was acquired from the Oracle.com web site (Oracle Corporation, 2009b). This Linux command line utility, `shp2sdo.exe`, made the process of loading the boundary geometries extremely easy by following these steps:

1. Navigated to the folder containing the shape files and ran the command line utility for each specific shape file. For example:

```
shp2sdo.exe states state_boundaries -g geom -d -x \(-180,180\) -y \(-90,90\) -s 8307 -t 0.5 -v
```

Where:

`states` - the shapefile to convert (expects `.dbf`, `.shp`, and `.shx` files)

`state_boundaries` - the name of the table to create and use in Oracle

`-g geom` - `geom` is the name of the column to load for the geometry object

`-d` - put the data in the control file generated by the tool

`-x` - the bounds of the first dimension in the coordinate system

`-y` - the bounds of the second dimension in the coordinate system

`-s` - the SRID (spatial reference system ID)

`-t` - the tolerance

`-v` - verbose output

The output of this command is three files:

state\_boundaries.sql – contains the SQL statements to create the table.

state\_boundaries.ctl – the control file for the SQL\*Loader program.

state\_boundaries.dat – the data file for the SQL\*Loader program.

2. Connected to the Oracle database as the schema user that will own the table and ran the state\_boundaries.sql file created in step 1 to create the table that will hold the spatial data. For example:

➤ *\$ORACLE\_HOME/bin/sqlplus /nolog*

➤ *Connect edms\_ref/\*\*\*\*\*@edms*

➤ *@state\_boundaries.sql*

3. Back at the command line, ran SQL\*Loader as the schema user that owns the table, referring to the control file that was created in step 1:

➤ *\$ORACLE\_HOME/bin/sqlldr edms\_ref/\*\*\*\*\*@edms state\_boundaries*

SQL\*Loader loaded the data from the dat file into the table created in step 2.

### **Point Geometries**

Emissions facility locations in the form of longitude and latitude coordinates simply stored as decimal numbers are submitted with point source emissions inventory data.



## Spatial Indexes

A spatial index must exist in order to successfully issue a query on a spatial data field. In order to successfully create a spatial index, meta data for the spatial data field must exist in the `mdsys.user_sdo_geom_metadata` view. Continuing with the above example:

- `$ORACLE_HOME/bin/sqlplus /nolog`
- `connect edms_ref/*****@edms`
- `insert into mdsys.user_sdo_geom_metadata`  
*(table\_name,column\_name,srid,diminfo) values*  
*('state\_boundarie','geom',null,sdo\_dim\_array(sdo\_dim\_element('longitude',-*  
*180,180,.5) sdo\_dim\_element('latitude',-90,90,.5))));*
- `create index state_boundaries_idx on state_boundaries(geom) indextype is`  
*mdsys.spatial\_index;*

## Spatial to Relational Data Relationships

New entity relationships as shown above in Figure 5 were implemented as follows:

- Emissions Data to State Boundaries - on the State FIPS column in each table.
- Emissions Data to County Boundaries - on the State FIPS and County FIPS columns in each table.

- Emissions Data to Tribal Boundaries – added a Tribal Code field to the Tribal Boundaries table and manually populated it by comparing Indian reservation and other territory names in the Tribal Boundaries table to the Tribal Codes table already present in the EDMS database.

### **Emissions Data Levels**

The Emissions Data Levels table is a lookup table containing five emissions levels for each unique combination of inventory version, boundary or facility type, sector type, sector category, and pollutant. When the map is updated, each boundary polygon color or color of facility marker is set to indicate which level applies to the emissions data. The levels are determined by querying the database using the Oracle *ntile* analytical function. Levels can be subjectively adjusted to provide logical value distribution while maintaining good distribution of boundary and facility marker colors. When the map is updated, the related levels are retrieved from this table if found. If not found, the *ntile* function is called, the related levels used to display and date, and the results inserted into the levels table for future use. An example of the *ntile* function is:

```
select lev,min(co),max(co),count(*) from

(select ntile(5) over (order by co) lev,sum(co) from tss_maps

sector_code='A' and co>0)

group by lev order by lev;
```

#### 4.4.3 Visual Studio and Oracle Database Setup

Various methods exist for accessing an Oracle database through an ASP.Net application. Fortunately, the latest version of Oracle Data Provider for .NET (ODP) and Oracle example files for creating custom classes for Oracle User Defined data types made the task very straightforward and was accomplished with the following steps:

1. Downloaded Oracle 11g Oracle Data Access Components (ODAC) 11.1.0.6.21 with Oracle Developer Tools for Visual Studio (which includes ODP) from the Oracle web site (Oracle Corporation, 2009a).
2. Installed all ODAC components on the development workstation.
3. Copied the existing TNSNAMES file (which defines the Oracle service names) from the previous Oracle client installation folder to the new ODAC installation folder.
4. Created a customized class library by copying the Object3.cs file from the \odp.net\samples\2.x\UDT folder of the new Oracle client installation and modifying to fit the implemented spatial data for this project. The library defines .NET objects which map to the Oracle spatial objects.
5. Added a reference to the compiled customized library (UDTClassLibrary) to the VS project.
6. Added “Imports Oracle.DataAccess.Client” and “Imports Oracle.DataAccess.Types” to the web page code behind page.

The spatial data could then be retrieved from the Oracle database using ODP methods and stored in variables declared as object types defined in the UDTClassLibrary.

#### **4.5 Prototype Instantiation**

The prototype instantiation includes all of the functions covered in the design artifact. Examples of the prototype instantiation are presented in Figures 11 – 15.

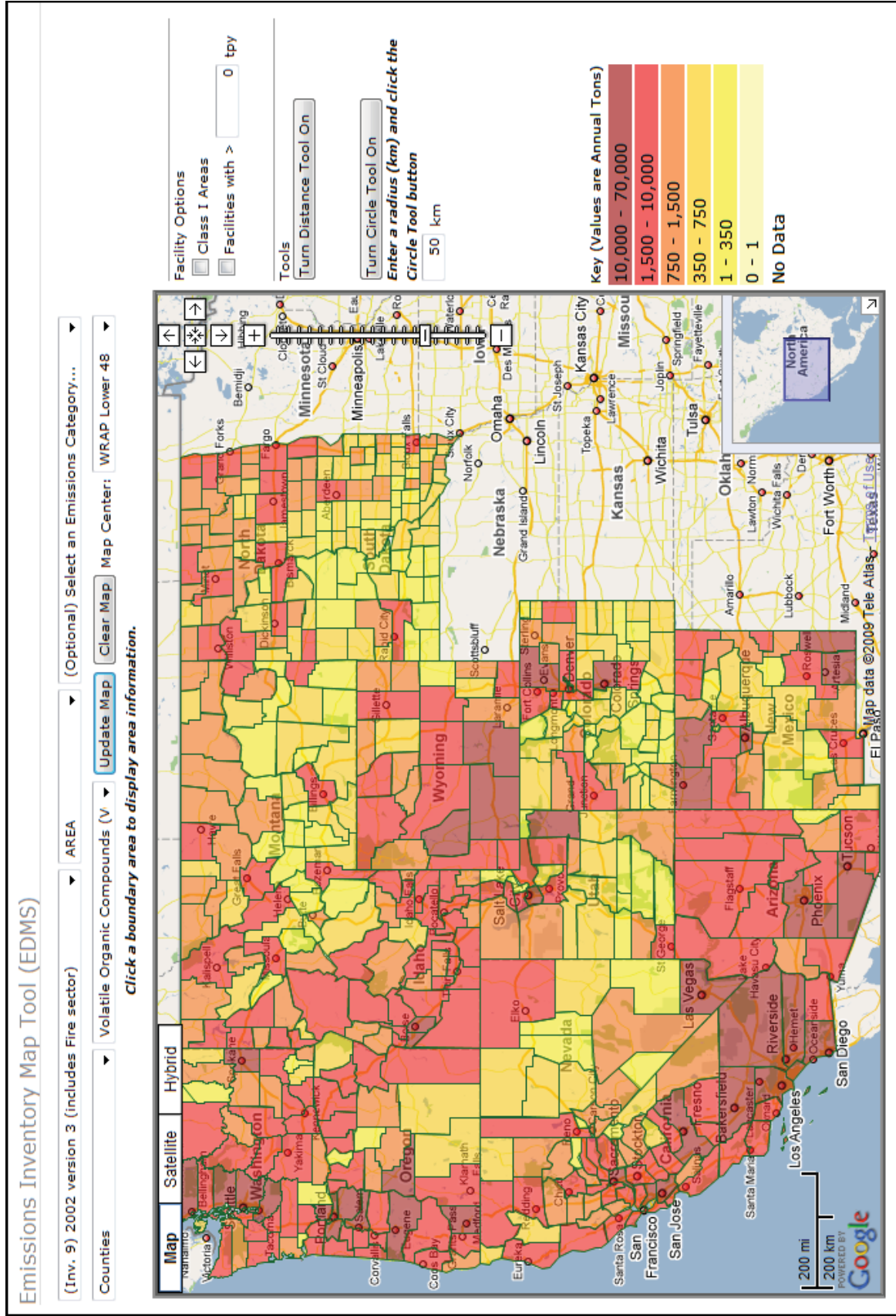


Figure 11. Area Source Emissions Data Displayed by County Boundaries.

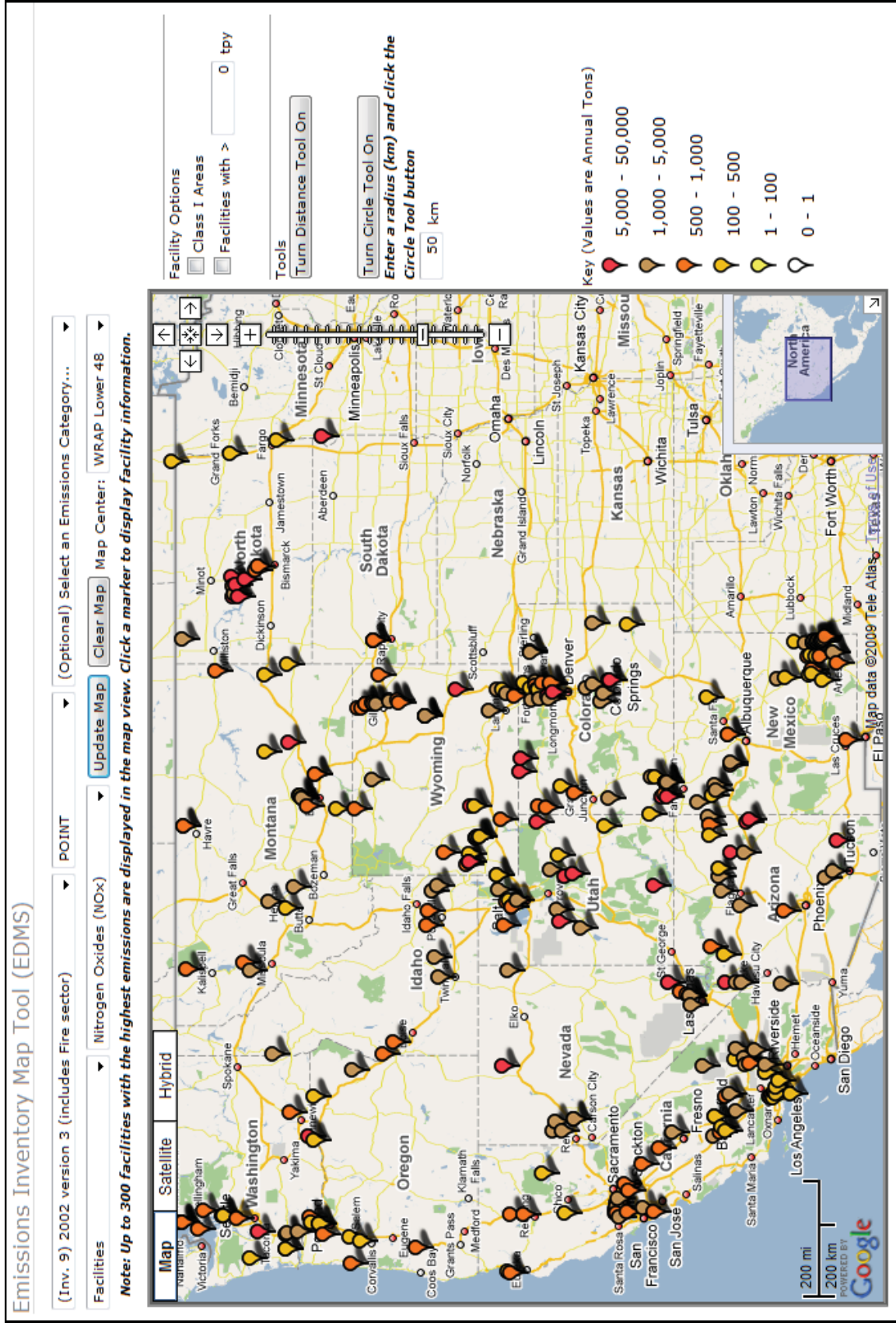


Figure 12. Point Source Emissions Data Displayed by Facility.

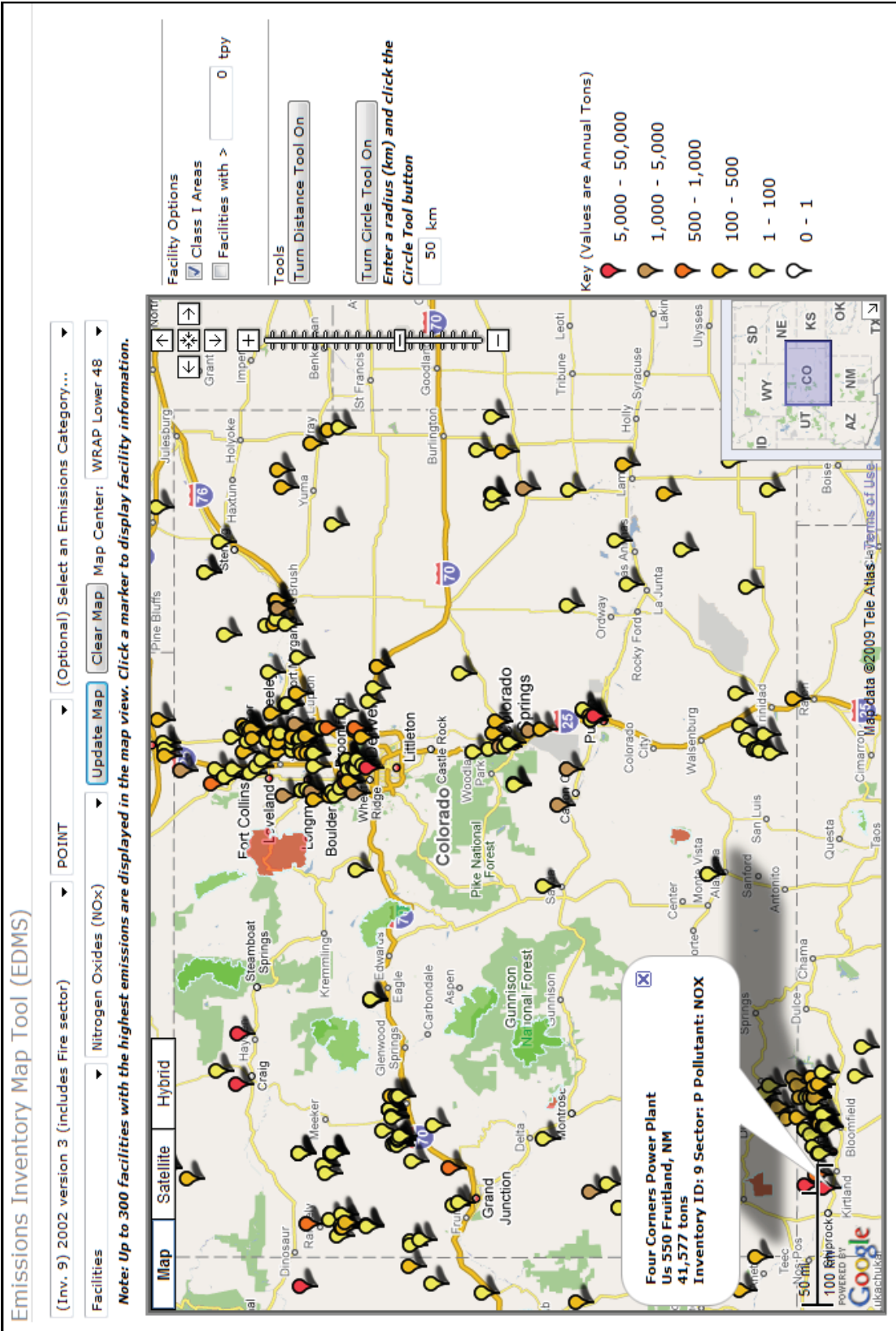


Figure 13. Point Source Emissions Data Displayed by Facility and Including Class I Wilderness Boundaries and Facility Information Window.

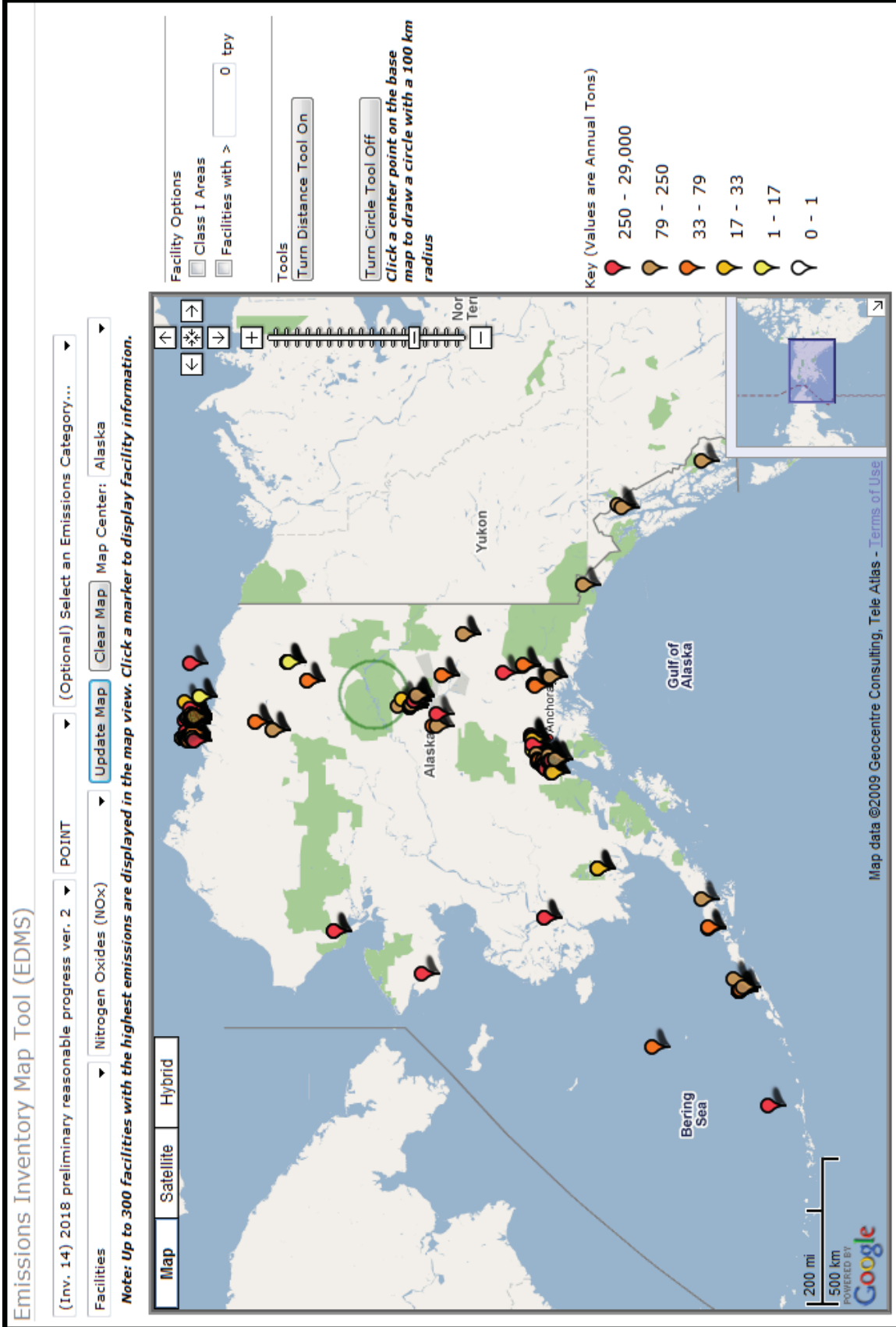


Figure 14. Distance Tool.

Figure 15. Circle Tool and Alaska View.



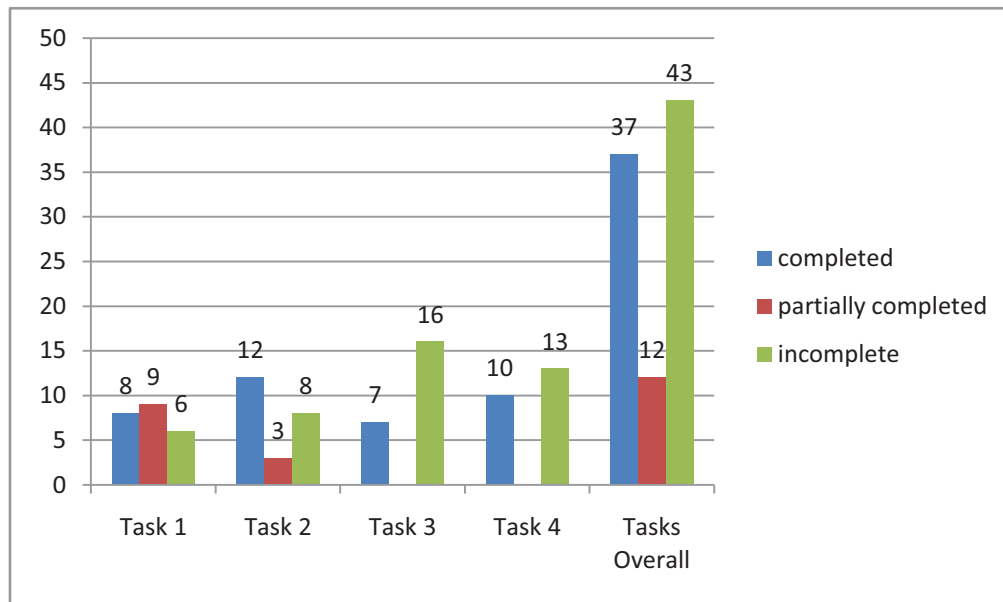
## 4.6 Evaluation

The prototype evaluation began with demonstration via a webinar to the WRAP emissions forum and included successfully presenting use case scenarios similar to those outlined above. Responses from the group were very positive and primarily consisted of suggestions for several enhancements such as adding population data to the database to allow display of emissions per capita, clustering of facility markers and the capability for users to customize bin levels. The users attending the webinar were given a link to the tool and asked to further evaluate and to respond with comments via email within a couple of weeks. However, no email comments were received.

To supplement the evaluation from the webinar, a survey was developed and, in addition to users within WRAP, the researcher solicited responses from co-workers and other acquaintances. Therefore, the respondents have quite diverse backgrounds, various amounts of knowledge regarding air quality data and issues, and computer use in general. The survey was designed primarily to further validate the functionality of the mapping tool by instructing respondents to perform a series of tasks similar to the use case scenarios. Secondary objectives included evaluation of response time, ease of use, appeal and usefulness.

Twenty-three (23) respondents completed the survey, only one of which is a likely future user of the tool. As shown in Figure 16, at least some of the respondents were able to successfully complete each task thereby validating the basic functionality of the mapping tool. Ease of use (Figure 17) varied widely and indicates that user training is advisable. Perceived response time (Figure 18) also varied significantly and, along with

some reports of script time-out errors, indicates that slower computers are not able to sufficiently handle the amount of Javascript processing required. In addition, these results indicate it would be prudent to investigate methods to optimize performance. The distance and circle functions are especially slow to respond when multiple markers are present in the view. Most respondents found the mapping tool to be appealing (Figure 18) and most believe it will be useful to air quality analysts (Figure 19). The complete survey is provided in Appendix A.



**Figure 16. Survey Results - Task Completion.**

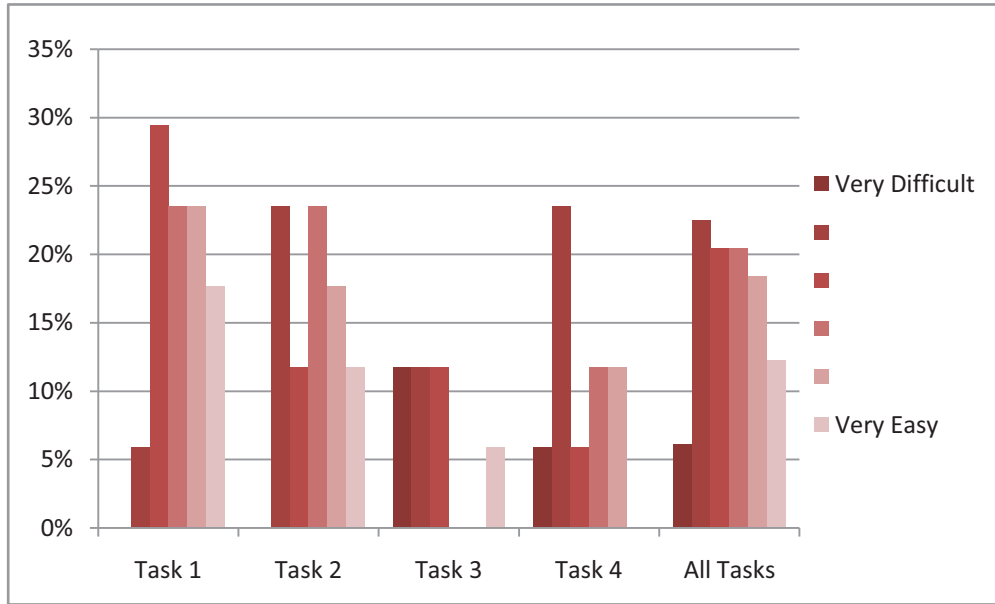


Figure 18. Survey Results - Usability.

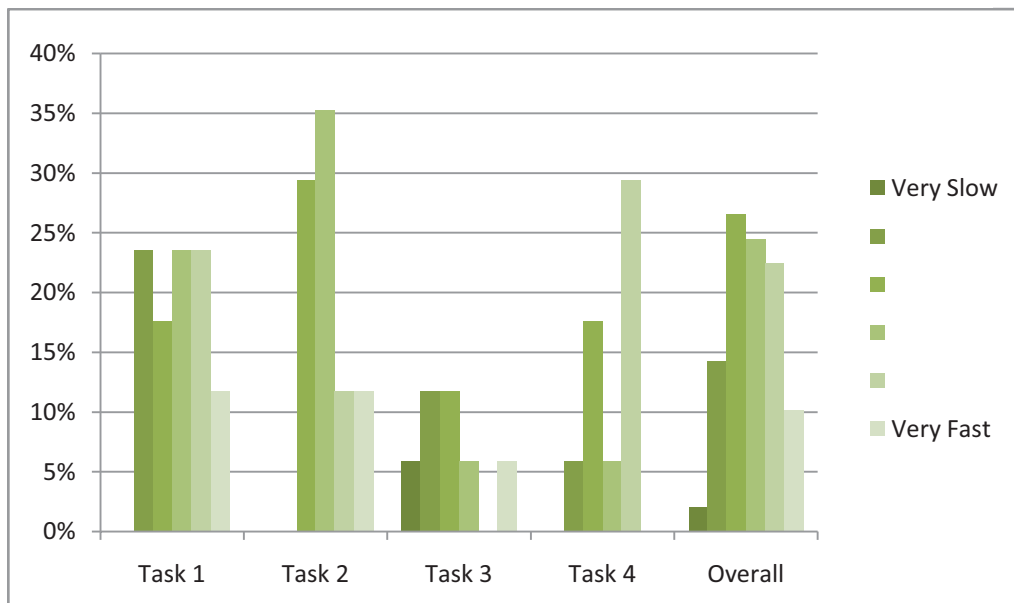
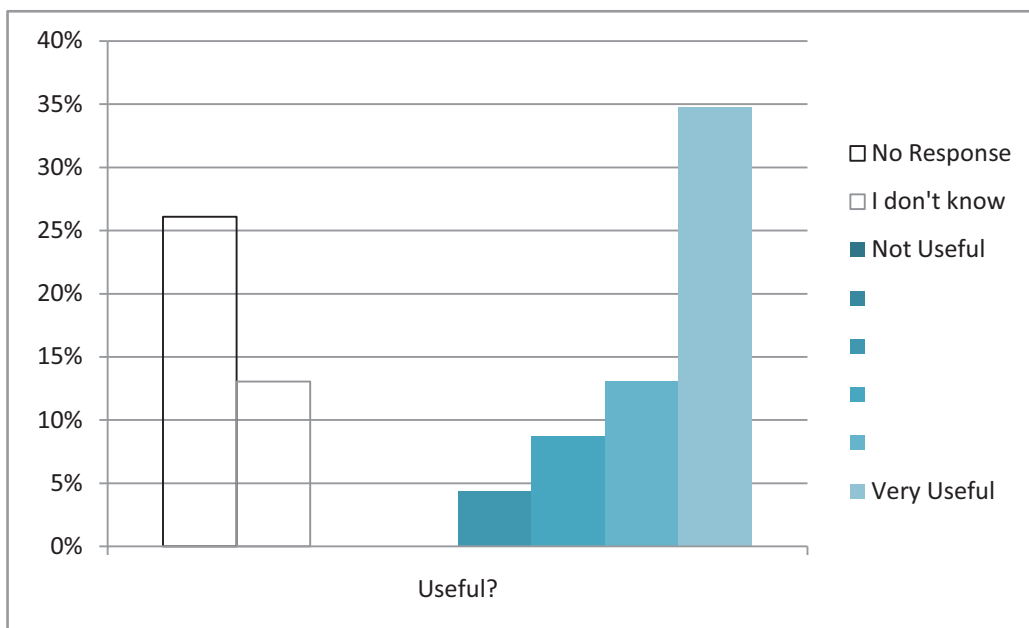
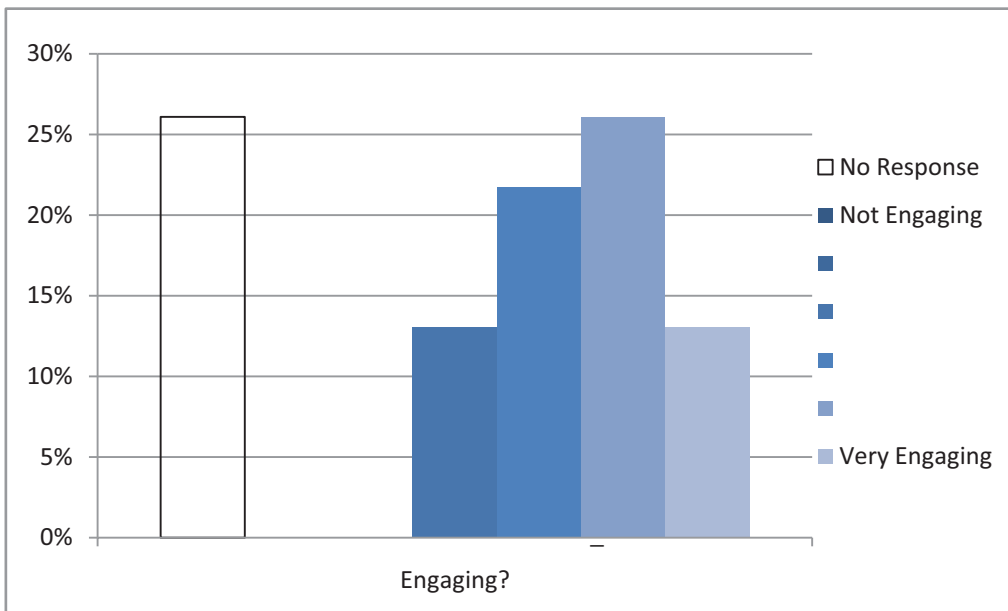


Figure 17. Survey Results - Responsiveness.



## Chapter 5 - Conclusions

The freely available Google Maps web service and published API have facilitated the rapid implementation of an internet mapping tool for displaying emissions inventory data. Following a design science methodology, the researcher seized an opportunity to solve a problem within the environmental sciences domain by applying this new technology combined with the spatial capabilities of Oracle Standard Edition Database server, the Google .NET control developed by Subgurim, and the researcher's experience with Oracle and software development. Developed solely by the researcher in less than four weeks at approximately 80% of working hours, it is assumed that the prototype was developed for a fraction of the cost of a traditional GIS.

As indicated by the survey results, there is work yet to be done on the tool to make it more reliable, especially on slower computers. Alternative methods of processing user actions as client events (processing takes place on the user's computer) versus server events (processing takes place on the web server) need to be developed and tested for each use case to determine which provide optimum response times. This aspect of the Subgurim control and Google Maps API has proven to be the most difficult for the researcher to comprehend. Based on experience of software development in general, the researcher also expects additional problems to be raised as the tool is used. For example, it was recently discovered that Internet Explorer version 8 does not correctly place polygon and marker information windows when clicked unless the browser is in "compatibility mode".

To improve usability, training will be provided through at least one webinar and it is likely an online video tutorial will be made available. Also, users have already requested enhancements such as the option to display emissions tons per capita and allowing user to set custom bin levels. It is expected that several enhancements will be implemented in version 2 of the tool.

## **Chapter 6 - Areas for Further Research**

The author hopes that this research will provide the inspiration and lay the foundation for others to develop similar tools. If there is an interest and funding is made available, the researcher will investigate the feasibility of packaging a mapping tool solution for other entities with emissions inventory data. Currently, the author is developing other Google maps mashups to display air quality monitoring locations and related gaseous pollutant and meteorological data.

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## **Appendix A – Survey Questions**

## 1. Consent Form

### \* 1. INFORMED CONSENT FORM FOR PARTICIPANTS RESEARCH PROJECT

**Title of Research Project: An Investigation Into the Development of a Practical GIS Supporting Emissions Inventory Information Throughout the Environmental Sciences Sector.**

You are invited to participate in a study that will measure usability of a web-based interactive mapping tool developed with Google Maps, .NET and data from the Western Regional Air Partnership (WRAP) Emissions Database Management System (EDMS). The results of the study will be used to evaluate the functionality of the mapping tool including ease of use, level of performance, and problem identification. In addition, this study is being conducted to fulfill the requirements of a Thesis Project and is being conducted by Betsy Davis-Noland. Ms. Davis-Noland can be reached at (970)206-1719 or e-mail at [bdavisnoland@frii.com](mailto:bdavisnoland@frii.com). The project is supervised by the student's Thesis Advisor, Charles Thies, Regis University, 3333 Regis Boulevard, Denver, Colorado 80221-1099, [cthies@regis.edu](mailto:cthies@regis.edu), (719) 310-9887.

Participation in this study should take about 15-20 minutes of your time. Participation will involve using the mapping tool during a testing session to perform several tasks, answer questions related to each task and to describe your overall experience of using the tool. Participation in this project is strictly voluntary and the risks associated with it are minimal. If, however, you experience discomfort you may discontinue the session at any time. We respect your right to choose not to answer any questions that may make you feel uncomfortable. Refusal to participate or withdrawal from participation will involve no penalty or loss of benefits to which you are otherwise entitled.

Your responses will be identified by code number only and will be kept separate from information that could identify you. This is done to protect the confidentiality of your responses. Only the researcher will have access to your individual data and any reports generated as a result of this study will use only group averages and paraphrased wording. However, should any information contained in this study be the subject of a court order or lawful subpoena, Regis University might not be able to avoid compliance

with the order or subpoena. Although no questions in this interview address it, we are required by law to tell you that if information is revealed concerning suicide, homicide, or child abuse and neglect, it is required by law that this be reported to the proper authorities.

If you have any concerns or complaints about how you were treated during the testing session, please contact Mr. Bud May, the director of the Regis University Institutional Review Board at (303-458-4206). If you do not understand any part of the above statement, please ask the researcher any questions you have.

I have read and understood the foregoing descriptions of the study called An Investigation into the Development of a Practical GIS Supporting Emissions Inventory Information throughout the Environmental Sciences Sector. I have asked for and received a satisfactory explanation of any language that I did not fully understand. I agree to participate in this study, and I understand that I may withdraw my consent at any time. I have received a copy of this consent form.

Note: If this document is being sent electronically, your typed signature will be considered your signature.

Name \_\_\_\_\_

## 2. Task 1 - County Boundaries

1. For Inventory 13 (Inv. 13), on-road mobile sector (ON-ROAD MOBILE), what are the tons per year of carbon monoxide (CO) reported for Larimer County in Colorado?

2. If you could not answer Task 1 Question 1, what is the reason?

- I could not figure out how to get the answer
- The web page displayed an error
- The web page stopped responding
- Other (please specify)

3. If you were able to answer Task 1 Question 1, how difficult/easy was it to find the answer?

Very Difficult Very Easy

Ease of use

4. If you were able to answer Task 1 Question 1, how slowly/quickly did the web page respond to your actions?

Very Slowly Very Quickly

Response time

### 3. Task 2 - Facilities

1. Zoom in on Northern Colorado. For Inventory 9, point sector (POINT), facilities, what are the reported tons per year of Nitrogen Oxides (NO<sub>x</sub>) for the Eastman Kodak facility in Windsor, Colorado?

2. If you could not answer Task 2 Question 1, what is the reason?

- I could not figure out how to get the answer
- The web page displayed an error
- The web page stopped responding
- Other (please specify)

3. If you were able to answer Task 2 Question 1, how difficult/easy was it to find the answer?

	Very Difficult					Very Easy
Ease of use	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

4. If you were able to answer Task 2 Question 1, how slowly/quickly did the web page respond to your actions?

	Very Slowly					Very Quickly
Response time	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>



#### 4. Task 3 - Distance Tool

1. Zoom in on the area around Page, AZ in the North Central part of Arizona. Check the Class I Areas box. Select Inventory 12, point sector, facilities, and PM10 Primary (PM10\_PRI). Using the Distance Tool, what is the approximate distance from the Navajo Generating Station to the Northeast boundary (near Marble Canyon) of Grand Canyon National Park?

2. If you could not answer Task 3 Question 1, what is the reason?

- I could not figure out how to get the answer
- The web page displayed an error
- The web page stopped responding
- Other (please specify)

3. If you were able to answer Task 3 Question 1, how difficult/easy was it to find the answer?

	Very Difficult						Very Easy
Ease of use	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

4. If you were able to answer Task 3 Question 1, how slowly/quickly did the web page respond to your actions?

	Very Slowly						Very Quickly
Response time	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

5. Were the Class I Area boundaries displayed?

- Yes       No

### 5. Task 4 - Circle Tool

1. Uncheck the Class I Areas box then click the Clear Map button. Next, zoom in on the area near Rocky Mountain National Park in Colorado. Using the Circle Tool, how many facilities are there with greater than 500 tons per year of PM Primary within 100 km of the approximate center of Rocky Mountain National Park?

2. If you could not answer Task 4 Question 1, what is the reason?

- I could not figure out how to get the answer
- The web page displayed an error
- The web page stopped responding
- Other (please specify)

3. If you were able to answer Task 4 Question 1, how difficult/easy was it to find the answer?

	Very Difficult						Very Easy
Ease of use	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

4. If you were able to answer Task 4 Question 1, how slowly/quickly did the mapping tool page respond to your actions?

	Very Slowly						Very Quickly
Response time	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

## 6. Follow-up

1. Overall, did you find the mapping tool to be engaging (i.e., interesting, visually appealing, cool)?

Engaging Not Engaging Very Engaging

2. How useful do you think the mapping tool will be to air quality analysts?

Usefulness Not Useful Very Useful I don't know

3. Which Internet Browser did you use to perform these tasks?

Internet Explorer 6/6.5

Internet Explorer 7

Internet Explorer 8

Firefox

Other (please specify)

4. Please provide any comments you have regarding the mapping tool including suggestions for improvement and/or additional features.