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Technical Memorandum
Task 2.8.2
Project Web Site: Assessment of Technical Framework

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Urbanomics

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DEMOGRAPHIC AND SOCIOECONOMIC FORECASTING

PROJECT WEB SITE: ASSESSMENT OF TECHNICAL FRAMEWORK

TECHNICAL MEMORANDUM NO. 2.8.2

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TECHNICAL MEMORANDUM NO. 2.8.2
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TABLE OF CONTENTS

APPENDICES

1. Google Maps Examples
2. ArcWeb Services Screenshots
3. ArcWeb Explorer Screenshots

Technical Memorandum No. 2.8.2
Project Web Site: Assessment of Technical Framework

1.1 INTRODUCTION

This technical memorandum presents the results of the second phase of research into the technical requirements of an enhanced forecast review web application. A prototype application was developed under Task 18.2.2. It included reporting of forecasts in tabular and graph form, along with limited static maps. NYMTC has decided that it is desirable that this application be enhanced, or a new application developed, to add a dynamic GIS mapping capability. Such a capability would greatly improve the user's ability to visualize forecasts and contextualize them in relation to local geographic knowledge. This, in turn, would facilitate a more thorough process of forecast review.

A first phase of research was conducted during the fall of 2006 to determine a suitable technical platform for these enhancements. A draft memorandum presented an initial review of technological options for implementation of a web mapping component, along with a framework for their evaluation. Although the focus was on technical options, a broader framework of goals and strategic considerations was also articulated in order to help structure the evaluation of technological issues. The draft memorandum included an initial detailed review of a group of candidate technologies. This final memorandum includes a further evaluation of these options, along with a discussion of developments in web mapping products and services since the completion of the draft memo.

Web based mapping continues to be a very dynamic field, with new products and services being introduced regularly that extend the powers of this technology to a broader audience at a lower price. Using technologies such as AJAX and Flash, mainstream companies such as Google and Yahoo have created services that are more interactive and intuitive to use and allow overlay of users' geographic data, extending web map development to a popular audience. At the same time, established GIS companies such as ESRI have enhanced their line of products and services to leverage their existing capabilities and bring them to a wider market.

Research for this memorandum was conducted during a period when promising new services and service upgrades were being introduced regularly, including ESRI's ArcWeb Explorer and Google Maps 2.0 application programming interface (API). The subject has therefore represented something of a moving target, especially since the capabilities being introduced are often very relevant to the requirements of this Task. An attempt has been made to understand new developments and their implications for this project, with the understanding that further changes, enhancements, and bug fixes to the technologies investigated are likely to continue at a rapid pace in the near future.

Research for this Task has focused on products and services that offer the potential to implement an immediate extension to the current prototype forecast review application within the schedule and budget of the current forecast and forecast review process. This has meant an emphasis on well-established products and services, and on web services in particular. More extensive server-based GIS frameworks, such as ArcGIS Server, were not investigated because they do not offer the potential for implementation within the scope of the current forecast review project. These technologies may provide the best option for development of a long-term solution to forecast analysis and review.

The forecast review application is best conceived as a tool for information visualization, exploration, and interpretation. This is a more specialized set of functions than many web-based GIS applications whose purpose, for example, might be to make a broad range of spatial data available for reference, or to support a full range of GIS functionality in a distributed environment. Therefore the review of various mapping technologies has focused on their ability to support this interpretive function. The Transportation Analysis Zone (TAZ) forecasts include a number of variables whose values are distributed across time and space, the understanding of which can be aided by a variety of forms of representation. Graphs can help visualize temporal distributions and trends. Thematic maps can perform a similar function for spatial distributions and patterns. Tabular and textual information can provide detailed information on specific locations. Various methods and technologies can help support different types of representations.

Therefore while the focus of this Task is on a review of technical options, the process has been an iterative one between understanding the capabilities of specific technologies and the goals they are intended to support. The rapidly developing technologies reviewed here present great opportunities for the forecast review process in terms of a visual, interactive and collaborative approach to understanding model outputs and their implications. However, no set of products and/or services was identified that supports all of these opportunities within the rapid application development process necessitated by this project’s budget and schedule. Therefore, an effort has been made to review a number of the most promising alternatives and understand their advantages and disadvantages, both for the current project and within a larger strategic framework. The latter is facilitated by contrasting two possible overall strategic approaches, which emphasize information architecture and software extensibility, respectively.

The remainder of this memorandum presents the background of the project and a discussion of the different technical options researched. It begins with a presentation of key findings and conclusions from the final phase of research. This is followed by the evaluation framework and initial review of technological options as presented in the draft memorandum. The first section briefly reviews the technical framework of the existing prototype application. This is followed by a discussion of different strategic approaches to development of the application, and of related information on the current technical context. To provide a better understanding of the information architecture oriented strategic approach, a brief review of information architecture practices and concepts is then presented. An outline follows of the main goals that a web mapping component should achieve in order to support the enhanced functionality of the application. There then follows a discussion of the specific technologies considered, including a review of various alternatives and their respective capabilities, limitations, and problems.

The memorandum continues with a discussion of major developments in web mapping technologies since the submission of the draft memorandum. This is followed by a description of the further evaluations of the two main candidate technologies identified in the draft memo, ArcWeb Services and Google Maps. The memo finishes with a summary of findings and discussion of conclusions.

1.2 KEY FINDINGS OF THE FINAL PHASE OF RESEARCH

- Commercial web mapping continues to be an extremely dynamic area, with significant new products and services introduced since the submission of the draft memorandum.
- The trend towards dynamic, Google Maps style web-based applications has continued, and is likely to establish itself as the dominant form of web mapping technology.
- Google Earth has gained greater prominence as a platform for geographic data visualization in three dimensions. Competing technologies, such as NASA's World Wind and Microsoft's Virtual Earth continue rapid development.
- Google Earth's KML (Keyhole Markup Language) has been proposed as a non-proprietary standard format for representation of geographic data for internet based visualization purposes, in both two and three dimensions, and is likely to become increasingly widespread in the near future.
- Third party technologies continue to be developed that help non-programmers exploit the potential of Google Earth, Google Maps and similar technologies. In particular, they help facilitate the use of existing GIS data with these products, partially circumventing the need for investment in server-side GIS components.
- Commercial licensing continues to be a gray area that hinders the exploitation of new technologies in many settings. Many technologies are split between free general use licenses for non-commercial purposes and expensive, enterprise-oriented alternatives. More liberal commercial terms of use have recently been introduced for Microsoft Visual Earth and Google Earth, but may still not be adequate for the Forecast Review application.
- Of the technologies reviewed, ArcWeb Services SOAP API best supports the requirements of the Forecast Review application in the short term. However, because it fails to take advantage of recent advances in web mapping technologies, an application developed on this platform will likely require substantial changes in order to keep pace with emerging standards for map-based web applications.

1.3 EXISTING PROTOTYPE APPLICATION

The existing prototype application is discussed in detail in Technical Memorandum 18.2.2, *Forecast Review Application Development*.[1] The application was developed using standard open source web development technologies, including PHP 4.3.10 and MySQL 4.0.22. Additional open source PHP scripts were used for dynamic generation of graphs. The application includes static maps, which were generated in advance using ArcView GIS software and uploaded to the site as gif images. The application is hosted along with Urbanomics' web site on a shared third-party host running an Apache version 1.3.33 web server on the Linux 7.3 operating system.

[1] Technical Memorandum 18.2.2, *Forecast Review Application Development*, June 2003. The prototype site is available at http://www.urbanomics.org/NYMTC/Forecast_Review/Review_Logon.php. It should be noted that some features may not be fully functional and data may not be accurate.

The use of the standard, widely supported open source web development technologies was considered desirable because of the simplicity, portability, and ease of development they offer. An important question considered for this Task was whether these technologies are adequate for the enhanced application or whether the use of a different framework will be necessary.

1.4 STRATEGIC APPROACHES

Development of any software application involves a number of choices regarding issues such as overall application goals, functional requirements, usability considerations, design, software architecture, and technical platform. In addition, any software project exists within a technological environment that is often subject to rapid change. Two broad trends provide the current context for development of the forecast review application. First is the ongoing development of server-based Geographic Information Systems (GIS) technology, and in particular a trend towards distributed application architectures based on a web services model. Second is the recent explosion in popularity of dynamic, interactive, web-based applications that mirror many of the features of desktop applications, under the "Web 2.0" framework.

Both of these trends present great opportunities for the forecast review process in terms of a visual, interactive and collaborative approach to understanding model outputs and their implications. However, no set of products and/or services was identified that supports all of these opportunities in the context of the rapid application development process necessitated by the project's budget and schedule. Therefore to clarify the complex set of issues and their relevance for the current project, two alternative strategic approaches to development of the forecast review application are outlined below. The first would emphasize development of an information architecture for the application; the second would be more concerned with issues of software design and extensibility. They differ in terms of the choice of development goals they emphasize and the technological opportunities of which they take advantage. In reality, any actual application development process will involve some combination of both approaches. The purpose of articulating these approaches is to help to place the needs of the current project in a larger context. A fuller resolution of goals, including functionality from an information architecture perspective and development of a long term technical framework, would require a broader strategic review of NYMTC's business goals and technical infrastructure.[2]

The information architecture emphasis would concentrate the project's resources on articulating a desirable set of features for both current application development and future extensions. It would involve developing as rich an interactive application as possible, while deferring to a later phase longer term software architecture and technical platform decisions. Full advantage would be taken of API features for development of dynamic, browser-based interactive applications (see discussions of Google Maps and ArcWeb Explorer, below). Development of the application would be guided by the methods of the emerging discipline of information architecture, which seeks to develop

[2] See for example "New York City's Spatial Service-Oriented Architecture: An Overview", City of New York Department of Information Technology and Telecommunications Office of Strategic Technologies, August 2006.

frameworks for information navigation, display, and interaction in a context grounded by the needs of specific users and applications. This approach operates at a level of abstraction above specific technical implementations. Its output would include an application that would be fully functional for current purposes but, in a broader strategic view of software architecture and implementation, might best be understood as a working prototype. An additional important output would be a set of documents including statements of application goals, desired features, and graphic representations of application functionality such as flowcharts and wireframes. These would present a preferred direction of application development. This would be partially realized in the prototype application but would also be used to guide future decisions about application extensions and technical implementation. Information architecture concepts and methods are discussed in more detail below.

The alternative approach would concentrate on the development of a technical implementation that promises to be extensible within the context of NYMTC's current and planned technical infrastructure. Emphasis would be given to understanding the extensibility implications of different products and/or services, and to the creation of a software design that supports future extensions on a technical level. These goals, however, might come at the expense of immediate or future application functionality, and of a fuller exploration of application goals and requirements from an information architecture perspective.

1.5 TECHNOLOGICAL CONTEXT

The approaches discussed in the previous section can be related to the rapidly changing technological landscape in which the application will be developed. This involves two distinct, though related and converging, strands of technological development. On the one hand is GIS, and in particular an increasingly powerful set of server-based GIS technologies. On the other is "Web 2.0," a rapidly emerging set of technologies and development practices intended to create browser-based applications that are increasingly dynamic and facilitate interactivity and collaboration.

Server-based GIS technologies bring a substantial set of GIS capabilities to a server environment. These include the ability to dynamically combine, symbolize and display geographic data layers into finished map images, to query both spatial and attribute data, and to perform geographic operations such as buffering, proximity analyses, geocoding, routing, and map projections. GIS sever technologies are available both as software applications that can be installed and maintained by the user, and as web services that provide discrete server technologies hosted and maintained by a third party service provider.

Web 2.0 technologies represent a relatively recent trend in web development that is rapidly becoming established in the marketplace. It involves the development of dynamic, interactive applications that are created using application scripts run within the web browser, a so-called "thick client" model of development. Although earlier technologies such as Java have been used to implement this type of approach, it is only recently that a consensus, standards-based approach (nicknamed AJAX) has emerged using technologies including JavaScript, Cascading Style Sheets (CSS) and Dynamic HTML (DHTML). An alternative, proprietary set of technologies based on Adobe's Flash and ActionScript technologies has also become well established.

A number of technologies bridge these two worlds. Google Maps, for instance, was the application that popularized the Web 2.0 approach in 2005. By giving users the ability to add their own data to maps it brought web mapping firmly into the cultural landscape, yet does not offer a full and sophisticated set of GIS server capabilities. ESRI's ArcWeb Explorer, a new (August 2006) offering, attempts to extend the benefits of the Google Maps dynamic client approach to the company's existing set of GIS-based web services. Other, more sophisticated GIS sever products are increasingly integrating dynamic Web 2.0 client capabilities. In the case of both Google Maps and ArcWeb Explorer, the potential for application interactivity is realized by a sophisticated browser-based API framework, which in turn supports the development of particular end-user applications. Such API's bring benefits in terms of application functionality and development speed, but can also introduce a number of dependencies. Most obviously, the application depends on the set of API libraries on which it is based. More significantly, however, specific browser-based mapping API's may also be dependent on a particular server-side mapping technology or service: Google Maps on Google's map tile server and ArcWeb Explorer on ESRI's ArcWeb Services. The nature and extent of these dependencies is an important consideration in longer-term strategic choices about application development, a fact that is increasingly recognized in the software development community. One open source software project, OpenLayers, is attempting to provide the benefits of a rich browser-based API without the dependence on a particular server technology; it will be discussed further later in this technical memorandum.

1.6 INFORMATION ARCHITECTURE CONCEPTS AND METHODS

Information architecture is an emerging professional specialization intended to improve the development of complex information-oriented applications, with an emphasis on web applications. The key idea behind the information architecture approach is that issues such as functional requirements, the characteristics of users and context(s) of application use, and large-scale design issues including site organization and navigation, are best considered at a higher level of abstraction than detailed graphic design and independently of particular technological implementations. Information architects have developed a number of techniques to facilitate this process. On a large-scale project, the information architect would be a separate specialist working in collaboration with graphic designers, software developers, and project managers. Even on a smaller project, it can be helpful to selectively apply some information architecture techniques so that the choice of a technological implementation does not end up driving the goals of the application. Information architecture is concerned with a number of factors, including the goals of project sponsors; the needs of users; the form and functionality of the information environment; the organization and presentation of content within this context; and the information and communication technology infrastructure.[3]

In an extended information architecture process, all these issues could be explored through detailed research, evaluation, and testing. In a more limited process they can still be addressed in an explicit way prior to site design and implementation. This can include a formal statement of desirable site goals and features; specification of

[3] Earl Morrogh, *Information Architecture: An Emerging 21st Century Profession,* Prentice Hall 2003, p. 109.

assumptions about user needs and capabilities; and an articulation of an overall site architecture in terms of navigation and the general layout of important pages.

These considerations can also be related to existing technical frameworks through a process called gap analysis. This process involves an identification of the disconnects between goals and user needs, and the practical limitations of existing technology infrastructure. Tools that might help close these gaps can be investigated and a process initiated to determine the practicality of integrating them within the context of the current project.[4]

A number of forms of documentation can help facilitate the information architecture process. Conceptual diagrams can help illustrate abstract concepts, such as the roles of the application and its users within the broader information environment. Blueprints can communicate the organization of the major areas and structures of the site, including the set of major pages and navigation between them. Wireframes can depict the organization of important individual pages from an architectural perspective, including a specification of the major elements to be included on the page, their overall layout, and important aspects of user interaction.

The use of these techniques can help clarify the goals and requirements of the site and its major features. They can articulate different alternatives and desirable features, even if these may be beyond the scope of a particular development cycle or existing technical framework. In this way they can help provide both a guide to immediate development goals and a strategic framework for future site development.

1.7 GOALS OF WEB MAPPING TECHNOLOGY

The addition of a web mapping component to the prototype forecast review application is intended to address a number of goals of the forecast review process. It is also subject to the schedule and budgetary requirements of the forecast development and review project. These requirements place constraints on the technological choices available for application development. These issues are discussed below in terms of functional and technological goals for the application development.

1.7.1 Functional Goals

The enhancement of the web application through a web map component is intended to help facilitate an improved review of the forecasts. It can accomplish this in two main ways: through improved navigation to data for the specific area(s) of interest to a given user and through improved support for interpretation of the forecasts compared to tables or conventional graphic techniques such as bar charts. These general goals of improved navigation and interpretation can be translated into more specific objectives for a web mapping application component:

- **Improved Support for Navigation**
    - **Ability to access information through map-based navigation.** Because most people do not think intuitively in terms of the geographic

[4] Louis Rosenfeld and Peter Morville, *Information Architecture for the World Wide Web, 2nd Edition*, O'Reilly 2002.

units for which forecasts are made, such as Transportation Analysis Zones (TAZs) and Census Tracts, accessing information through tables and charts based on these units can be cumbersome and time consuming. Presenting these areas graphically on a map for the user's chosen area of interest would greatly enhance their ability to find the data they need. This would be further enhanced by the ability to access further information through a "point and click" mechanism. The ability for the user to easily pan across the map and zoom to desired locations would also facilitate quick access to desired information.

- **Improved Support for Forecast Interpretation**
    - **Visualization of geographic context of forecast geographies.** Visually locating forecast geographies, such as TAZs, in relation to more familiar geographic features is one of the most powerful advantages of mapping compared to other graphic visualization approaches. This can be achieved through the overlay of forecast geographies on other geographic features. The web mapping component should therefore offer the ability to overlay these units on other layers representing well known geographic features such as streets, parks, and water bodies.
    - **Contextual presentation of information in tabular, chart and other forms.** One of the most powerful capabilities of hypermedia systems, such as the web, is to provide a framework in which a variety of different forms of information can be dynamically presented in an integrated manner. Therefore it is desirable that any mapping technology chosen supports the ability to easily integrate presentation of other forms of information such as tables, charts, and hyperlinks to additional resources.
    - **Ability to aid interpretation of the forecasts by mapping of spatial patterns and distributions.** Conventional reporting techniques such as tables and line graphs can facilitate the presentation of projection series over time. However, an important aspect of the Transportation Models and Data Initiative (TMDI) forecasts is their geographic distribution across the region, and this can best be visualized by means of thematic maps. For example, standard techniques such as graduated color maps can be used to represent magnitude or rate of forecasted change of population or employment. Such forms of spatial representation can make trends and patterns clearer and more comprehensible and relevant to the concerns of stakeholders.

1.7.2 Technological Goals and Constraints

In addition to the functional requirements discussed in the previous section, the following technological considerations must be taken into account.

- **Rapid Application Development.** Because of the accelerated schedule for completion of the forecasts, including forecast development, review and revision, the need for rapid application development is crucial.
- **Server Configuration.** As discussed above, the existing application is hosted on a shared Linux/Apache server. NYMTC has indicated that, given their current server configuration and resources, they will not be able to host the web mapping component of the application during the period of forecast development and review, though they may wish to host it afterwards. Urbanomics does not

maintain its own server. Therefore it is important that the application be able either to run on the existing server platform, or that the time and work necessary to move the application to a new server environment be minimized to the extent possible.

- **Compatibility with NYMTC's Server Platform.** Because NYMTC uses Microsoft's Internet Information Services (IIS) technology for their web server, any application must be capable of being run on IIS.

1.8 TECHNOLOGIES REVIEWED

A number of technological options were considered, including both open source and commercial web mapping applications, as well as free and commercial web services.

The options considered can be divided into two main types: the maintenance of a GIS map server and the outsourcing of the web map component through use of a web service. Because of the development time and server configuration considerations discussed above, research for this task has focused on web service options, though options for setting up a web mapping application server have also been reviewed.

1.8.1 GIS Server Applications

Two server side web mapping application packages were reviewed: MapServer and ArcIMS. MapServer is a leading open source web mapping application. ArcIMS is a map publishing application from ESRI, a major commercial GIS vendor. MapServer was considered because it is a relatively well established product whose direct support for PHP scripting would allow a direct extension of the current PHP-based prototype application. ArcIMS was reviewed because it is the product that NYMTC currently runs on its server.

MapServer

MapServer is a leading open source web mapping application originally developed by the University of Minnesota and now supported by a community of developers. It offers an extensive set of capabilities that are fully able to support the requirements of this project. These include advanced cartographic output capabilities such as thematic mapping using logical or regular expression based classes, and spatial querying of feature attributes. MapServer provides good support for the geographic data sources already in use for the TMDI project, such as ESRI shape files, as well as MySQL databases, which are used by the prototype forecast review application. MapServer can be scripted using PHP, the scripting language used for the prototype application, as well as by other popular open source and commercial languages including Perl, Python, Ruby, Java and C#. It can be run on a variety of platforms, including Linux and Windows. MapServer can also be configured to run as a web service, meaning that it can be flexibly integrated with applications running on separate servers (see discussion of web services, below).

The major disadvantages of MapServer in the context of the current project include server configuration and technical support. MapServer software would need to be installed and configured on a server, which is not possible in the prototype application's current shared hosting environment. Therefore a new and more flexible server plan would need to be negotiated at a higher cost, including the likelihood of additional staff time for installation of the MapServer application and any necessary ongoing support by server maintenance staff. Unlike a commercial product such as ESRI's ArcIMS, MapServer does not come with a set of technical support services, though some support is available through the MapServer user community. Successful deployment of open source applications can require technical knowledge beyond that required to install commercial software on standard operating systems such as Windows. An industry has developed that offers tested configurations and technical support to users of open source software, exemplified by Red Hat's deployment of Linux, which did much to popularize that operating system within the business community. Alternatively, organizations may choose to rely on in house staff but in that case must make sure that they have the technical skills and staff time available to resolve problems that may arise with a deployment in a particular operating system environment. In sum, though free of licensing fees and restrictions and often offering capabilities to rival commercial applications, open source software can entail hidden costs that must be judged against the capabilities and resources of any given organization.

In conclusion, MapServer is an appealing application whose capabilities fit the requirements of this project well. It is in some ways the most directly compatible with the existing prototype application because of its support for PHP scripting on the server. However, the difficulty and likely cost of setting up and maintaining the application on a server make it a problematic and risky choice given the current project's scheduling and budget requirements.

ArcIMS

ArcIMS is a web map publishing application developed by ESRI, a leading commercial vendor of GIS technologies. ESRI's ArcGIS desktop products are already in use by both NYMTC and Urbanomics for other aspects of the TMDI project. Like MapServer, ArcIMS offers an extensive range of capabilities that are fully able to support the project's requirements.

ArcIMS is used to set up map publishing services on a web server. These can then be accessed programmatically on the server through Java, ColdFusion, or Microsoft's .NET languages (Visual Basic .NET and C#), which enable ArcIMS maps to be fully integrated within web applications. Alternatively, ArcIMS maps can be accessed directly from the web browser using HTML or Java viewers provided with the ArcIMS installation.

The major disadvantage of ArcIMS for the current project is the extensive commitment it would require in terms of server maintenance, similar to that required for MapServer. In addition, unlike MapServer it does not support scripting in PHP, the language used for the current application, or other open source scripting languages popular for web development, such as Perl and Ruby. Instead its support is limited to the commercial frameworks Cold Fusion and .NET and to the Java language, which is generally used for large enterprise systems and not for rapid web application development. Therefore, use of MapServer entails a greater commitment to one of these broader frameworks. Licensing for ArcIMS also entails a substantial up front cost.

In sum, ArcIMS is best suited for settings where organizations have made a major long-term commitment to operating a web mapping server and to one of the development environments (Java, .NET) that it supports. These, however, fall outside the scope of the current project.

1.8.2 Web Services

Because they offer the potential to immediately extend the prototype forecast review application, web services were the main focus of review for this Task. They are designed to circumvent the heavy commitment to server operation and maintenance discussed above, as well as the upfront software costs associated with commercial web mapping applications such as ArcIMS. In this model, specialized application components, such as map generation and spatial queries, are hosted on separate servers maintained by the service provider, which may be located anywhere on the web. These can be accessed programmatically in any language through common protocols, including SOAP and REST. Client organizations may then contract with web service providers for just the capabilities they need to develop a specific application. Although the term "web services" is used within the software development community to refer to particular sets of protocols, such as SOAP and REST, for the purposes of the current discussion it will be used to refer more broadly to any technology, such as Google Maps, where a portion of application functionality is hosted by a third party service provider.

Because of the potential of this approach to bring specialized software capabilities to a much broader market, web services have received strong backing from major industry players such as Microsoft. Within the GIS world, ESRI has shown a strong commitment to web services through its ArcWeb Services framework, which uses SOAP as it main protocol.[5] Use of a SOAP-based web service within a particular application is supported by use of a toolkit, which translates between the intermediate SOAP protocol and the native language of the client application. Such toolkits are available for all major programming languages and are part of the core of Microsoft's .NET languages (Visual Basic .NET and C#).

Mapping related web services have recently gained a high profile through the success of Google Maps, as well as competing products offered by companies such as Yahoo. These make the development of custom mapping applications available at little or no cost to a broad audience through the development of "mash ups," which allow users to overlay their own data on Google base maps. Though further from the full set of GIS capabilities than commercial web services such as ArcWeb, within their limitations they nevertheless provide the ability to develop attractive and functional applications.

Two web services were evaluated for the current task: Google Maps, the leading web mapping service intended for a broad public audience, and ESRI's ArcWeb Services.

Google Maps

Google Maps garnered broad attention for its dynamic user interface, which allows viewers to seamlessly pan and zoom across maps within the browser without the need to refresh the entire web page. It is considered by many to be the "killer application" of a new generation of highly interactive web applications, popularly labeled Web 2.0, which are bringing the capabilities of web applications closer to those of conventional desktop

[5] "Understanding ArcWeb Services: An Overview for Developers," ESRI Technical Paper, May 2004. See also "The GeoWeb: Spatially Enabling the Next-Generation Web," ESRI White Paper, April 2006.

programs through techniques referred to as AJAX. Google Maps was designed from the ground up to allow users to overlay their own data using a simple JavaScript API, though this is most easily done for simple point symbols rather than polygon or raster layers. Because all calls to the map server are made from the browser through JavaScript, Google Maps is not tied to any server side scripting language. The appeal of the Google Maps approach, in particular its dynamic client side user and programming interfaces, is attested to by the development of competitive products with similar capabilities such as ESRI's ArcWeb Explorer, discussed below.

One of the most common uses of Google Maps is as an aid to searching for information about locationally based entities. For instance, customers can locate shops and restaurants for a particular area on a map and then retrieve information such as products, services, and opening hours. Google Maps facilitates this through the ability to easily program information windows that are embedded within the map. The contents of these windows is HTML and therefore they can contain anything that can be shown on a standard web page, including graphic images, tabular data, and hyperlinks to other pages. The latest version of Google Maps includes enhanced features such as windows that contain more than one information tab.

Google Maps easily facilitates the overlay of point data, which can be rendered using custom symbols supplied by the user. Thus colors, shapes, and graphic images can be used to make the maps easier to interpret. In addition, external software libraries make possible the creation of on-the-fly symbols on the server. For example, Tract or TAZ identifiers or other textual information can be drawn from a database and used as the basis for map symbols. Marker qualities such as color, size, value and shape can be dynamically generated to symbolize location attributes. It is also possible to overlay polylines based on a series of coordinates

The last major version of Google Maps, 2.0, added the ability for users to overlay their own raster images on Google's base maps, or to use such images to create their own custom map types. Doing so, however, requires either the advance preparation of raster images through preprocessing or the use of the user's own server-side scripting technology to generate them dynamically. These capabilities are not supported directly by Google Maps, but a body of third-party technologies has begun to emerge including open source scripts developed by the user community. A particularly promising commercial technology is Arc2Earth, which has been released in a major new version since the completion of the draft Technical Memorandum. It offers the ability to automatically generate Google Earth and Google Maps-compatible data directly from within ESRI's popular ArcMap desktop GIS application. Arc2Earth is discussed further in the section on recent web mapping developments, below.

Google continues to regularly offer incremental upgrades to Google Maps' functionality. Recent improvements include marker management, which makes possible the presentation of larger amounts of overlay data than was previously feasible, using techniques such as marker clustering. A recent, feature, which has become officially supported since the draft memorandum, is browser-based polygon overlays. However, because of the computational demands it places on the web browser, this feature may be of limited use for applications, including the Forecast Review, which require the mapping of hundreds or thousands of features.

Google Maps' greatest strengths lie in the realm of browser-based, dynamic Web 2.0 application development. Compared to true server-based GIS technologies it suffers from some important limitations. First, it does not offer the ability to dynamically overlay custom data layers to create composite map images from the map server. Nor does it provide direct support for common polygon-based thematic mapping techniques such as graduated color or dot density maps. Rather, overlay of custom data is handled in the client web browser through JavaScript programming. As discussed above, conventional GIS capabilities such as custom base maps and popular thematic mapping techniques are left to the user to implement. Nor does Google Maps offer spatial or attribute querying capabilities. These can be developed, or simulated, but again it is up to the user to do so.

It should also be noted that competitors such as Yahoo and Microsoft have developed similar web mapping services to compete with Google. Microsoft's Virtual Earth, in particular, has emerged as a strong competitor in recent months with favorable terms of use, the development of high quality data sets, and a recent commitment to the development of high quality 3D modeling capabilities.

Google Maps is available through a public use license that requires any web site that uses it to be available to the general public. The terms of the license in this regard might be satisfied by making some information (such as 2005 baseline data) available to the general public while restricting access to other information to project stakeholders. The public license is free of charge. Google also offers an Enterprise license for its mapping services, though it does not publish rates or terms. It is also important to note that the license agreement does not place Google under a contractual obligation to continue to provide the service and they are legally free to discontinue it at any time, though this is unlikely in the near future. The license also permits Google to alter the service in ways that might include changing of its appearance, alteration of the programming interface, or inclusion of sponsored advertisements.

Google Maps is currently used to support a wide variety of applications in areas including real estate, education and public health. A set of examples is included in Appendix 1.

Judged against the goals for a mapping component outlined above, Google Maps displays a combination of strengths and weaknesses:

- **Ability to access information through map-based navigation.** Google Maps' map-based navigation is one of its great strengths. Seamless panning and zooming makes access to data fast and intuitive through the map interface.
- **Visualization of geographic context of forecast geographies.** Google Maps uses a good general reference map (or rather set of maps, depending on zoom level) as a backdrop for custom overlays. Alternatively, satellite images or a street map/satellite hybrid can be used. It is possible to customize these using raster overlays, or replace them entirely with a custom map type. However, doing so requires a substantial amount of programming or preprocessing of geographic data using separate software. This is in contrast to ArcWeb Services (discussed below) where custom GIS layers can be uploaded to the web service site and overlaid seamlessly into a single map image using a simple API.

- **Contextual presentation of information in tabular, chart and other forms.** Google Maps offers excellent support for integration of textual and graphic data through its easily programmed Information Window. Because this is simply an HTML document division (div) element, anything that can be included in a web page can be integrated within the map, including tabular data, graphic images, and hyperlinks. Other forms of contextual information display, such as custom tool tips, can be created with a moderate amount of programming
- **Ability to aid interpretation of the forecasts by mapping of spatial distributions.** As mentioned above, Google Maps has recently introduced the ability to render filled polygons, in addition to polylines and points. However, the computational demands that this places on the browser mean that it may not be adequate for common polygon-based thematic mapping techniques, such as graduated color and dot density mapping, where large numbers (hundreds or thousands) of features must be represented. These can be developed but doing so requires pre-processing of imagery and/or custom server-side scripting, as discussed above. Google Maps' native polyline overlays can be used to achieve some more limited techniques for showing spatial distributions, for example simple bar graphs and circles that display magnitudes using size and color. More flexible is the use of custom markers. These can be defined statically based on custom designed graphic images, or dynamically using server side image generation software that customizes the size, color, and shape of the symbol based on the attributes of each location. When generated dynamically, they can be used to achieve some useful thematic mapping techniques, such as graduate and proportional marker symbols. It should also be noted that Google Maps' reliance on JavaScript in the web browser means that overlaying large numbers of markers (i.e., greater than 100) can lead to degradation in performance. However, a number of techniques are supported to limit the number of markers displayed for a given extent (for example, based on proximity to a selected location of interest), or to generalize individual locations so that they are represented by a single cluster marker at smaller scales and by separate markers at larger scales.

It should be noted that the consultant has experience with development using Google Maps that could be transferred to the forecast review application, including PHP code libraries and simple AJAX-based browser interfaces for dynamic user interaction.

ArcWeb Services

ArcWeb Services is subscription-based set of Web service APIs that offer a subset of the capabilities of ESRI's desktop and enterprise GIS software for incorporation into web applications. Using the ArcWeb portal, developers can create custom services for tasks such as map image generation, spatial queries, and route finding. Map image services can combine the user's own GIS layers and attribute data, uploaded to the ArcWeb server, with layers hosted by ESRI. Each map image service is analogous to an ArcMap data frame, and is made up of a set of layers that, when rendered together, make up a map. Symbolization of each layer can be customized by the user. Spatial query services return attribute data associated with geographic features based on input coordinates representing points, polygons, or extent envelopes.

Programmers can access ArcWeb Services within their applications through a number of different APIs, including SOAP and JavaScript. SOAP is a standard protocol for accessing web services over the internet, and serves as an intermediate communication layer to facilitate interaction between programs written in different languages and running in different environments. Use of a SOAP-based web service within a particular application is supported by a toolkit, which translates between the intermediate SOAP protocol and the native language of the client application. ArcWeb Services uses SOAP as the primary API through which it makes all service capabilities accessible. Other APIs include a subset of the SOAP capabilities. Although use of SOAP means that ArcWeb Services can in principle be accessed from within any programming language, ESRI only offers support and testing for toolkits used by three programming environments: Sun's Java, Microsoft's .NET, and Macromedia's Cold Fusion. Toolkits are available for other languages, including PHP, but because SOAP is a relatively new standard, incompatibilities remain and not all toolkits are fully compatible with ArcWeb Services. It is possible to send SOAP requests to the ArcWeb Server directly without using a toolkit but this involves a far more time-consuming development process. With the support of a toolkit, programmers can interact ArcWeb Services APIs as if they were application components located on the same server.

ArcWeb Explorer is a relatively new (August 2006) client for ArcWeb Services that uses a combination of Flash and JavaScript to access them directly from the browser. Flash is used to render the map, including raster images and vector overlays drawn dynamically within the browser. The Flash map is controlled programmatically using a JavaScript API. This technique facilitates dynamic interaction with the map similar to that offered by Google Maps, including seamless panning and zooming and overlay of markers. The drawback of ArcWeb Explorer is that it does not yet support the full set of SOAP services. Most importantly for the current project, thematic mapping using custom data is not yet available. The SOAP interface, on the other hand, delivers a single map image from the server with each request, meaning that interaction with the map is slower and more limited, and requires more programming overhead.

A detailed assessment of ArcWeb Services was conducted under a 90-day commercial evaluation license agreement using the prototype application's web hosting platform, which is based on PHP 4, MySQL, and Linux. A shape file containing Census Tract boundaries for the New York Metropolitan Region was uploaded to the server and used to build two services: a MapImage service and a SpatialQuery service. SOAP testing was conducted under PHP 4 using the open source NuSoap toolkit version 0.7.2. ESRI does not officially support any PHP toolkits at this time, and does not offer code samples for them in their ArcWeb Services documentation comparable to those for other toolkits used in Java, .NET and ColdFusion. However, non-supported code samples have been developed by ESRI support staff and distributed in an unofficial capacity through the ESRI web site's user forums. Additional code samples for NuSoap have also been made available on the web by the larger user community, including both ESRI staff and others.

While the map image creation services were successfully tested, some problems were encountered with spatial query functionality. These problems may have to do with the lack of support for the NuSoap toolkit. In order to generate a complete and valid SOAP request, the SOAP client must be initialized using the web service's Web Service Description Layer (WSDL), which, among other things, specifies details of data types used as parameters in the request to the server. It is possible to generate a SOAP request in NuSoap without this initialization that, though incomplete, may still be executed successfully by the server. For reasons that are unclear, all the NuSoap sample scripts offered by both ESRI staff and third parties do not initialize the SOAP client using WSDL.

The latest PHP sample scripts posted to the user forum by ESRI staff do use WSDL to initialize the SOAP client. However they are developed not with the NuSoap toolkit but instead with the newer native PHP SOAP extension incorporated in PHP version 5. PHP 5 is not supported by the prototype application's current shared host, but is offered by other shared hosting providers at a low cost.

The major implication of these tests is that use of ArcWeb Services would best be supported by some sort of change to the forecast review application's server platform. This might involve upgrading to a host that supports PHP 5, in which case current application code could be retained. This, however, would necessitate adequate testing of the PHP 5 SOAP toolkit since it is not officially supported by ESRI. Alternatively, the application could be ported to an officially supported framework. In this case, an initial review indicates that Microsoft's .NET framework would offer the best set of rapid web development capabilities.

Although ESRI offers a variety of interfaces to ArcWeb Services, including SOAP and REST, at present the full set of features is supported only by the SOAP interface. Therefore, if NYMTC wishes to move this functionality in house at some point in the future, through ArcIMS or another server technology, it would be necessary to encapsulate this technology within a SOAP interface parallel to ESRI's. This would be in line with the emerging Service Oriented Architecture (SOA) approach to enterprise software development, and should be a routine programming task. Following the SOA model, it would be compatible with the use of any framework used for the forecast review application, including the current PHP/Linux platform. Alternatively, the code used to access the web mapping functionality could be rewritten to access ArcIMS directly through a server-side connector. This option would only be available if the forecast review application were ported to a compatible framework such as .NET.

Appendix 2 includes screenshots of a web mapping application developed using ArcWeb Services. Although the server-side scripting used to generate this application is not accessible to the user, its functionality is consistent with a SOAP-based application. Appendix 3 includes screenshots of ESRI's ArcWeb Explorer demo application. This demo includes a full set of ArcWeb Explorer capabilities, not all of which may be relevant to the forecast review application. For example, the thematic maps shown in the Appendix are generated using data hosted by ESRI. Such map types may not be fully supported for custom user data.

The SOAP and JavaScript ArcWeb Services APIs are evaluated separately against the mapping component goals.

SOAP API:

- **Ability to access information through map-based navigation.** The SOAP-based API is commonly used for the generation of single map images through server-side scripting. This means that the dynamic, client-side interactivity of Google Maps and ArcWeb Explorer is not supported. Panning and zooming are therefore slowed by the necessity of a separate request to the server for each new map extent. The

SOAP interface does support the ability to query map locations based by pointing and clicking.

- **Visualization of geographic context of forecast geographies.** Because ArcWeb services allows users to host custom GIS layers on their servers and combine these with ArcWeb layers to produce map images, this option offers great flexibility for the presentation of contextual geographic information.
- **Contextual presentation of information in tabular, chart and other forms.** The SOAP API does not support the integration of other types of information, such as tables and images, directly on the map. Some level of such integration may be achievable, but would require JavaScript programming. A simpler approach would be presentation of additional contextual information elsewhere on the screen, either in a static, page-like layout or in a more dynamic user interfacing through techniques such as tabbed windows or floating panels.
- **Ability to aid interpretation of the forecasts by mapping of spatial distributions.** The SOAP API offers support for common thematic mapping techniques used for displaying spatial distributions, such as graduated color polygon layers.

JavaScript API (ArcWeb Explorer):

- **Ability to access information through map-based navigation.** The JavaScript API offers seamless panning and zooming similar to that of Google Maps.
- **Visualization of geographic context of forecast geographies.** The JavaScript API supports the presentation of contextual geographic information through the use of user-defined custom map services, which can combine custom GIS layers with ESRI data.
- **Contextual presentation of information in tabular, chart and other forms.** Rich Flash markers enable the display of information in a variety of media, including text, graphics, audio and video.
- **Ability to aid interpretation of the forecasts by mapping of spatial distributions.** Currently, unlike the SOAP implementation, the JavaScript API does not support thematic mapping with custom data. Some thematic mapping functionality, such as graduated polygon maps, may be possible but would require set-up as separate map services on the ArcWeb Server, thus circumventing ArcWeb Explorer's dynamic JavaScript API.

An Open Source Alternative

Both of the dynamic client-side alternatives, Google Maps and ArcWeb Services/ArcWeb Explorer, rely on proprietary technology and licensing. Both typically are tied to a particular service provider to serve map images. OpenLayers, an open source alternative, has been developed to overcome these limitations and provide a modular, extensible application architecture in line with best software development practices. It consists of a set of JavaScript libraries functionally similar to Google Maps but capable of interacting with a variety of server technologies to serve map images. These include Google Maps, Microsoft Virtual Earth, MapServer, WMS-compliant web services (such as ArcIMS with the WMS extension), and custom map image sources developed by the user. OpenLayers, therefore, offers the potential for development of Google Maps style dynamic applications without dependence on Google. Google Maps could be used initially as a source of map images, and then later substituted with another source if desired. For this draft memorandum, OpenLayers' API was reviewed but the software was not tested. As an open source project, OpenLayers may suffer some disadvantages compared to Google Maps and other commercial products. The latter may be first to offer useful feature enhancements, such as the marker management recently added to Google Maps. They may also be quicker to respond to changes in browser technology, such as the recent release of Microsoft's Internet Explorer version 7, which have the potential to introduce subtle compatibility problems with existing scripting frameworks. Popular services such as Google Maps receive real world testing through application development by a broad user community. Still, if the extensibility advantages offered by OpenLayers are considered important, it may be an option worth reviewing for the final draft of this memorandum.

1.9 REVIEW OF TECHNOLOGICAL DEVELOPMENTS SINCE THE DRAFT TECHNICAL MEMORANDUM

In the several months since the completion of the draft technical memorandum, a number of significant products and services have been released that have the potential to significantly shape the nature of web-based mapping applications over the next few years. In particular, new technologies are increasing the recent emphasis on highly dynamic, interactive applications in both two and three dimensions. Major companies, such as Google, Microsoft, and ESRI, are actively competing to establish an increased presence in this area. A number of smaller companies and open source projects are also actively engaged in offering alternative or complementary products.

Google continues to be a dominant force in the development of web-based mapping technologies for a broad market. Their two-dimensional mapping technology, Google Maps, has already been discussed above. They also offer Google Earth, a three-dimensional application that simulates a traditional earth globe, with the ability to dynamically overlay web-based layers in one, two or three dimensions.[6] Google Earth uses a stand-alone viewer application that must be downloaded and installed by the user. It is available free for non-commercial use, and recent changes to the licensing terms also offer the potential for at least limited uses in a commercial setting. There are also a number of paid license versions that offer additional features.

Google Earth offers the potential for a powerful environment for geographic data visualization, though its adoption has been limited in commercial settings until recently by restrictions in the terms of use, as well as the fact that users must download and familiarize themselves with a new application. However, its role is likely to expand due to several factors. First, Google has recently invested in increasing integration between Google Earth and Google Maps. Support has also been introduced in Google Maps for Google Earth's KML data format (though this is still limited to relatively small data sets). This offers the possibility of using the web to publish information that can be viewed either directly in a web browser through a two-dimensional map interface, or in three dimensions using the separate Google Earth viewer. Google has also recently announced their intention to seek approval of the proprietary KML data format as a public standard. This would establish it as a common language for representation of map data and therefore could help dramatically increase its use by encouraging adoption by third party application developers.

[6] See http://earth.google.com for more information.

A related development is the increasing availability and sophistication of applications, both free and commercial, that address the problem of converting existing GIS data to KML format and publishing it to the web. Perhaps the most significant of these is Arc2Earth Publisher[7], which offers an integrated solution that includes exporting of ArcGIS thematic layers to KML, generation of JavaScript for a basic web viewer, and posting the data to S3, an inexpensive hosting service offered by Amazon.

Although this suite of technologies is relatively new and therefore not yet extensively deployed in real world applications, reaction in the GIS developer community indicates that it may represent an important new option that will help improve the quality and reduce the expense of developing sophisticated web-based mapping solutions.[8]

1.10 ADDITIONAL EVALUATION OF CANDIDATE TECHNOLOGIES

During the summer of 2007, additional testing was performed on the two leading candidate technological alternatives, ArcWeb Services and Google Maps.

1.10.1 ArcWeb Services

Because of problems encountered using ArcWeb Services with SOAP toolkits under PHP, as discussed above, an additional series of tests was conducted using Microsoft's ASP .NET, which is officially supported by ESRI. A new evaluation account was opened and Map Image and Spatial Query services were created. Basic web application pages were developed in ASP .NET using Visual Basic, and were deployed to a test server. No major problems were encountered with the functionality of the services using the ASP .NET SOAP toolkit. However, there were some difficulties properly setting up the Map Image service. For example, there were problems with the rendering of map layers at small scales. Also, automatic generation of display ranges for graduated polygon maps did not function properly, necessitating time-consuming manual entry of ranges.

Overall, ArcWeb Services performed adequately in the new round of tests. However, unless a solution is found, problems with setting up the Map Image services could significantly increase the time necessary to deploy the Forecast Review application.

In addition, it should be noted that an application developed using ArcWeb Services at this time would not take advantage of ArcGIS Server's Application Development Framework (ADF) technology. ArcGIS Server and ADF are discussed further in the Conclusion to this memorandum.

1.10.2 Google Maps

Additional evaluation of Google Maps focused on possibilities for implementing graduated polygon maps, which is an important capability for the visualization of TAZ level forecasts. Review of the on-line literature indicated that the new browser-based polygon rendering capability would not be adequate for the hundreds or thousands of

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[7] http://www.arc2earth.com/default.htm.

[8] See for instance the Spatially Adjusted blog at http://www.spatiallyadjusted.com/2007/04/23/the-day-arcims-died.

features that would need to be displayed in the Forecast Review application. Therefore two alternative techniques were explored: use of Google Map's new support for KML to render polygons, and export of ArcMap layers to image files that can be overlaid on the Google base map.

Use of KML offers the most straightforward technique for rendering polygons in Google Maps. ArcMap layers can be exported to KML using any number of free or commercially available technologies. The KML file can then be deployed to a server. A simple JavaScript reference to the KML file is all that is required to overlay the polygons in Google Maps. However, at the time that testing was conducted, significant limitations were encountered in the number of KML features that Google Maps was able to render. For example, a KML file containing polygons for the roughly 300 Census Tracts in Suffolk County could not be displayed and produced an error message.

The most common technique encountered for displaying polygons in Google Maps is the export of a map layer to a set of graphic image files. These are then uploaded to a server and, using JavaScript programming, are overlaid on the image tiles that make up the Google Maps base map. The Arc2Earth Publisher application, discussed above, is designed to facilitate this process, automatically generating the appropriate image tiles to be displayed in Google Maps at a variety of zoom levels. Arc2Earth can also automatically upload the tiles to Amazon's S3. This is a special hosting service specifically designed for storing and serving large volumes of data. Because of the large amount of image data needed render a geographic area as large as the New York region, use of such a bulk server would be advisable in order to reduce hosting costs.

Based on a review of the Arc2Earth documentation and secondary literature, this software would probably offer the most feasible scenario for producing graduated polygon displays in Google Maps. However, compared to the use of KML, it would involve a greater level of effort to manage the image tiles, write the JavaScript necessary to overlay them, and set up hosting. Therefore this option was not tested directly for this Task.

In addition to these technical considerations, licensing for Google Maps remains a gray area at this time, as discussed above. In particular, the fact that the Forecast Review application would not be accessible to the general public would contradict the current Google Maps terms of use.[9]

1.10.3 Summary of Evaluation

The evaluation of the two leading alternatives, Google Maps and ArcWeb Services SOAP API, is summarized in the table below.

[9] Compared to Google, Microsoft has recently announced liberal commercial use licensing terms for their competing Virtual Earth service. However, even these terms make the use of the technology for non-public sites problematic. See http://virtualearth.spaces.live.com/Blog/cns!2BBC66E99FDCDB98!8654.entry.

Criterion	Google Maps	ArcWeb Services SOAP API
Access information through map-based navigation	Supported	Supported
Visualization of geographic context	Google Maps base maps and satellite images are standard. Overlay of custom map layers requires separate software and/or programming.	Overlay of custom map layers is supported. Use of a variety of base map layers and imagery is available as standard part of service.
Contextual presentation of tabular and chart data	Multi-tabbed pop-up windows allow seamless integration of a wide variety of information.	Not directly supported, but could be partially achieved using JavaScript and DHTML.
Ability to map spatial distributions through graduated polygon maps	Display of large number of polygon features would require pre-preparation using separate software in order to achieve acceptable performance.	Directly supported, though problems with automated set-up may make production time consuming.
Licensing for use in non-publicly accessible applications	Precluded by general terms of use. Enterprise license available, but costly.	Supported.
Upgrade path to new standards for interactive mapping and 3D visualization	Upgrade path is promising due to Google's investment in data standards and integration of Google Maps and Google Earth Technologies.	ESRI's ArcGIS Server and ADF represent logical upgrade path for ESRI-based web mapping applications. Forecast Review application would require substantial alterations to be compatible with this framework.

1.11 CONCLUSIONS

From a technical standpoint, both ArcWeb Services and Google Maps offer viable alternatives for a Forecast Review application. Google Maps, and supporting technologies such as Arc2Earth, have matured to the point where they present an attractive option for developing highly interactive web-based mapping applications that do not require investment in server-side GIS and are therefore relatively simple and inexpensive to deploy. Furthermore, Google is making substantial investments to integrate Google Maps and Google Earth technologies and to establish KML as a public standard for publishing geographic data on the web. This means that an application developed using Google technologies would almost certainly have a good upgrade path as standards for interactive web mapping improve, as well as the support of a large community of users and developers. However, the problems regarding commercial licensing terms mean that Google Maps is not a feasible alternative in the short term given that the Forecast Review application will not be accessible to the general public. This situation may change in the near future as Google continues to face strong competition from Microsoft, which has recently extended improved licensing terms to developers of commercial applications. Reevaluating Google technologies might make sense at that time.

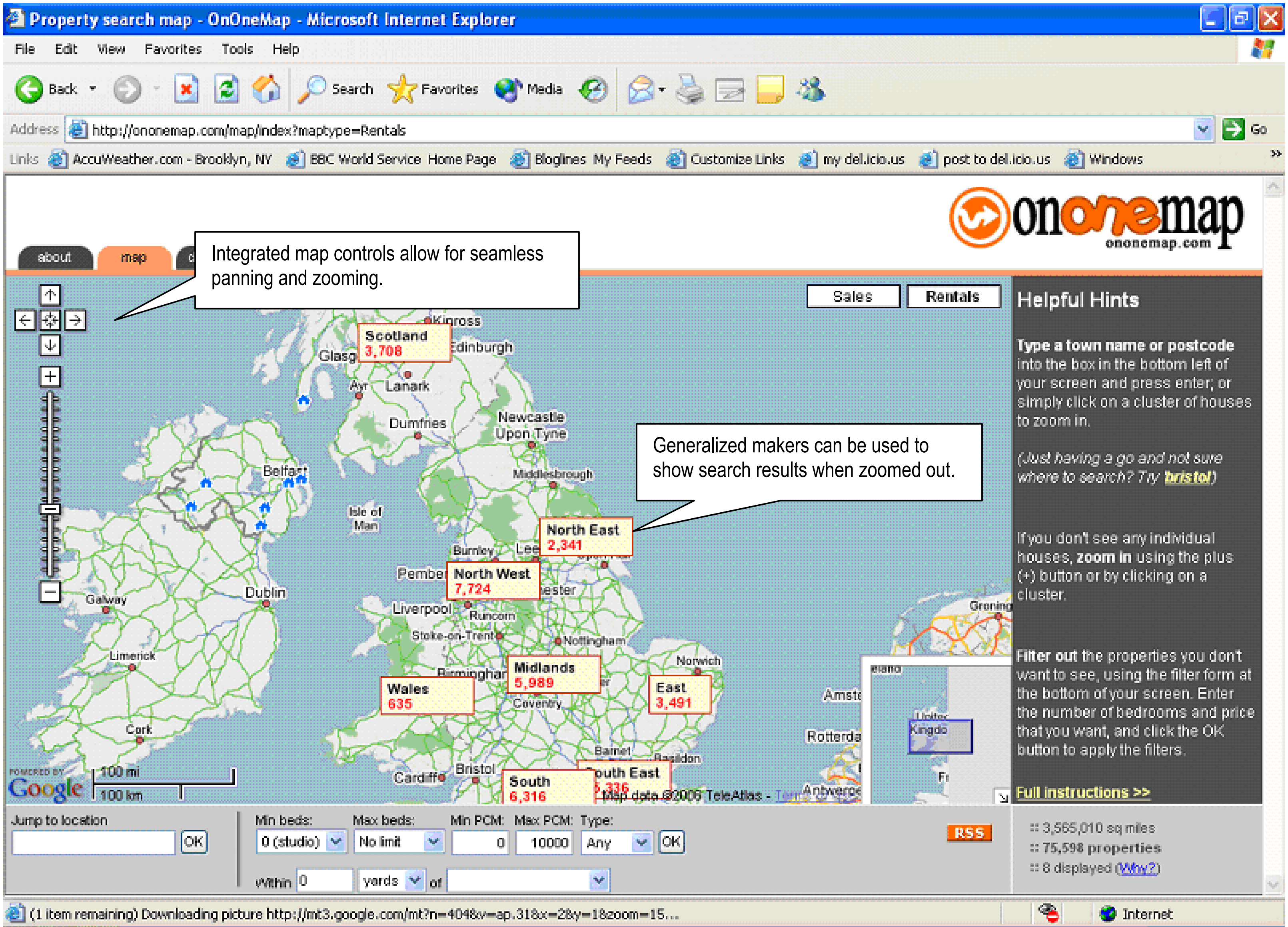
In comparison, ArcWeb Services offers the appropriate commercial licensing for the Forecast Review application. However, only the SOAP version supports the full range of required functionality. This technology involves the generation of single, static map images with each request to the server. This is in contrast to the dynamic, interactive mapping interface offered by Google Maps and a growing number of competing products such as Virtual Earth and OpenLayers, discussed above. Therefore, while an ArcWeb Services based application would be able to support the requirements of the Forecast Review application in the short term, substantial revisions to such an application, or the development of a new one, would probably be desirable in the near future to take advantage of the improved web mapping technologies now emerging.

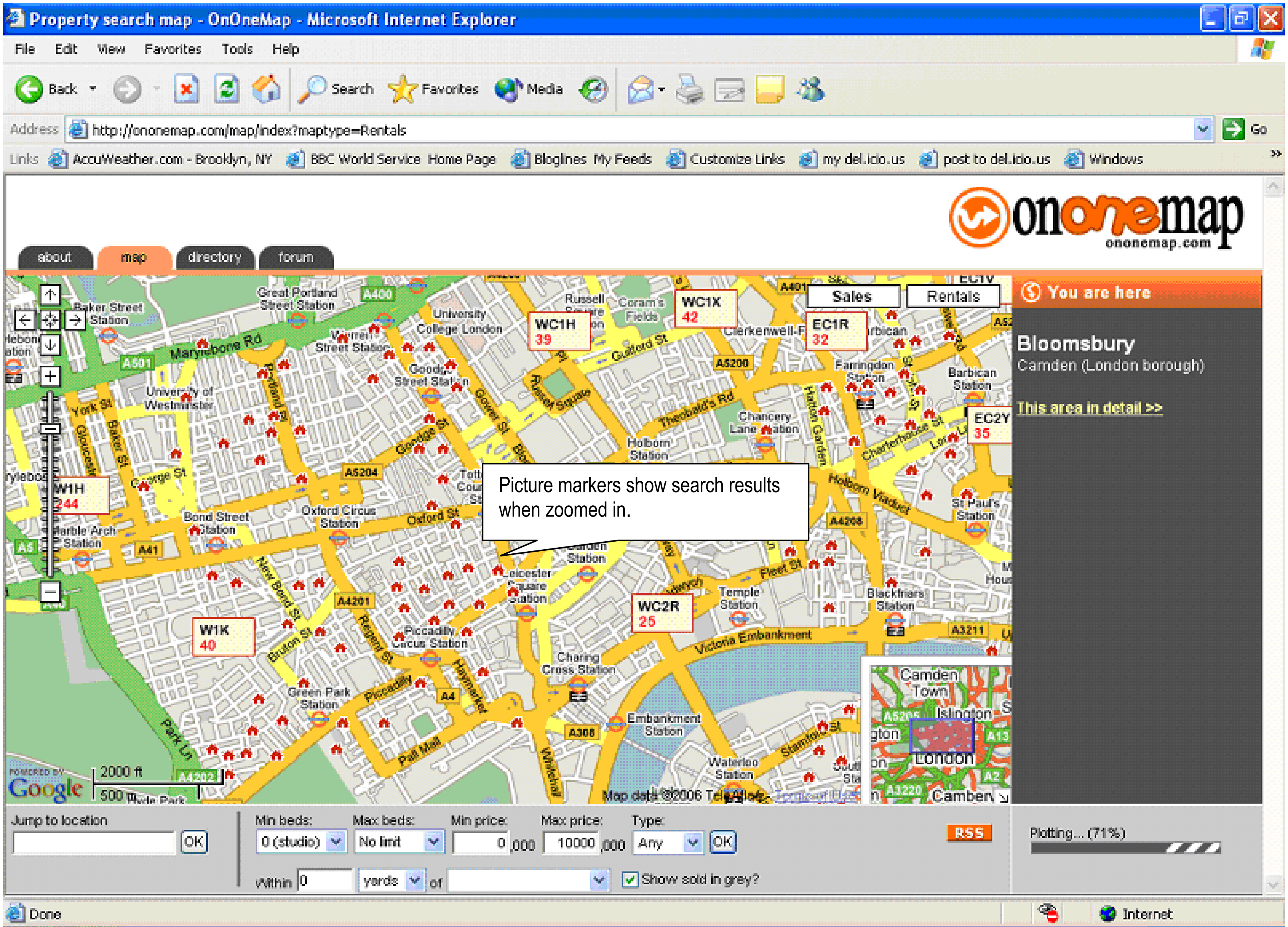
Apart from the technologies reviewed above, ESRI's ArcGIS Server represents that company's commitment to a new generation of web mapping applications. As mentioned earlier, ArcGIS Server was not reviewed for this Task because the substantial investment in server software is not feasible as a short-term solution for review of the current round of travel demand forecasts. However, depending on NYMTC's strategic approach to GIS server technology, it may offer the best long-term alternative as a web mapping application development platform. ArcGIS Server includes an Application Development Framework (ADF) for both Microsoft .NET and Java.[10] The .NET ADF, for example, makes GIS functionality directly available within Microsoft Visual Studio for simplified integration with web application development using ASP .NET. The ADF also supports asynchronous, AJAX style functionality, which facilitates more dynamic and interactive applications. ArcGIS Server and the ADF provide a streamlined platform for GIS-based publishing and application development over the web. Although this platform exceeds the immediate requirements of a Forecast Review application, its capabilities would provide a logical foundation if NYMTC is making a long-term investment in ESRI technology. It would simplify and reduce the cost of application development, and provide an upgrade path as ESRI continues to develop its server-based GIS technology. In comparison, an application developed separately using ArcWeb Services would involve duplication of functionality provided out of the box by ArcGIS Server and the ADF, and would also require reengineering later on to be made compatible with those technologies.

[10] See *ArcGIS Server: ESRI's Complete Server GIS*. http://www.esri.com/library/whitepapers/pdfs/arcgis-server.pdf

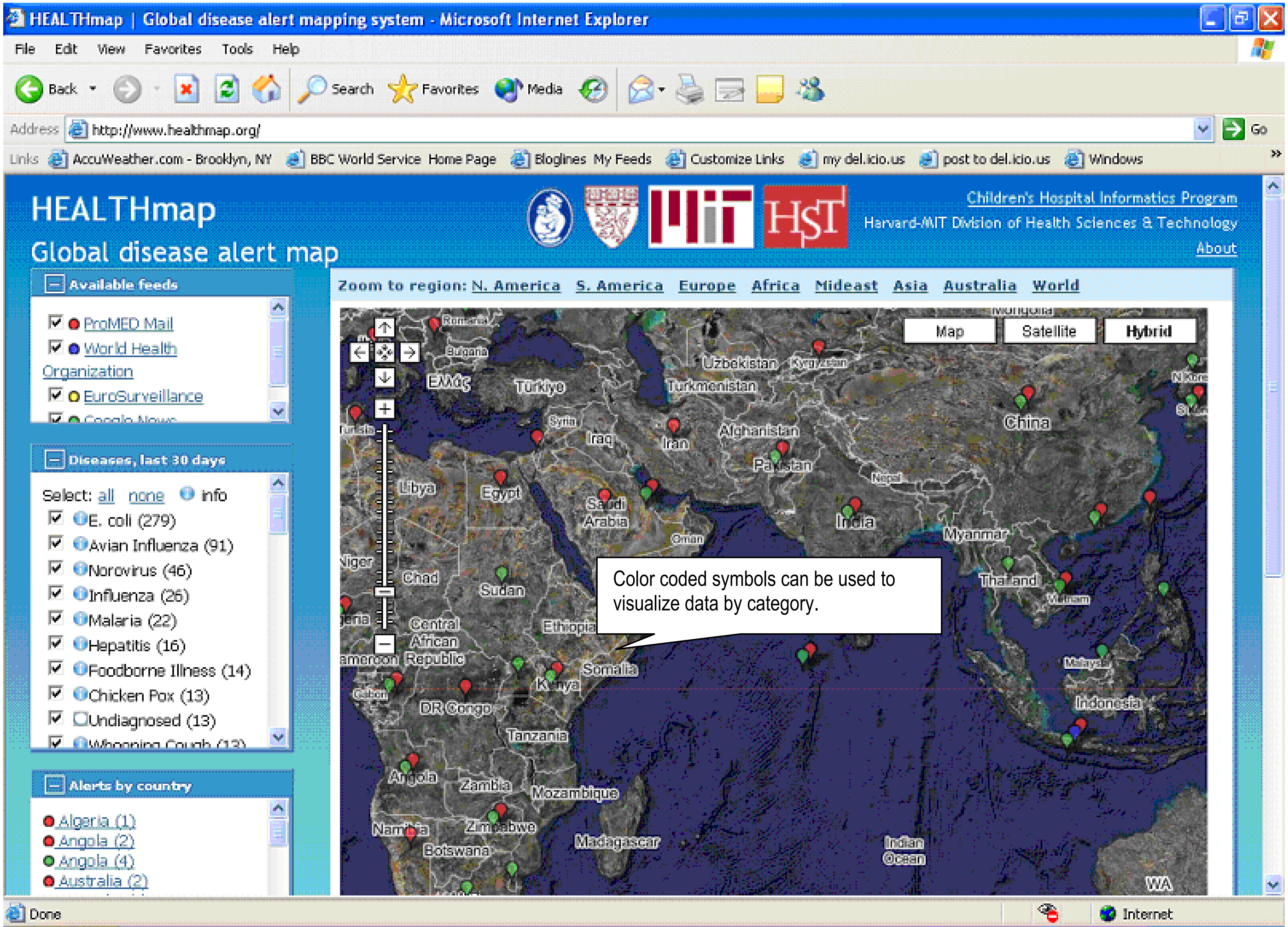
Appendix 1
Google Maps Examples

Ononemap.com:

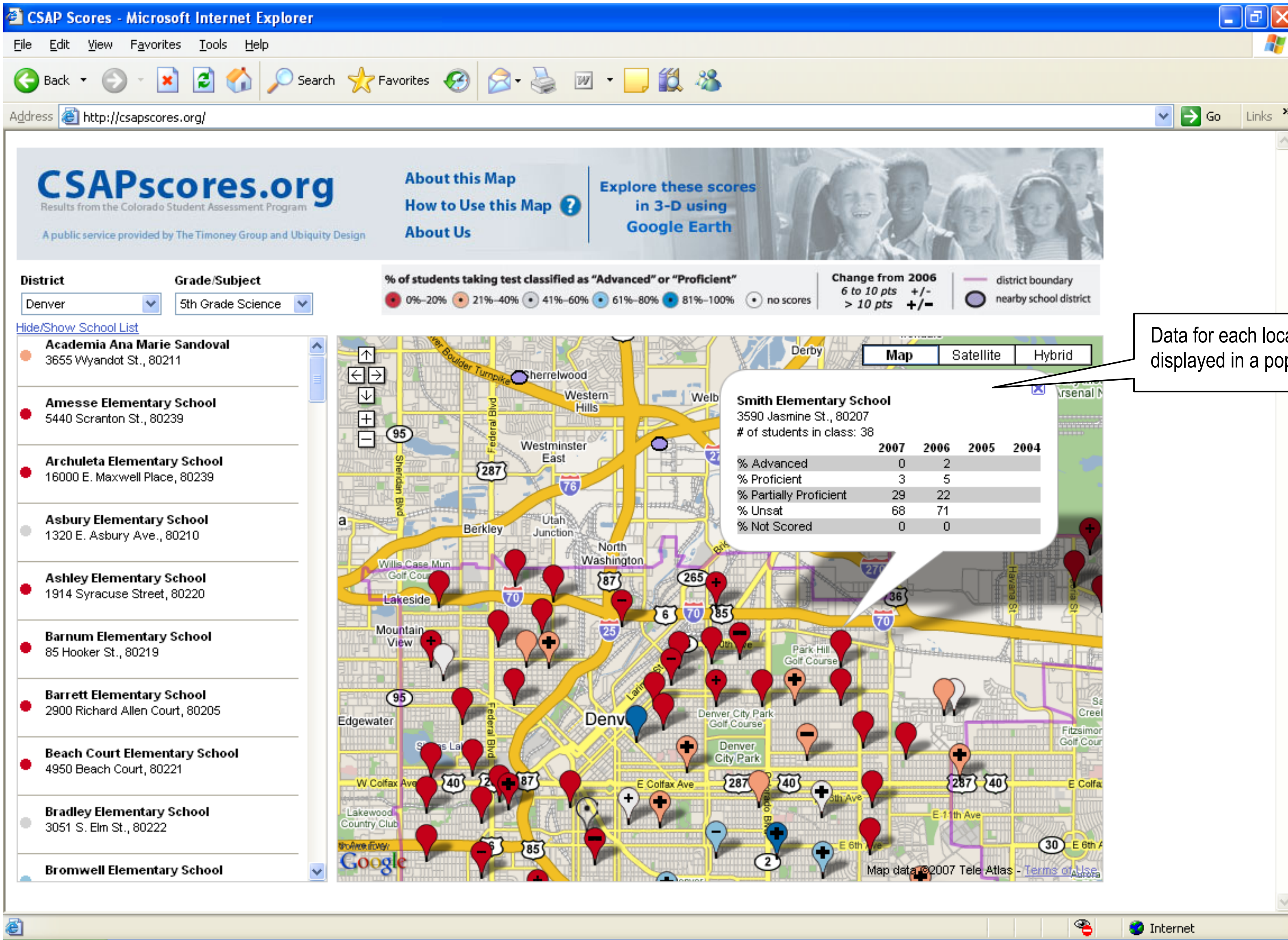



Property search map - OnOneMap - Microsoft Internet Explorer
File Edit View Favorites Tools Help
Back Search Favorites Media
Address http://onomemap.com/map/index?maptype=Rentals
Go
Links AccuWeather.com - Brooklyn, NY BBC World Service Home Page Bloglines My Feeds Customize Links my del.icio.us post to del.icio.us Windows
onomemap
onomemap.com
about map directory forum
Sales Rentals
Picture markers show search results when zoomed in.
W1H 244
WC1H 39
WC1X 42
EC1R 32
EC2Y 35
W1K 40
WC2R 25
You are here
Bloomsbury
Camden (London borough)
This area in detail >>
Jump to location
OK
Min beds: Max beds: Min price: Max price: Type:
0 (studio) No limit 0 ,000 10000 ,000 Any OK
Within 0 yards of
Show sold in grey?
RSS
Plotting... (71%)
Done
Internet

Healthmap.org:

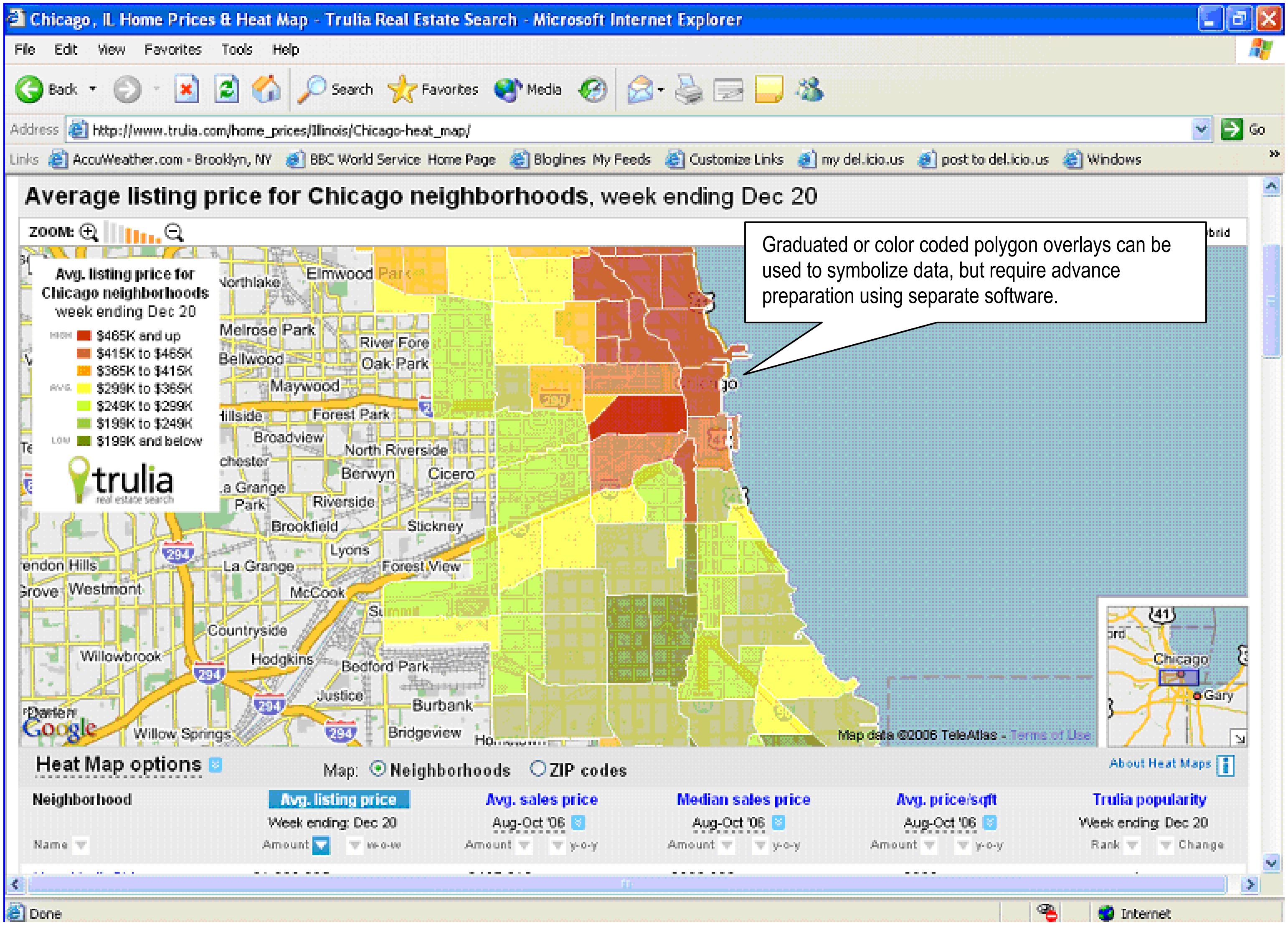


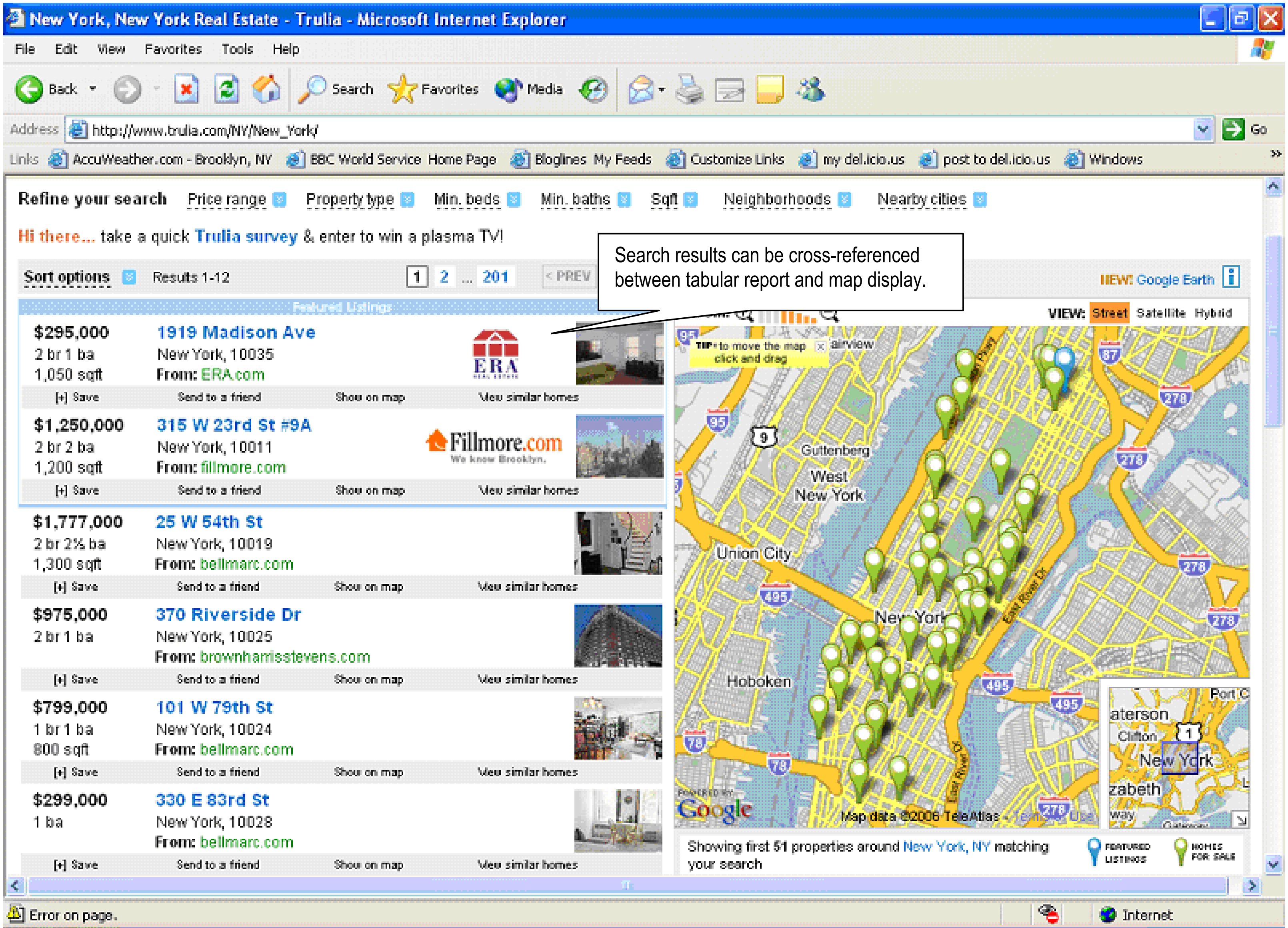
CSAPscores.org:



Data for each location can be displayed in a pop-up window.

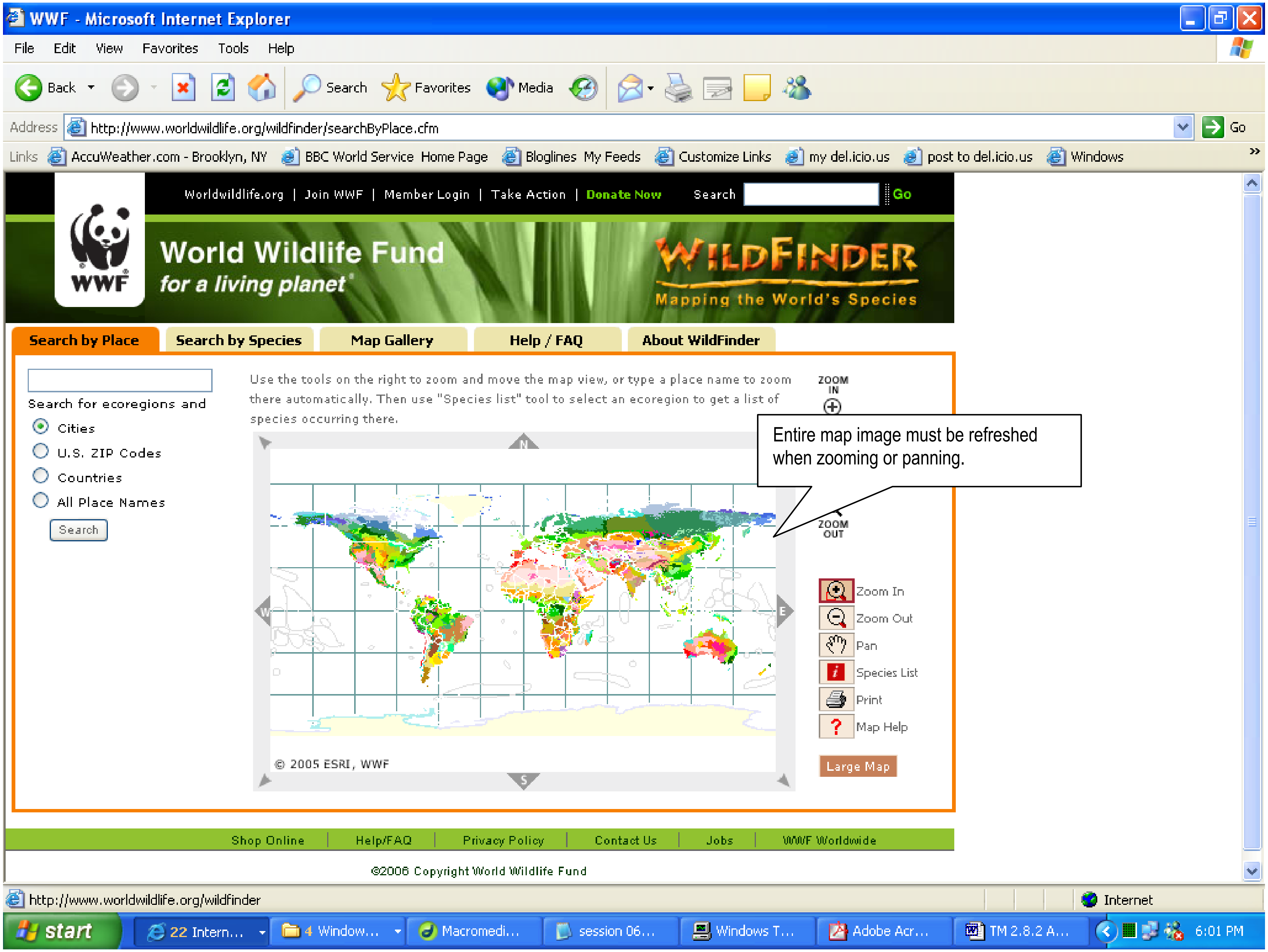
Trulia.com:


Chicago, IL Home Prices & Heat Map - Trulia Real Estate Search - Microsoft Internet Explorer
http://www.trulia.com/home_prices/Illinois/Chicago-heat_map/
Average listing price for Chicago neighborhoods, week ending Dec 20
Avg. listing price for Chicago neighborhoods week ending Dec 20
$465K and up
$415K to $465K
$365K to $415K
$299K to $365K
$249K to $299K
$199K to $249K
$199K and below
trulia
Graduated or color coded polygon overlays can be used to symbolize data, but require advance preparation using separate software.
Heat Map options
Map: Neighborhoods ZIP codes
Neighborhood
Avg. listing price
Avg. sales price
Median sales price
Avg. price/sqft
Trulia popularity
Week ending: Dec 20
Aug-Oct '06
Map data ©2006 TeleAtlas - Terms of Use

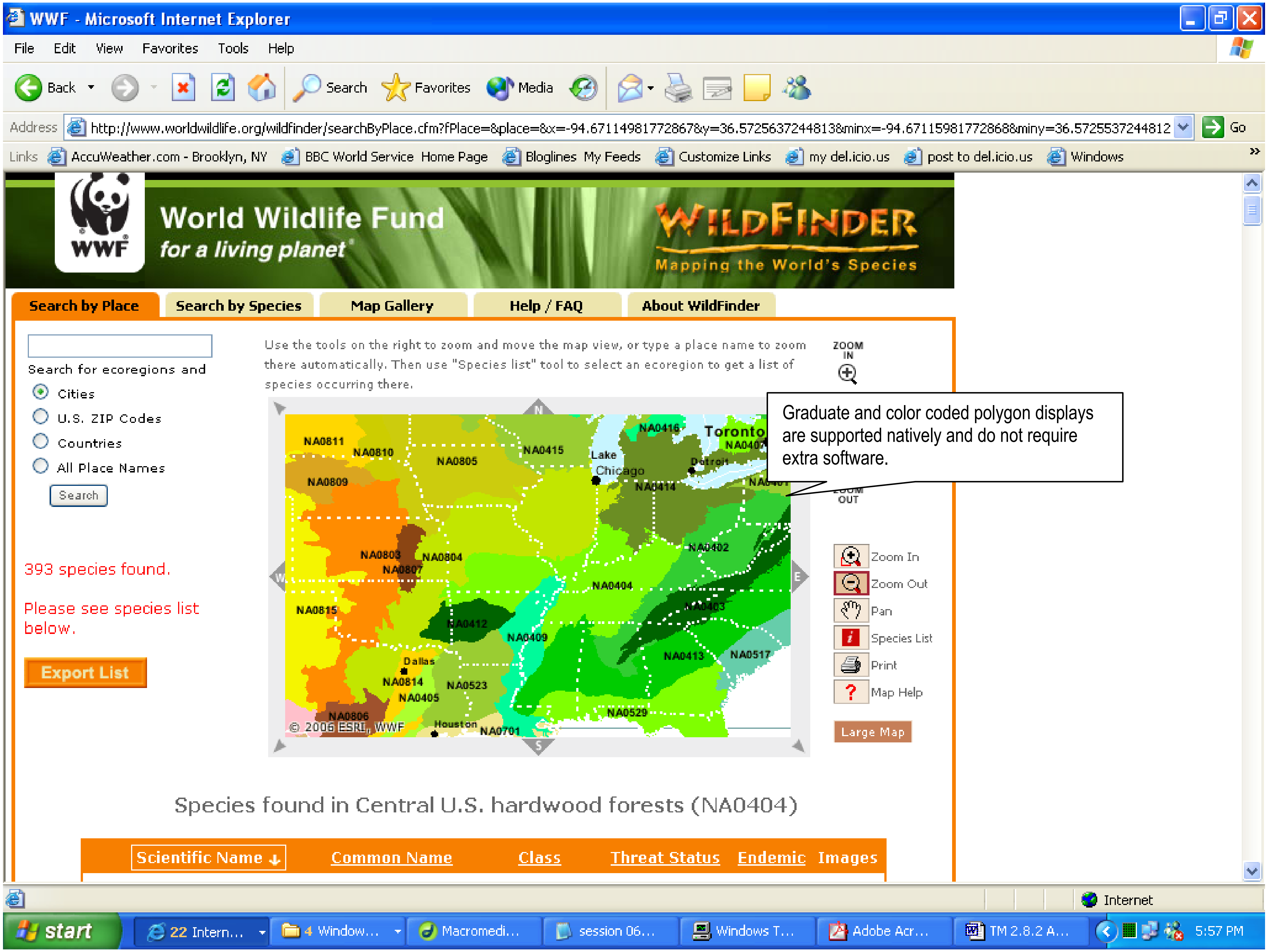

New York, New York Real Estate - Trulia - Microsoft Internet Explorer
File Edit View Favorites Tools Help
Back
Search
Favorites
Media
Address
http://www.trulia.com/NY/New_York/
Go
Links
AccuWeather.com - Brooklyn, NY
BBC World Service Home Page
Bloglines My Feeds
Customize Links
my del.icio.us
post to del.icio.us
Windows
Refine your search
Price range
Property type
Min. beds
Min. baths
Sqft
Neighborhoods
Nearby cities
Hi there... take a quick Trulia survey & enter to win a plasma TV!
Search results can be cross-referenced between tabular report and map display.
Sort options
Results 1-12
1 2 ... 201
< PREV
NEW: Google Earth
Featured Listings
VIEW: Street Satellite Hybrid
$295,000
1919 Madison Ave
2 br 1 ba
New York, 10035
1,050 sqft
From: ERA.com
[+] Save
Send to a friend
Show on map
View similar homes
$1,250,000
315 W 23rd St #9A
2 br 2 ba
New York, 10011
1,200 sqft
From: fillmore.com
Fillmore.com
We know Brooklyn.
$1,777,000
25 W 54th St
2 br 2½ ba
New York, 10019
1,300 sqft
From: bellmarc.com
$975,000
370 Riverside Dr
2 br 1 ba
New York, 10025
From: brownharrisstevens.com
$799,000
101 W 79th St
1 br 1 ba
New York, 10024
800 sqft
From: bellmarc.com
$299,000
330 E 83rd St
1 ba
New York, 10028
From: bellmarc.com
TIP: to move the map click and drag
Guttenberg
West New York
Union City
Hoboken
New York
East River Dr
Map data ©2006 TeleAtlas
Showing first 51 properties around New York, NY matching your search
FEATURED LISTINGS
HOMES FOR SALE
Error on page.
Internet

Appendix 2
ArcWeb Services Screenshots

World Wildlife Fund Wildfinder Application Navigation:

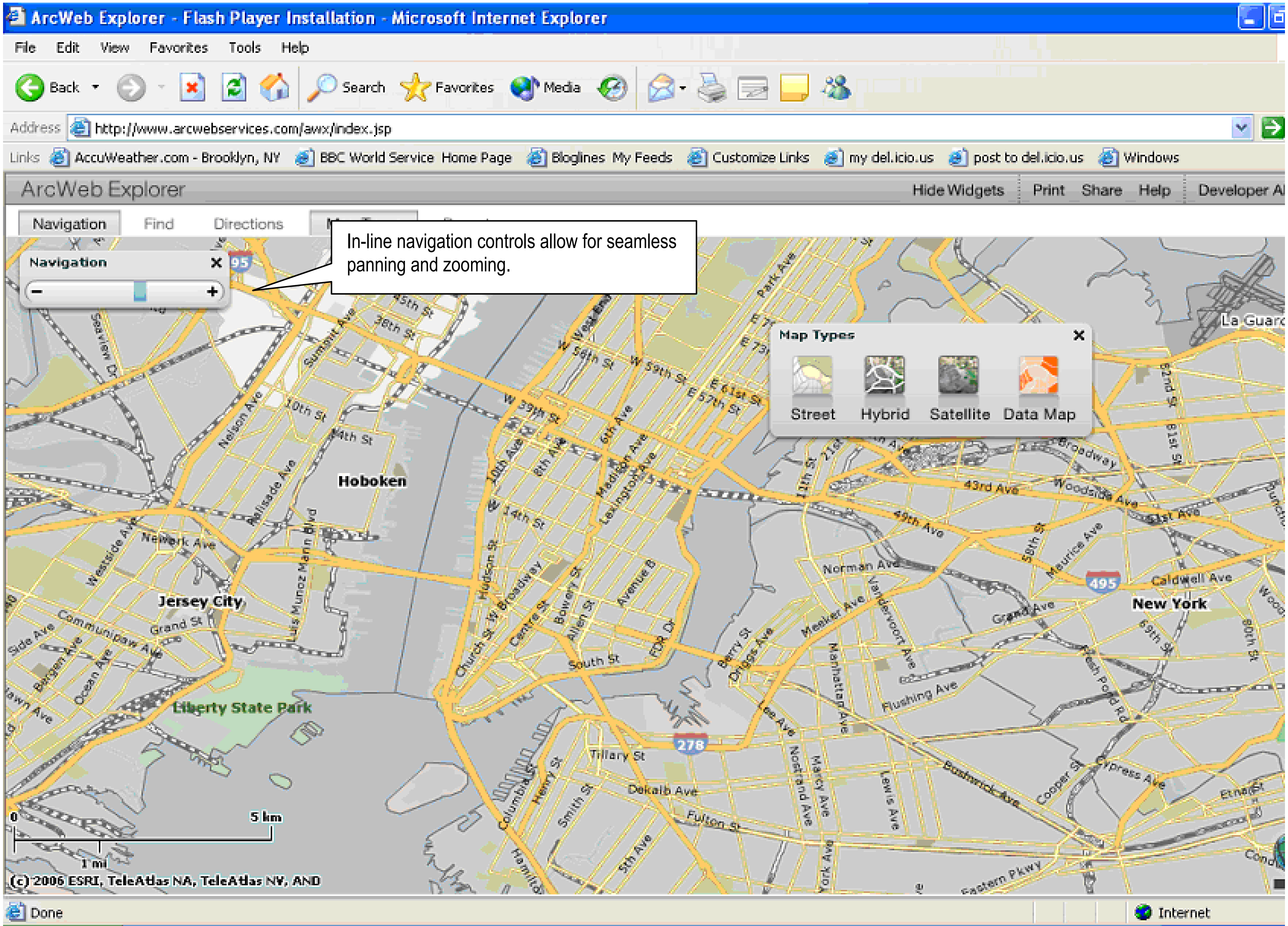


World Wildlife Fund Wildfinder Application Spatial Query Results:



Appendix 3
ArcWeb Explorer Screenshots

ArcWeb Explorer Navigation:



Thematic Mapping Using ESRI Data Sources: