Developing a Web 2.0 GIS website for the Gauteng City-Region

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Abstract
Successful Web GIS (Geographical Information System) applications are achieved by the right combination of GIS layers symbolised in a visually dynamic way, with an easy to use application, that is stable and responsive and meets the user requirements of both GIS and non-GIS users. Web 2.0 has produced a flood of development starter kits, sample viewers and APIs (Application Programming Interface), with the result that almost anyone involved in GIS or IT (Information Technology) – even with limited or no programming experience – can build a GIS website. This has lead to an exponential growth of Web GIS applications and data, which although a necessary step in increasing accessibility to spatial data and GIS applications, may result in online mapping applications that do not satisfy user requirements. The Gauteng City-Region Observatory (GCRO) identified a business need to develop a Web 2.0 GIS website to enable users to attain a better understanding of the Gauteng City-Region (GCR). The website makes use of data mashups to integrate data from various sources, and is one of the first government GIS websites in South Africa to utilise open datasets such as Google Maps to provide the base data. The website was built using rich Internet application (RIA) technology provided by the ESRI Adobe Flex viewer to offer an enhanced user experience, with popup windows and dynamic graphs linked to the maps. A five step Web GIS development methodology was employed to build the GCRO GIS website. This paper will examine each of the GIS development design steps that were followed to ensure an optimal functioning application, with responsive and secure map services. Specific Web mapping optimisation techniques, such as applying specific cartographic techniques and map designs to assist in overcoming the additional layer of Web design complexity introduced by spatial data will be reviewed.

Keywords: Web 2.0, Web GIS, g-government

1.   Introduction

Worldwide there has been an explosion of Web 2.0 applications with Internet users embracing applications such as MySpace, Flickr, You Tube, Facebook and Twitter.

The 2010 statistics are staggering with over 500 million active users on Facebook (Facebook, 2010) and 190 million users tweeting 65 million times a day on Twitter (Schonfeld, 2010). Prior to Web 2.0, people could access information off the Internet but did not really participate in its evolution (Townes, 2006), i.e. the Web consisted mainly of static Web pages. Web 2.0 in contrast, represents the second generation of Web development and design with new Web applications that enable improved interaction, communication, interoperability and sharing on the Web (Wikipedia contributors, 2009). Web 2.0 is not just about new technologies such as blogs and wikis, it represents a shift in culture that views the Internet as a platform for deploying services, rather than merely a source of information from static Web pages (Hughes, Macmillan & Medd, 2008). Web 2.0 promotes the principles of sharing, collaboration and data integration on the Internet.

Web GIS refers to any GIS (Geographic Information System) application that uses Web technologies to communicate between components such as the Web GIS server and a Web browser, desktop or mobile client (Fu & Sun, 2011a:13). Web GIS applications have evolved to support the Web 2.0 principles of rich graphic user interfaces, user participation and data mashups, with commercial mapping applications such as Google Maps, Google Earth, Microsoft Bing Maps, Yahoo Maps and MapQuest, considered to be good examples of Web 2.0 (Fu & Sun, 2011a:10). The growth of Web GIS and online maps is impressive with nearly a billion people having used Google Maps, and at least 500 million downloaded Google Earth (O'Doherty, 2010).

However, Murugesan (2007:41) cautions that although Web 2.0 applications have enabled better, faster and richer applications, it also poses a new design and development dilemma: "fast and easy versus well designed and well engineered". Various open source applications and widgets, small stand-alone applications embedded in third party sites and originally derived from the idea of code re-use (Wikipedia contributors, 2011), are freely available online. Inexperienced developers can easily build applications by copying source code from existing websites or integrating widgets and modifying sample viewers (Rudman, 2010: 217). This "wave of cookie-cutter sites emerging on the Internet", have been built and deployed, with in many cases very little thought to originality and user interaction with the site (Noyle & Bouwman, 2010:42). Not only is there a danger of good Web design practices being ignored, but developers may, according to Rudman (2010: 217), unknowingly incorporate malicious code into their applications, giving rise to security weaknesses.

GIS applications add a further layer of Web design complexity in terms of appropriate cartographic techniques and map design. Web maps have different requirements to traditional maps, as complex detailed Web GIS maps will not be easily understood by users or result in frustratingly slow downloads. Users have grown used to simple map interfaces and fast map downloads from mapping sites such as Google Maps and Bing Maps. Successful and simple to use online maps often means making compromises and resisting classical GIS interfaces which only GIS professionals will understand (Diacono, 2009). A good public mapping website, according to Charlie Savage, founder of social mapping website Mappbuzz, has to be: "the obvious things – fast, intuitive, easy to navigate, nice graphic design – but it

shouldn't overwhelm the user, either with data or unfamiliar concepts" (Diacono, 2009).
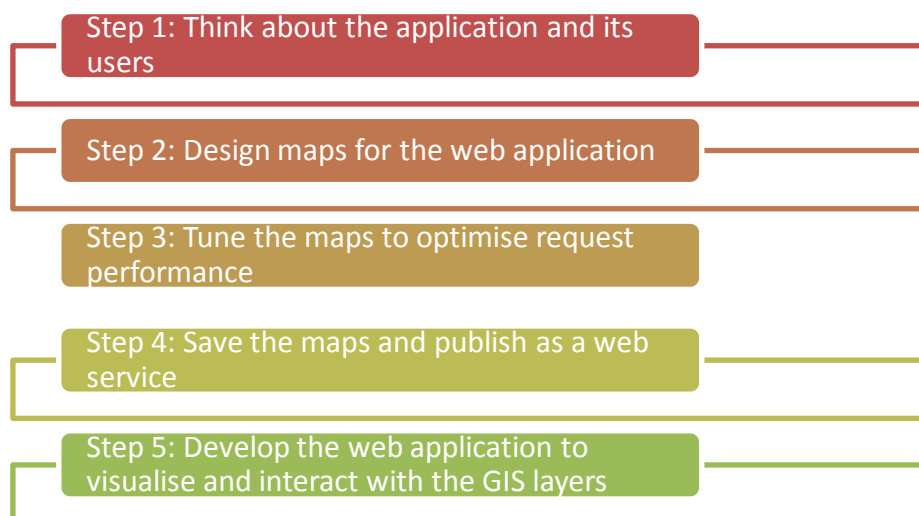
In January 2010, the GCRO (Gauteng City-Region Observatory) embarked on a project to develop an interactive GIS website for the Gauteng City-Region (GCR). The GCRO is a partnership between the Gauteng Provincial Government (GPG), the University of Johannesburg (UJ) and University of the Witwatersrand, Johannesburg (Wits); with local government also represented on the GCRO board. Behind the motivation for setting up the GCRO is a vision for a fast growing and dynamic GCR, which through better planning and management, and in particular improved co-operative government relations between all spheres of government, will become more functionally integrated, spatially coherent, globally competitive, economically productive, environmentally sustainable and socially inclusive. The GCRO recognised the need to provide online spatial information and GIS tools to develop a better understanding of the GCR, assist the GCR policy-makers to make better informed decisions and open up public access to government datasets. This business need was met through the development of the GCRO GIS website that provided a g-government solution for the GCRO and its provincial and local government stakeholders. G-government relates to the use of maps, the Internet (and more recently Web 2.0 technologies) and GIS to create more effective government service delivery (Thomas, 2001; Tickner, 2009). The website makes use of Web 2.0 technologies such as data mashups to integrate data from various sources. It is one of the first government GIS websites in South Africa to utilise open datasets such as Google Maps to provide the base data, and was built using rich Internet technology (RIA) provided by the ESRI Adobe Flex viewer to offer an enhanced user experience, with popup windows and dynamic graphs linked to the maps.

This paper will discuss a Web 2.0 GIS development methodology, with specific reference to the GCRO GIS website and use of ESRI ArcGIS Server Web GIS software. It is important to note that this paper is derived from a Masters research project at the School of Electrical and Information Engineering, Wits (Wray, 2011). Another paper which also draws on the Masters research, but is focused on the use of user- and usage-centric design methodologies and discusses the Technology Acceptance Model (TAM) survey results conducted at the completion of the prototype and website launch, has been prepared for the IEEE Africon 2011 conference.

2. A Web 2.0 GIS design methodology

Agrios (2009:44) argues that "effective Web maps have a specific focus and are designed so users can interact with them to accomplish meaningful tasks". In order to achieve this, a five step methodology for developing an effective Web GIS map application with optimal performance, was used to design and build the GCRO GIS website. This methodology is depicted in Figure 1 and each of the steps will be considered in more detail.

Figure 1: Methodology for creating effective Web mapping applications (adapted from Agrios (2009:44))

Step 1: Think about the application and its users

Step 2: Design maps for the web application

Step 3: Tune the maps to optimise request performance

Step 4: Save the maps and publish as a web service

Step 5: Develop the web application to visualise and interact with the GIS layers

2.1 Step 1: Think about the application and its users

Step 1 is an obvious starting point when planning a GIS website, but should be considered carefully in terms of a number of questions to be used as a guide for planning a map-based Web application:

- "What is the business need/purpose of the Web mapping application?
- Who are the end users?
- Is this an internal or external website?
- What data will be included in the application?
- How will the data be used? Visualisation? Spatial query? Attribute query?
- Will the data be used with other services to create a mashup?" (Agrios, 2009:44)

These questions were debated during a brainstorming session with GCRO staff held in January 2010. This process assisted GCRO to think about the GCRO GIS website users and how the application could benefit them – important considerations prior to drawing up a GIS website specification.

The business need was identified as: enabling users to develop a better understanding of the GCR by providing base data and thematic layers offering different perspectives of the GCR, such as population distribution, poverty and the latest 2009 Quality of Life survey results as Web maps and dynamic graphs; and GIS analysis tools for the user to make better informed decisions and policies regarding the future development of the GCR. The main users of the application were identified as the GCRO staff and stakeholders, namely: the GPG Planning Commission, GPG Office of the Premier, GPG Department of Economic Development, local government officials and other GCR government agencies. These users are responsible for planning the future development and direction of the GCR and are mainly high ranking government officials with no mapping or GIS experience. Hence the need for a simple "Google Maps-like" Web GIS design. Public

access was also a requirement, ensuring open access to information describing the GCR through the Internet to all GCR citizens. Therefore, a freely accessible, simple to use, Internet site was required to provide access to local and provincial government and citizens.

A Web 2.0 GIS application specification was compiled for the GCRO GIS website that required the use of the latest Web 2.0 tools such as GIS data mashups (including the use of Google Maps to provide the base mapping data), APIs (Application Programming Interface) and RIAs.

2.2   Step 2: Design maps for the Web application

### 2.2.1   Separating data into base map and operational layers

Good Web GIS map design practice is to divide data into base map layers, which primarily are used as background layers, and operational layers that users interact with to perform decision-making and task-based functions (Agrios, 2009:45; ESRI, 2009c). Operational layers are normally served dynamically, whereas base map layers, that typically do not change or require updating frequently, should be cached. According to ESRI (ESRI, 2009a), "Map caching is a very effective way to make your ArcGIS Server maps run faster. When you create a map cache, the server draws the entire map at several different scales and stores copies of the map images. The server can then distribute these images whenever someone asks for a map". A disadvantage of cache is that it takes a long time to create and should not be used if features are regularly updated, as this would require a regeneration of the map cache each time a layer is updated. One of the reasons that Google Maps download and display so fast is that they make use of server-side caching (ESRI, 2009a). The Google Maps layers were therefore designated as base map layers within the GCRO GIS website, with the API accessing the Google Maps cache from the Google servers.

Figure 2: An example of map cache at different scales (ESRI, 2009a)
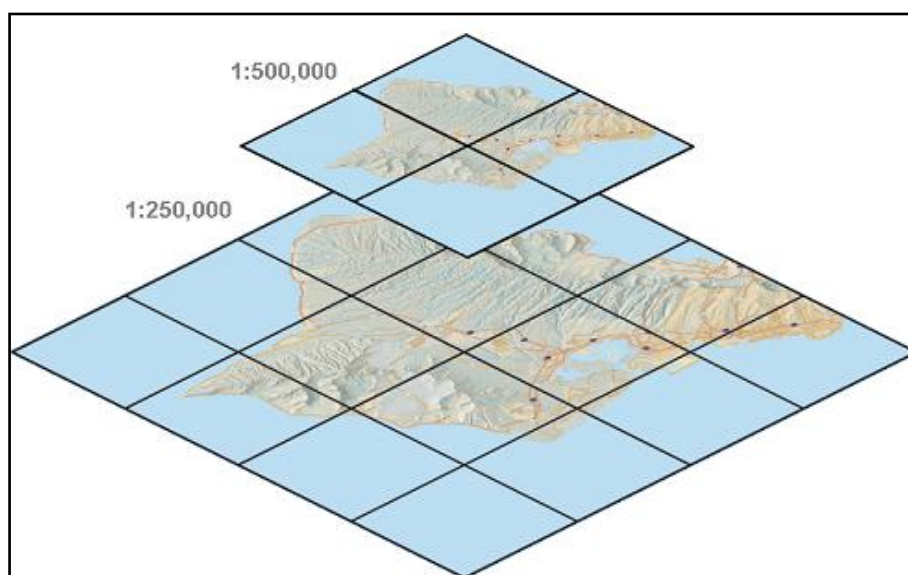
With regard to the various GCRO GIS layers that had been assembled, the data was divided into various themes to be used to analyse and obtain a better understanding of the GCR. Six themes were identified, with the GCRO administrative layers theme designated as a base map as it provided the GCR administrative base map context and is switched on by default when the application is opened. It was not, however, cached and therefore functions like an operational layer.

Figure 3: GCRO GIS application: base map and operational (dynamic theme) layers (Wray, 2011:56)
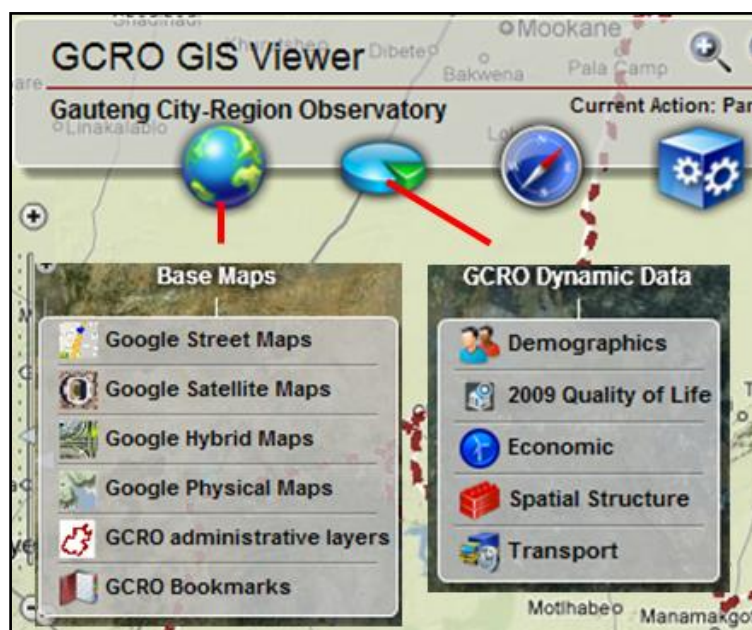
The remaining five GCRO themes were designated as operational or dynamic themes (illustrated in Figure 3 above). As ESRI ArcGIS server 9.3.1 Web GIS software was utilised by the GCRO to publish the data, the data were mapped and symbolised in ArcMap (ArcView licence), with each of the five operational themes and GCRO administrative layer theme, created in separate ArcMap map documents.

2.2.2 Web GIS mapping compromises

Diacono (2009) states that "designing maps for the Web means making compromises". These include: employing strong cartography, using scale dependency to enhance performance and improve clarity and maintaining coordinate systems for all layers used in the application (Agrios, 2009:44). Strong cartography was employed in the GCRO themes by ensuring both the layer symbology and labels were clearly visible on a standard PC (Personal Computer) or laptop screen, and that each layer within a theme was uniquely represented and identifiable with other GCRO theme layers switched on or overlaid on the various Google Maps base maps. The use of Google Maps as base map layers also required that the GCRO themes used the same scales and coordinate system (WGS84 Web Mercator) as Google Maps (ESRI, 2009a). Each of the GCRO theme layers were projected to

WGS84 Web Mercator and the Google Maps scale levels applied to the ArcMap documents.

Scale dependencies, whereby layers only display at predetermined scales, were applied where possible to some of the GCRO layers to ensure the layers only displayed at an appropriate scale to avoid unnecessary processing by the server and improved performance. For example, the Gauteng land use layer in the Spatial Structure theme is not clearly discernable at the Gauteng extent and took a long time to draw at small scales. A scale dependency was set whereby the layer is only visible when a user zooms in beyond a scale of 1: 288 895.

2.3   Step3: Tune the maps to optimise performance

To ensure that the maps that users request are rendered by the server as quickly as possible, it is necessary to tune the maps to optimise performance.

2.3.1   Using the Map Service Publishing toolbar

The desktop software (ArcMap version 9.3.1) used to design the Web maps for the GCRO GIS website, provides a new tool called the Map Service Publishing toolbar, to analyse the performance of each of the layers in the ArcMap map document. The Analyse map button provides the main functionality as it cycles through each layer and generates a report indentifying potential performance bottlenecks and/or errors that must be addressed before a map service is published (Agrios, 2009:46).

As visible in Figure 4, a dialog box opens at the bottom of ArcMap application when the analyse tool is run and contains errors, warnings and messages. These guide the user to:
- Identify errors that may prevent the service from being published (which in the case of the .msd file format, must be resolved before saving),
- Resolve warnings to ensure optimal performance from the published map service.

The preview window tests the draw speed of the layers at different scales and provides the developer with an opportunity to test the effect of changing various settings on draw speeds before implementing the optimal Web map drawing settings.

Figure 4: Map Service Publishing toolbar analyse dialog box and preview window (Wray, 2011:59)
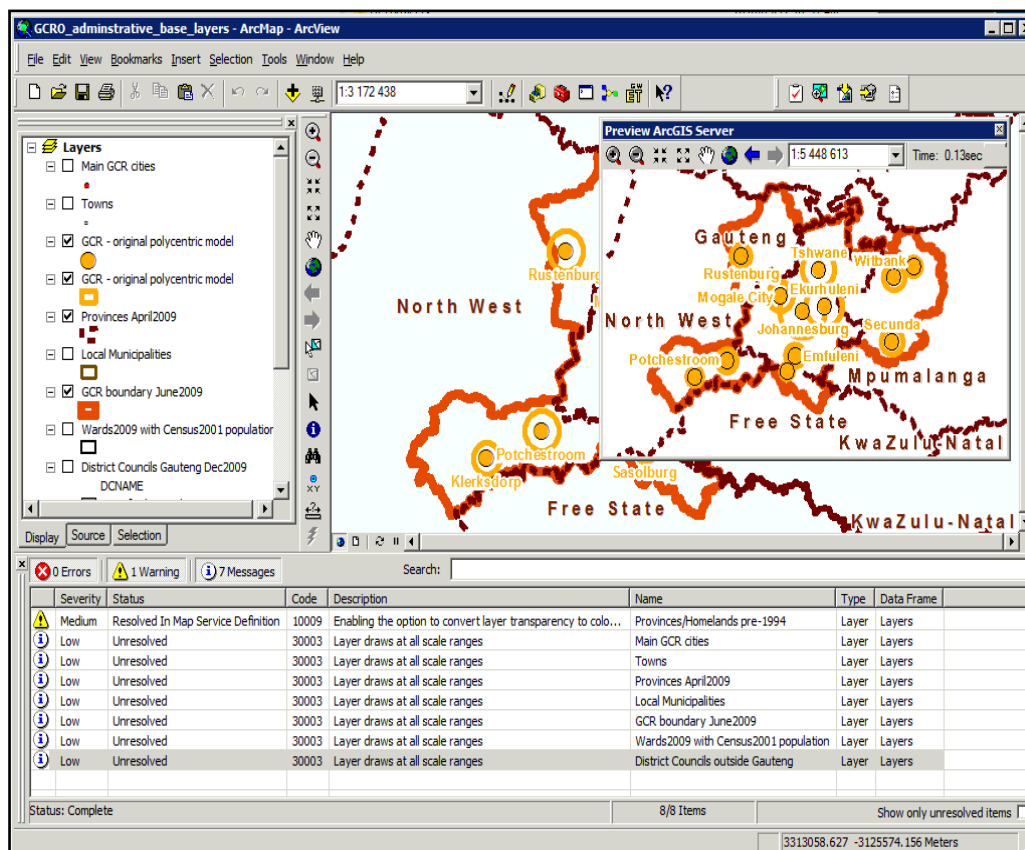
2.3.2 GIS data formats

The format of the GIS data is another factor that may influence performance. ESRI advises that an enterprise ArcSDE geodatabase should be used for large ArcGIS Server system implementations, as ArcSDE provides benefits such as hi-availability support, backup and recovery, concurrency, scalability and a tendency to provide superior performance (ESRI, 2009b). However, the performance of map services sourcing data from an ArcSDE geodatabase is dependent on a dedicated database administrator to tune, optimise and maintain the ArcSDE geodatabase. Provided that the published data is relatively static and enterprise capabilities of ArcSDE such as versioning are not required, a file geodatabase offers a good alternative to serve Web GIS data, as they provide great performance with minimal extra configuration (ESRI, 2009b). For this reason, all the vector data accessed by the GCRO GIS application are stored in file geodatabases.

Various server hardware, network and scalability configurations will also affect the Web map's performance, but are beyond the scope of this paper.

2.4 Step 4: Publishing the maps as Web services

2.4.1 Map Service Definition (MSD) format

According to Agrios (2009:47), depending on how the map will be used and the type of data it contains, a user has the choice of saving the ArcMap documents in one of two formats used to publish the map services:

- **MXD**: if the map user's layers are "not supported by the 9.3.1 optimised rendering engine" (Agrios, 2009:47), for example, dot density symbology, or the published map service uses analysis tasks such as geoprocessing.
- **MSD**: if the map service will be served dynamically and only provide mapping, KML (Keyhole Markup Language) or WMS (Web Map Service) capabilities.

The MSD (Map Service Definition) format is an optimised version of the standard ArcMap .mxd project document file format specifically designed to enhance the performance of published map services (ESRI, 2009b). Cached maps may provide the best performance for serving GIS data, with less load placed on the server (ESRI, 2009c), but dynamic MSD services provide a good alternative, having the additional advantages such as providing users with the flexibility to toggle the visibility of individual layers and the ability to serve the updated data as soon as the geodatabase is updated (Agrios, 2009:47). None of the GCRO themes could be cached because of the dynamic MXD/MSD functionality that was required in the application (such as dynamically switching on and off individual layers within each theme). However, good response times for rendering the map services were achieved due to the use of the cached Google Maps base layers, and in most cases, only a couple of dynamic GCRO theme layers switched on at any point in time. The result: a vast improvement in server response times and reduced server load compared to earlier GIS website applications using older Web GIS software such as ESRI ArcIMS Web GIS software, which required the server to render all the visible layers.

Four of the GCRO themes (GCRO Administrative layers, 2009 Quality of Life, Spatial Structure and Transport) were published as optimised MSD map services using the Publish to ArcGIS Server tool, within the Map Service Publishing toolbar. Two of the themes had to be published as MXDs due to the dynamic cartographic symbology used to visually represent the Census 2001 population and unemployment data as dot density maps, which is not supported in the MSD format.

2.4.2 Securing Web mapping services

Securing Web services is an important part of securing a Web application, especially in the case of potentially sensitive government information. Various techniques were implemented to safe guard the GCRO GIS server and Web services, including:

- Hosting the GCRO GIS server in a secure data centre that deploys security measures such as IPS (Intrusion Prevention System), which is designed to monitor the network and system activities for malicious activities and attempt to block and report any malicious activity (Wikipedia contributors, 2010).

- Role based authentication that was applied to the GCRO GIS Web services to ensure that only authorised users can access the map services through the Web.
- A security token that was implemented in the GCRO GIS viewer to allow the GCRO GIS application to access the map services without the need for user names and passwords.

According to Fu and Sun (2011b:86), further security measures that can be used to secure GIS data published as Web services include:

- The use of a private network if the Web service and clients are on a separate private network.
- The use of a VPN (Virtual Private Network) to enable secure connections across the Internet.
- Implementing HTTPS (Secure Hypertext Transfer Protocol) which encrypts the data transferred between the Web service and client.
- Installing a reverse proxy that provides an additional layer of defence by masking the Web server behind the reverse proxy.

2.5   Step 5: Web application development

Once the optimised, tuned map services have been published, a Web GIS application is required to serve the GIS data. ESRI provides a range of RIA Web 2.0 software development kits (SDKs) such as Web mapping APIs and application development frameworks to build dynamic applications that access the ArcGIS Server services (ESRI, 2009c). These include: Java, Adobe Flex, Microsoft SharePoint, .NET and Silverlight. The availability of programming skills is the most important factor to consider when deciding which software and APIs to use to develop a GIS website (ESRI, 2009c). The GIS viewer was developed by two student interns from the JCSE (Johannesburg Centre for Software Engineering) based at Wits (JCSE, 2010), who had no prior development experience with any of the ESRI Web APIs. However, as an increasing number of ESRI Adobe Flex websites were being developed and deployed, it was decided to develop using the ESRI Adobe Flex sample viewer. Flex is based on an "open source framework for building expressive Web applications that deploy consistently on all major browsers, desktops, and operating systems by leveraging the Adobe® Flash® Player and Adobe AIR® runtimes" (Adobe, 2010) and deploys across all browsers and operating systems.

**Figure 5: Structure of the GCRO Web GIS application (Wray, 2011:67)**
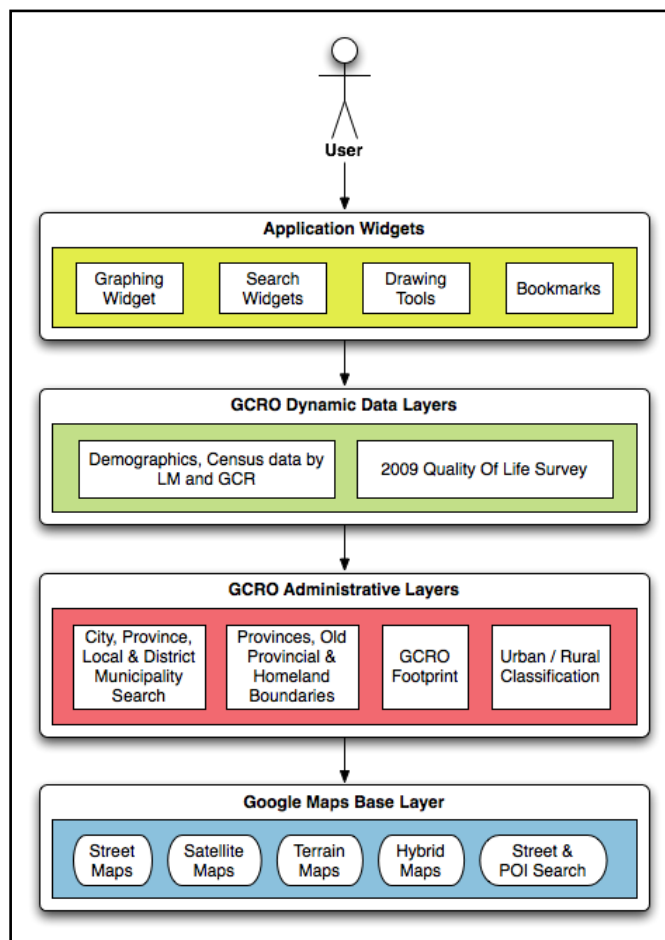
The basic structure of the GCRO Web GIS application prototype is illustrated in Figure 5 and was developed by customising ESRI Flex sample viewer version 1.3 with the ESRI Flex API version 1.3 and Google Maps API for Flash, to incorporate the GCRO design and functionality detailed in the specification. An advantage of customising the sample viewer is that all the base functionality and tools such as navigation tools, basic searches and drawing tools were already included. Only the additional tools that the GCRO required, such as dynamic themes and graphs, had to be developed. However, a cautionary note is provided by Noyle and Bouwman (2010:42): with the wealth of development tools, developers should consider only including the essential tools from sample viewers and design them to be intuitively obvious to the user.

The prototype development was completed by June 2010 when it was presented to the GCRO and GPG Department of Economic Development staff. The response was extremely favourable and the prototype viewer specification was refined to include enhancements and staff suggestions made during the prototype presentation. Version 1.0 of the GCRO GIS website was released and publically launched on 1 September 2010.

3. GCRO GIS website

The GCRO GIS website is viewable in all the main Internet browsers (such as Internet Explorer, Safari, Firefox and Google Chrome), but does require a reasonable broadband Internet connection and the Adobe Flash Player plug-in (version 9) to be installed. It is accessed from the GCRO website (www.gcro.ac.za) by selecting the Interactive GIS link. The website consists of the mapping window that utilises the full extent of the browser window and the main user interface in the top left corner with the website tools grouped into: base data, dynamic themes, navigation tools (which are also easily accessible on the main interface), website tools and help. Some of the tools and themes pop up on the right hand side of the viewer when selected.

**Figure 6: GCRO GIS website (Wray, 2011:76)**
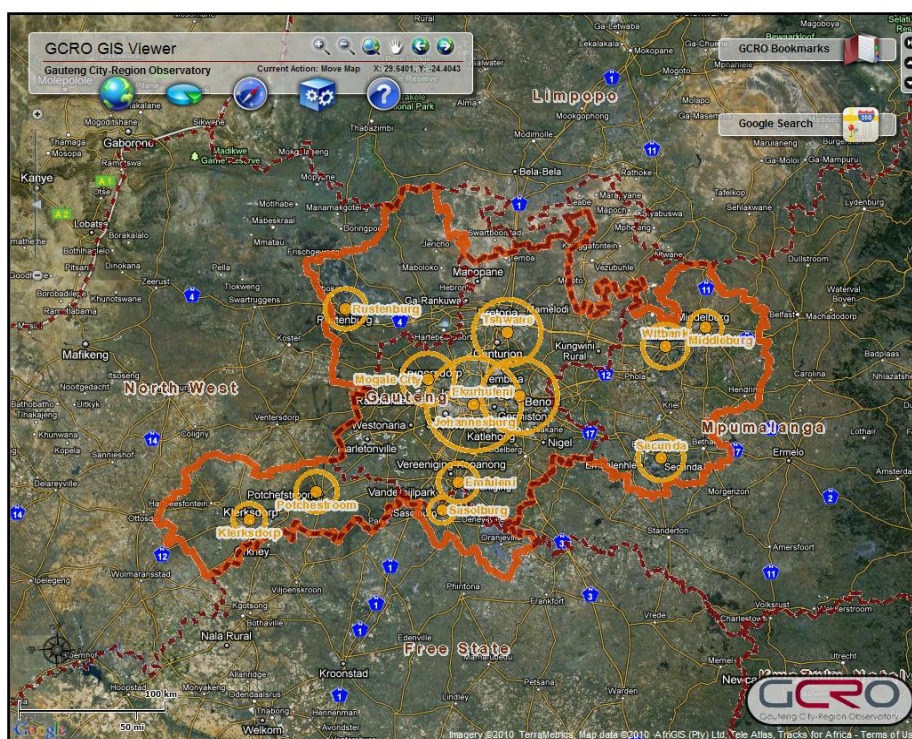
Users interact with the data by selecting the appropriate Google Maps base layer and then overlay the various GCRO GIS layers from each of the GCRO themes. Two different search tools are available. The first is a Google search which utilises the power of the Google Maps search engine and allows the user to search for a point of interest, street address or any other feature stored in the Google Maps database. The GCRO search provides for searches on specific GCRO layers such as local municipalities or wards. There is also an identify, draw and printing tool, which allows the user to choose a base layer and print to an A4 landscape or pdf file. Finally, a comprehensive help page is provided that explains each tool in detail.

An example of dynamic Web 2.0 RIA functionality is provided in Figure 7, which depicts the visualisation of the 2009 Quality of Life survey, with the satisfaction with

local government layer displayed on the map and dissatisfaction with government drawn in the graph.

Figure 7: 2009 Quality of Life dynamic theme with graph (Wray, 2011:80)
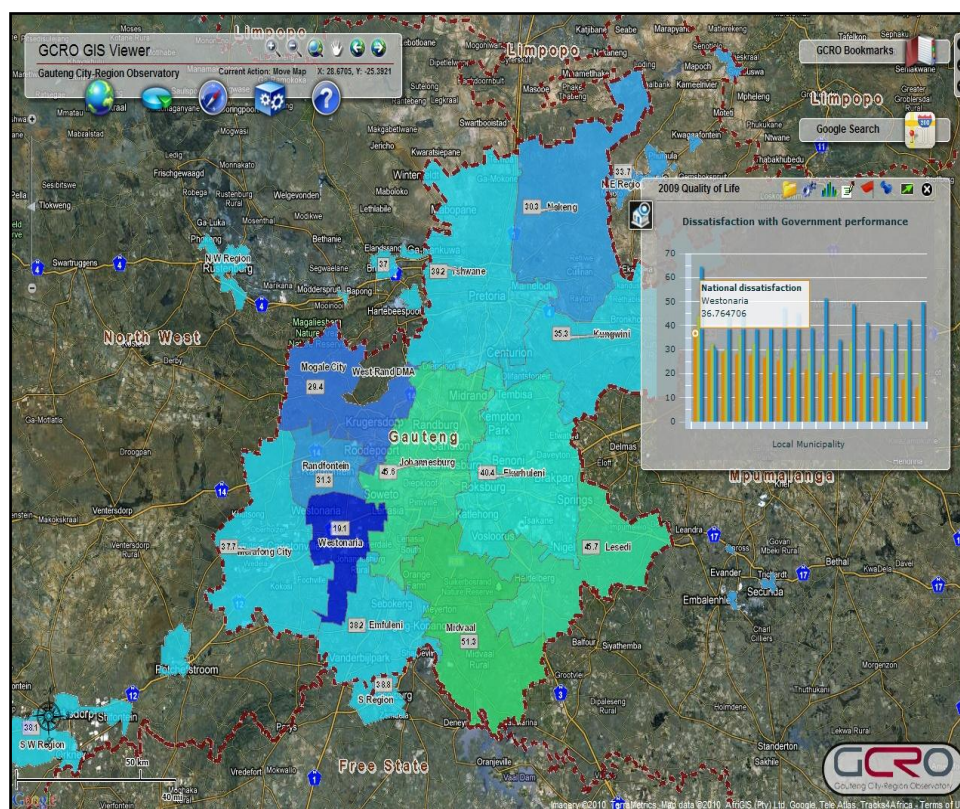
The Technology Acceptance Model (TAM), the most widely employed model of IT adoption and use (Venkatesh and Bala, 2008:274), was used to determine the success of the GCRO g-government website by measuring user acceptance at the prototype and implementation stages of the project. High user acceptance scores were achieved for perceived usefulness, perceived ease of use and data quality across both professional technical and non-GIS management staff (Wray, 2011:87). An average score of 6.82 out of a maximum of 7.00 for behavioural intention to use, indicates the intention of the questionnaire respondents to utilise the GCRO GIS website, and that the Web GIS design met the needs of the its intended users (Wray, 2011:87).

4. Conclusion

Web 2.0 technologies such as the Google Maps mashups and the RIA tools available in the ESRI Flex sample viewer, have been successfully combined with the dynamic maps and graphs of the GCRO government datasets to provide a g-government website for the GCR. The GCRO GIS website offers comprehensive base data and thematic layers covering the GCR, and is fast and easy to use, with a fun element of RIA popup windows and dynamic graphs.

A five step Web 2.0 GIS website design methodology was utilised to guide the entire project and ensure an optimal functioning application with responsive and secure map services, by applying various Web mapping optimisation techniques. These include:

- Designing the maps for a Web application by separating the data into base maps and operational layers.
- Making Web mapping compromises such as setting scale dependencies and using common coordinate systems for all data mashup layers.
- Serving cached or optimised MSD Web services.
- Tuning the maps for optimal map service performance.

As more online data sources and mapping applications are becoming available, developers should take note of Web GIS design and optimisation techniques (such as the design methodology discussed in this paper) to be applied to Web applications containing GIS data.

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