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Web-based Remote Sensing Applications and Java Tools for Environmental Monitoring

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1. Introduction

The progress of information technology (IT) and the need for global distribution of geospatial information and remotely sensed imagery create strong needs for web-based geographic information systems (GIS) and remote sensing facilities (Tsou and Battenfield, 1998; 2002; Limp, 2001). This paper introduces a web-based remote sensing application that can provide advanced image comparison and processing functions for natural habitat conservation and environmental monitoring. This project is one of several ARC projects supporting the Environmental Monitoring Focus Area being developed at San Diego State University in response to NASA's Earth Science Enterprise (ESE) program at ARC Universities. This program is an infrastructure support project to provide basic operational remote sensing capabilities to a diverse user community of resource managers.

To provide comprehensive tools for habitat monitoring and management, the principal task of this research is to integrate web-based mapping functions for vector-based GIS data and remotely sensed images. This research utilizes Java programming and commercial Internet Map Server technology to provide

integrated web-based geospatial services to regional government agencies and park services. A prototype website was established to demonstrate the on-line analytical functions and potential operational applications for environmental monitoring and habitat management.

Environmental Monitoring is a challenging task for local and regional governments. Recent research indicates that the adoption of remotely sensed images and the analysis of habitat changes recorded by these images is effective for monitoring multiple plant and animal species across regions. However, traditional remote sensing software and GIS software applications are very expensive and difficult to use without professional training and sophisticated computer equipment. Regional program managers and park rangers, responsible for habitat monitoring tasks, seldom have the necessary computer resources or training to access remotely sensed images or GIS data for their work. There is a strong need to develop an easy-to-use, inexpensive set of analytical tools for viewing remotely sensed imagery and accessing GIS data, needed to enhance existing environmental monitoring and habitat management practices.

Web-based analysis and management applications are a significant potential solution as they resolve many of the limitations currently hindering the adoption of geospatial technologies by habitat managers. With a web-based system, users only require a simple web browser to access remotely sensed imagery and

perform spatial analyses without the requirements or costs of installing GIS and image processing software packages. Inclusion of user-friendly interfaces and analytical tools can significantly reduce training needs. Development of Internet mapping facilities providing analytical tools, and imagery archives when combined with basic Internet access can become an effective management tool for environmental monitoring programs. Such capabilities and analytical resources can be easily shared by multiple users from different locations at the same time. For example, the Human-Environment Regional Observatory (HERO) project at the Penn State University, GeoVISTA center, developed several Java applications (HEROINE, GeoVISTA Studio, etc.) for communicating user-initiated events among networked collaborative applications (MacEachren, et al. 2001). These web-based tools can facilitate collaborative visualization, which involves multiple participants using visual displays to support data exchange, shared controls, dynamic interaction, ease of learning, and shared application mode (Brewer, et al. 2000).

2. The Development of Web Technologies

To establish comprehensive web-based remote sensing tools and internet mapping services, two major web technologies were adopted in this research: Internet Map Servers and Java programming language. The establishment of Internet Map Servers provides integrated web-based map browsing, spatial query, and map overlaying capabilities (Plewe, 1997). Java language is used for the development of on-line remote sensing tools and spatial analytical functions.

The history of Internet Map Servers can be traced back to the development of the Xerox Map Viewer (Putz, 1994) in 1994. The Xerox Map Viewer was using the Web Browser via HyperText Markup Language (HTML) format and Common Gateway Interface (CGI) programs to provide interactive mapping functions via the Internet. The technical framework of the Map Viewer is followed by many early on-line GIServices applications. Another important research project is the Alexandria Digital Library Project (Buttenfield and Goodchild, 1996), which explored comprehensive services for on-line spatial queries, map browsing, and metadata indexing. The early development of on-line remote sensing applications mainly focuses on the cataloging functions and graphic display. Very few applications can provide advanced functions of remote sensing analysis, such as the display of multiple bands, georeferencing, image overlay, and change detection, etc. Until the early 2000s, with the progress of web technologies, including Java programming and image compression techniques, the remote sensing industry began to develop on-line remote sensing data servers and viewers, such as ER Mapper's Image Web Server (with ECW viewer) and Liztech's Content Server (with MrSID image format). However, these software packages still lack fully integrated capabilities with other GIS Internet Mapping packages. The intension of this project is to demonstrate a possible framework for the integration of both online GIS and remote sensing application under a single access portal.

In general, most Internet map servers adopt a three-tier architecture for the system implementation (Figure 1). The first tier is called “the client tier” which includes the user-side web browser and user-resident Java applets/HTML documents. The client tier is used by the user to make requests and to view maps and remote sensing data. The second tier is the middleware tier that includes the Web Server and the Server Connectors (such as Servlet connectors or ASP connectors) to bridge the communication between clients and the map servers. The third tier is the data storage tier that includes the map server and the database server. The three-tier software architecture of web-based GIS provides customizable functions for different mapping applications and scalable implementation for different hardware (Orfali and Harkey, 1997). Recently, the development of commercial Internet Map Servers adopted more complicated frameworks, including Microsoft Active Server Pages (ASP), ColdFusion connector, ActiveX connector, Servlet Engines, Web Services, etc. The architecture of many commercial IMS, such as ArcIMS 4.0, becomes multiple-tiers (ESRI, 2002).

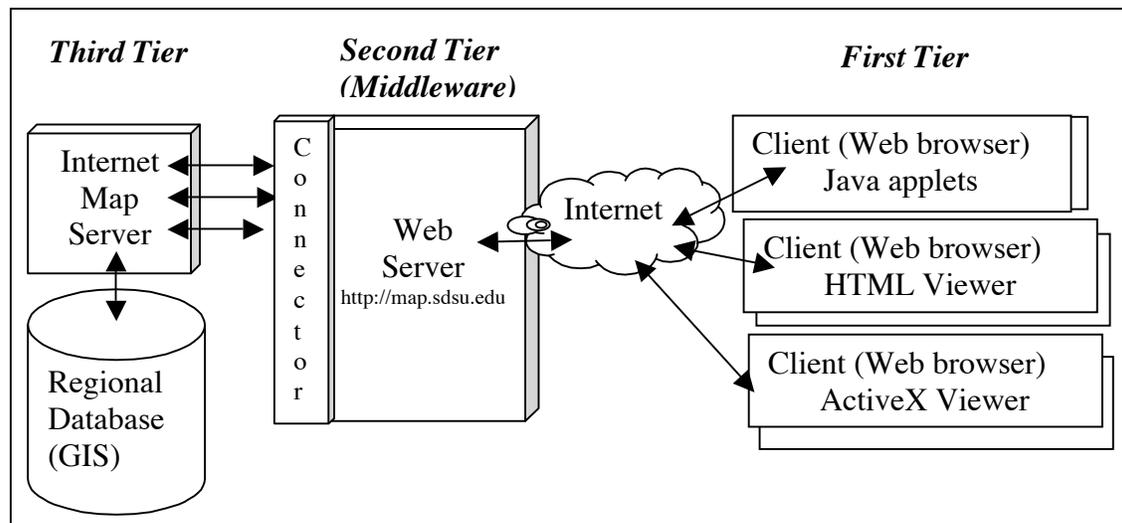


Figure 1. The architecture of three-tier Internet Map Server.

Another contributing web technology is the Java language for developing on-line remote sensing analytical and change detection functions. The Java language is a pure object-oriented language, designed to enable the development of secure, high performance, and highly robust applications on multiple platforms in heterogeneous, distributed networks (Gosling and McGilton, 1996). From the computer programming perspective, Java is similar to C and C++ programming languages which are capable of advanced functions, such as preprocessor, unions, pointers, and multiple inheritance.

There are three types of Java programs: Java application, Java applets, and Java servlets. Java applications are stand-alone programs. They don't need to be embedded inside a HTML file, or use any Web browser to execute the programs. Java applications can provide full access to the entire local machine

resources, such as writing files and changing database contents. Also, Java applications run faster than Java applets because the applications do not need to deal with browsers and have full control of the local client environment. A Java applet is a specific kind of application that can only run from within a Web browser which contains the Java Virtual Machine. In contrast to a Java application, Java applets must be included as part of a Web page in HTML format. Java applets are designed for WWW and can be dynamically downloaded via the Internet. In order to protect the Web users and prevent possible damage to the local machines, Java applets execute within a closed, secure Web browser environment and have only limited access to the memory, data, and files on the local machine. More recently, server-side Java programs, called Java servlets, become more and more important for distributed computing environment and the Internet. Java servlets can let a user upload an executable program to the network or server. These servlets can actually be linked into the server and extend the capabilities of the server. By interacting with server-side applications, a Java servlet can share the loads between servers and clients. The results will reduce server load and provide the balance of functionality on server and client machines (Peng and Tsou, 2003).

Current Java System Development Toolkits (JDK) provides a series of well-defined Application Programming Interfaces (API) for image processing and display, such as Java 2D API and Java Advanced Imaging (JAI). The Java 2D API is a set of object classes for advanced 2D graphics and imaging,

encompassing line art, text, and images in a single comprehensive model. The Java Advanced Imaging APIs are used for manipulating and displaying images and range in complexity from simple operations such as contrast enhancement, cropping, and scaling to more complex operations such as advanced geometric warping and frequency domain processing. These APIs are used in a variety of applications including geospatial data processing, medical imaging, and photography. This project utilized the two APIs (2D and JAI) to customize web-based user interface and analytical tools. This project adopted Java applets to provide on-line analytical functions for remotely sensed images and change detection analyses. The principal reason for selecting Java applets is that Java applets are originally designed for the distributed network environment, such as the Internet and Intranet and are capable of providing advanced image processing and comparison functions suitable for habitat monitoring.

On the other hands, there are also several limitations in Java applets. First, the Application Programming Interfaces (API) of Java applets can not provide a data streaming functions from servers to web browsers. The I/O functions of Java applets can not handle external events outside the web browsers or applets. Also, there are not effective data compression tools or formats in the Java API, which may cause a very long download time for large-size remotely sensed imagery. An alternative solution is to create Java applications rather than Java applets which were discussed in previous section.

3. The Implementation of Project Web Site

A web site (Reference: ARC project 2001) was created for developing the prototypes of integrated web-based geospatial services and the evaluation of on-line analytical tools. Figure 2 illustrates the home page of the project web site which includes project-related information (such as project overview, research team, and on-line questionnaire) and multiple web-based geospatial services (data warehouse, interactive mapping, and on-line tools). The following sections will illustrate the establishment of Internet map servers and Java-based analytical tools for remote sensing data and habitat management.

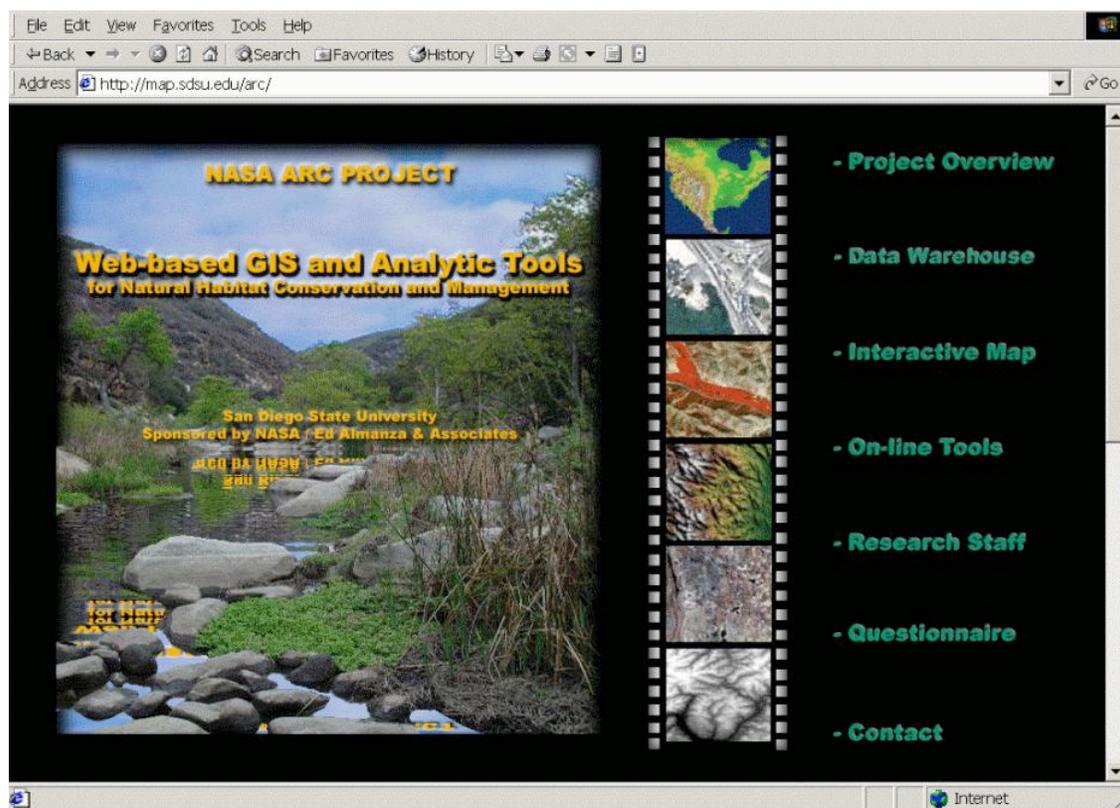


Figure 2. The home page of the project web site (<http://map.sdsu.edu/arc>).

3.1 Internet Map Servers

This project used ESRI's ArcIMS (<http://www.esri.com/software/arcims/index.html>) to provide interactive web mapping services and the display of remote sensing data. ArcIMS is one of the most popular Internet map service packages and supports OGC Web Mapping Standard Web Mapping Services Specifications. ArcIMS can provide comprehensive on-line mapping capabilities, including zoom-in, zoom-out, pan, spatial query, buffering, and measuring (ESRI, 2001).

One of the main features in the prototype is the display of GPS data, remote sensed imagery, and the Internet Map servers. This project gathered several GPS data layers, such as park trails and BMX bicycle sites generated by Mission Trails Regional Park (MTRP) park rangers with their hand-held GPS devices. The GPS data sets were transformed into shapefiles and combined with georeferenced Airborne Data Acquisition and Registration (ADAR) images (Figure 3). The average size of these ADAR images is 15 MB in a TIFF format and 1.7 MB in a JPEG format. Park rangers and habitat managers can use these web-based mapping facilities to perform various tasks, such as monitoring the change of landform, querying the locations of sensitive plants, and evaluating the accessibility of park facilities from their local web browsers.

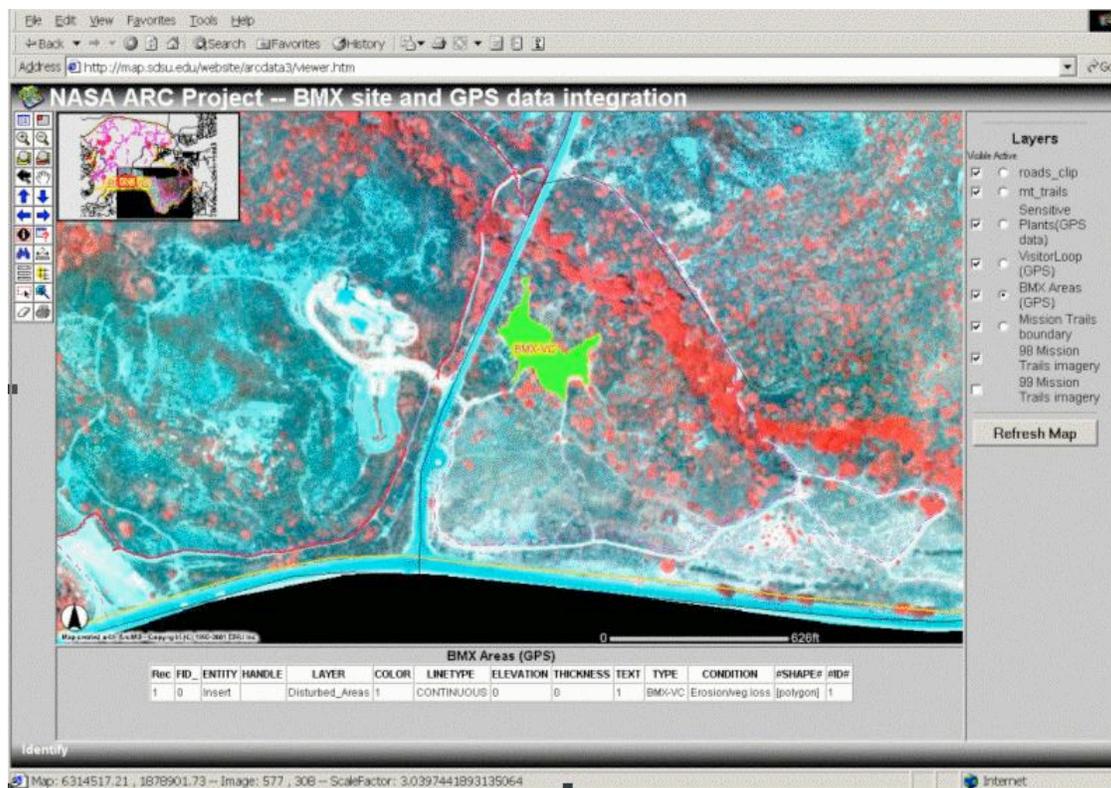


Figure 3. The display of GPS, remotely sensed imagery, and GIS layers (Reference: IMS-example).

3.2 Java-based On-line Analytical Tools

This project adopted Java programming tools to create a series of Java applets that can perform multiple image analyses and change detection functions. These Java applets were organized into an image analysis toolbox, where users can select different buttons to launch different applets (image processing functions) in separate windows. This design of the image analysis toolbox adopted a user-friendly graphic user interface (GUI) that allows users to access analysis tools by simple clicking a toolbox button (Figure 4).

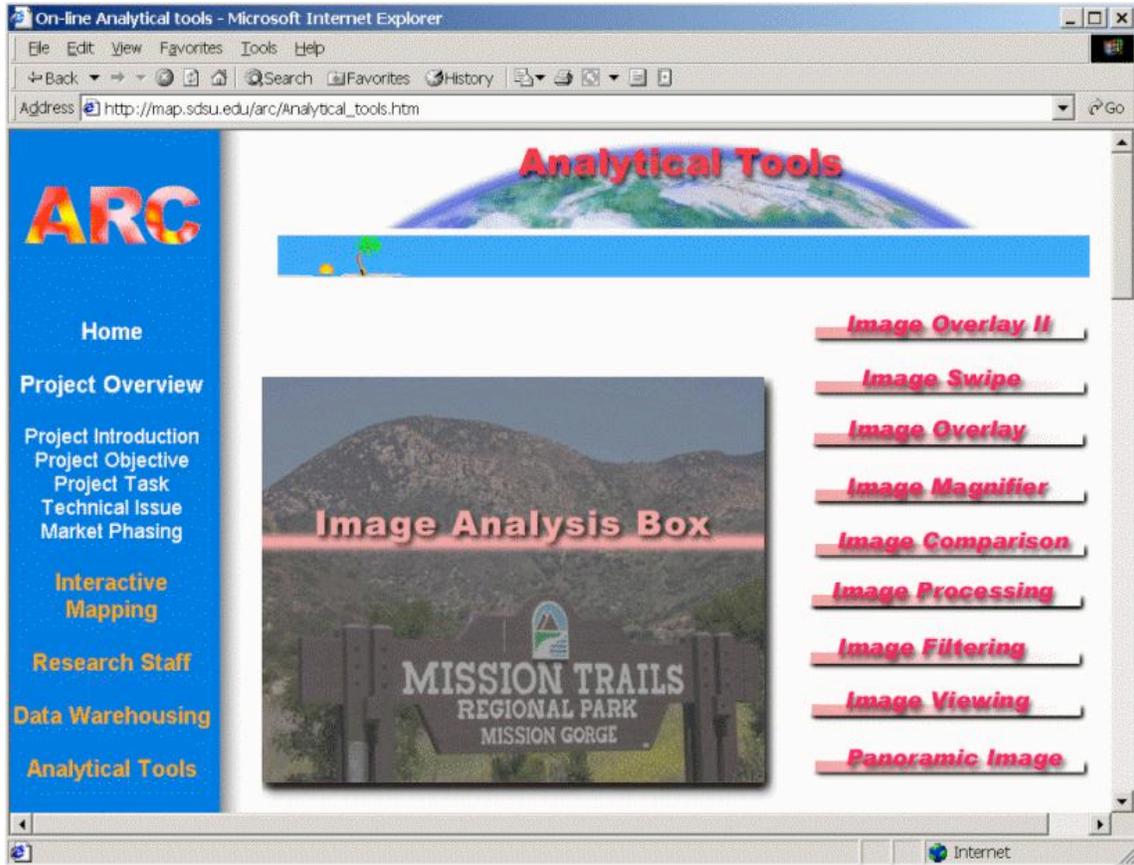


Figure 4. The graphic user interface design of “Image Analysis Toolbox”.

There are eight different Java applets implemented in the Image Analysis Toolbox, including: Image Overlay-I, Image Overlay-II, Image Swipe, Image Magnifier, Image Comparison, Image Processing, Image Filtering, and Image Viewing. The following paragraphs describe two representative Java applets and their analytical functions for remotely sensed imagery and change detection analysis.

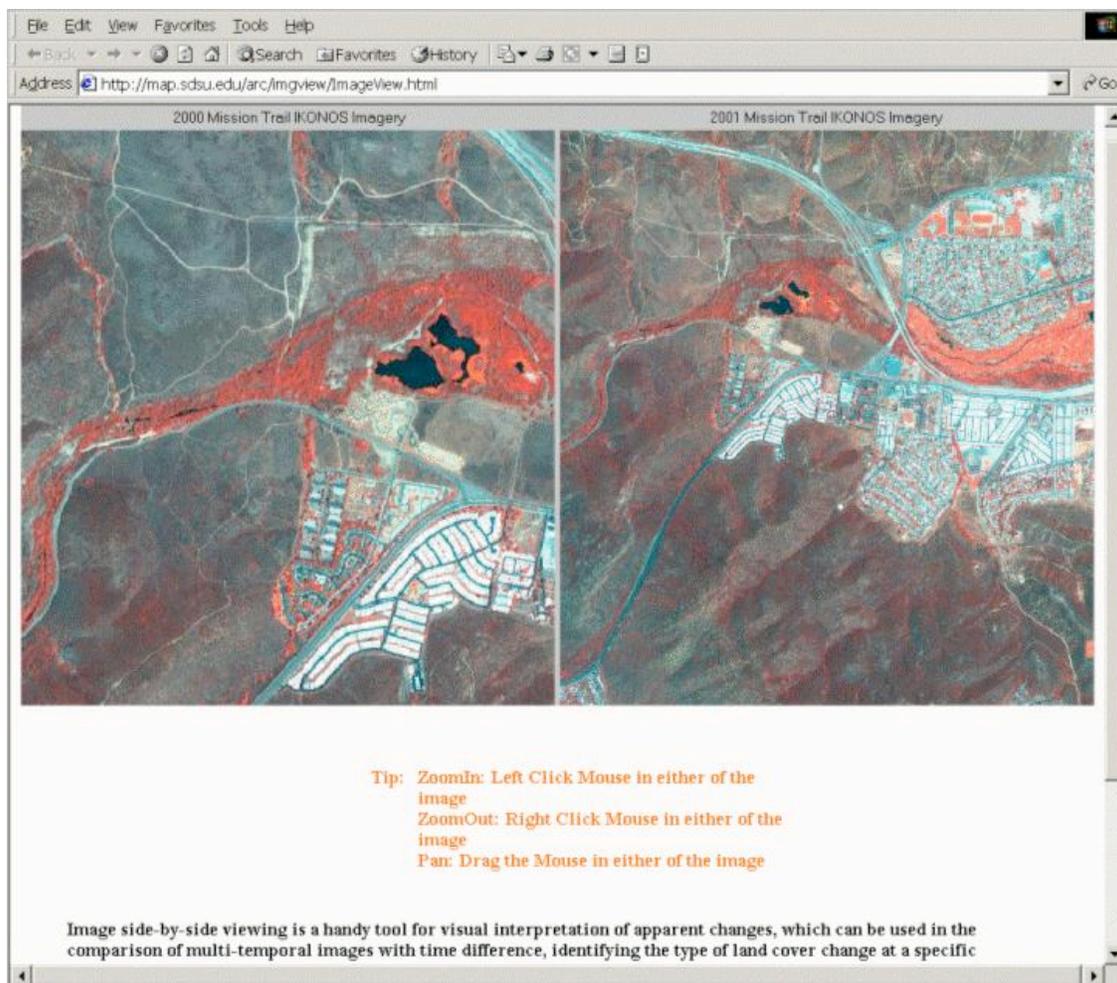


Figure 5. The Image Viewing Java applet (Reference: Java-example1).

Image Viewing: The Image Viewing Java applet provides a flexible means for displaying two images side by side. Users can zoom-in, zoom-out, or pan each image independently. Image viewing is a handy tool for visual interpretation of apparent changes, which can be used in the comparison of multi-temporal images or identifying the type of land cover change at a specific location.

Image Comparison: The Image Comparison Java applet is designed to visualize the temporal changes among matching remotely sensed images. Users can

move the mouse cursor to the location of interest within an index image and the zoom-in box then displays three different images (1998, 1999, 2000) with the same extent at the same time (Figure 6). This tool is able to compare the change of landform and the monitoring of habitat environment.

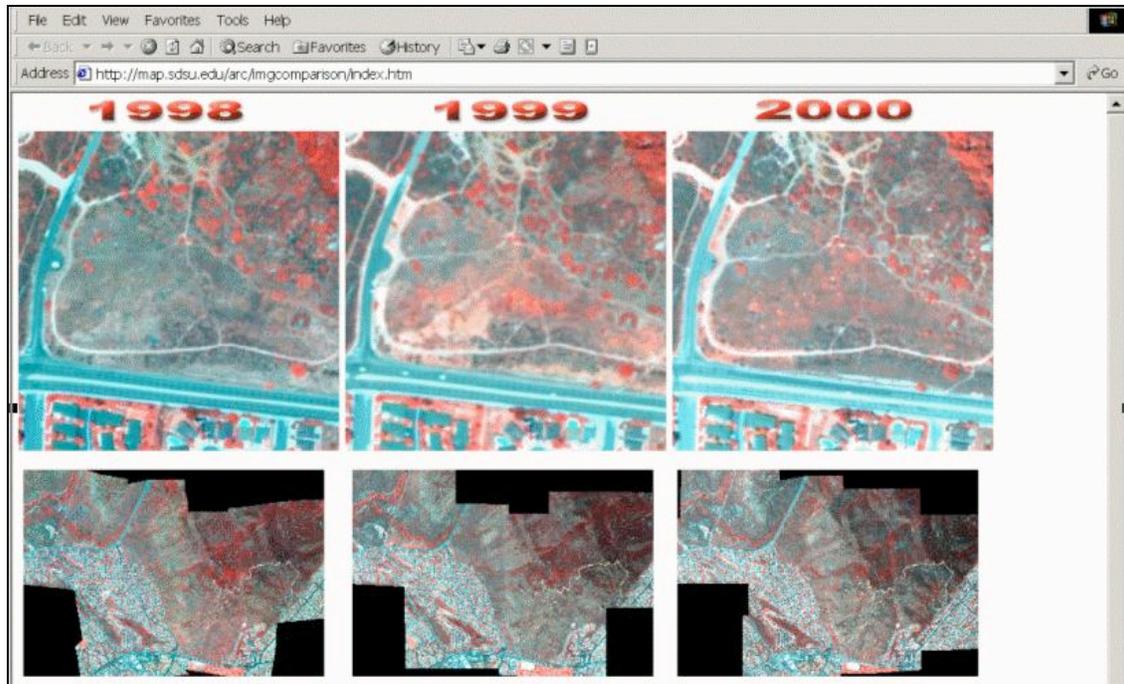


Figure 6. The Image Comparison Java applet (Reference: Java-example2).

3.3 Prototype Testing and Evaluation

The final task of this project is to test the prototype and to evaluate web mapping functionality and analytical tools. The research team conducted two expert review sessions with participating park rangers, and several GIS professionals.

Both testing sessions were structured with 20 minutes of introduction and background of remote sensing and a second 20 minutes of on-line tutorials of the prototype. The tutorials focused on two user scenarios: 1) equestrian facility management and 2) BMX site monitoring and GPS data integration (Figure 7). The documents of prototype tutorial and questionnaire were formatted in several standardized PDF files and were posted on the project web site. Therefore, future potential web users can download these documents and fill out the questionnaire following their review.

In general, all participants felt that these tools are useful for many of their day to day tasks and clearly have application for habitat management. The following list contains key points from the user feedback.

- Java tools are easy to use (comparing to other GIS/Remote Sensing software).
- Need to clarify some information in metadata and IMS tools (explain the terminology from SANDAG and FGDC).
- Need to clarify temporal or seasonal information about remotely sensed imagery and GIS data sets.
- These web tools will be a good information resource for MTRP visitors.
- Internet Map Servers are difficult to view/query data layer while remotely sensed imagery is in the background.

- ADAR and IKONOS magnifier tools could be added into the Data Warehouse section.

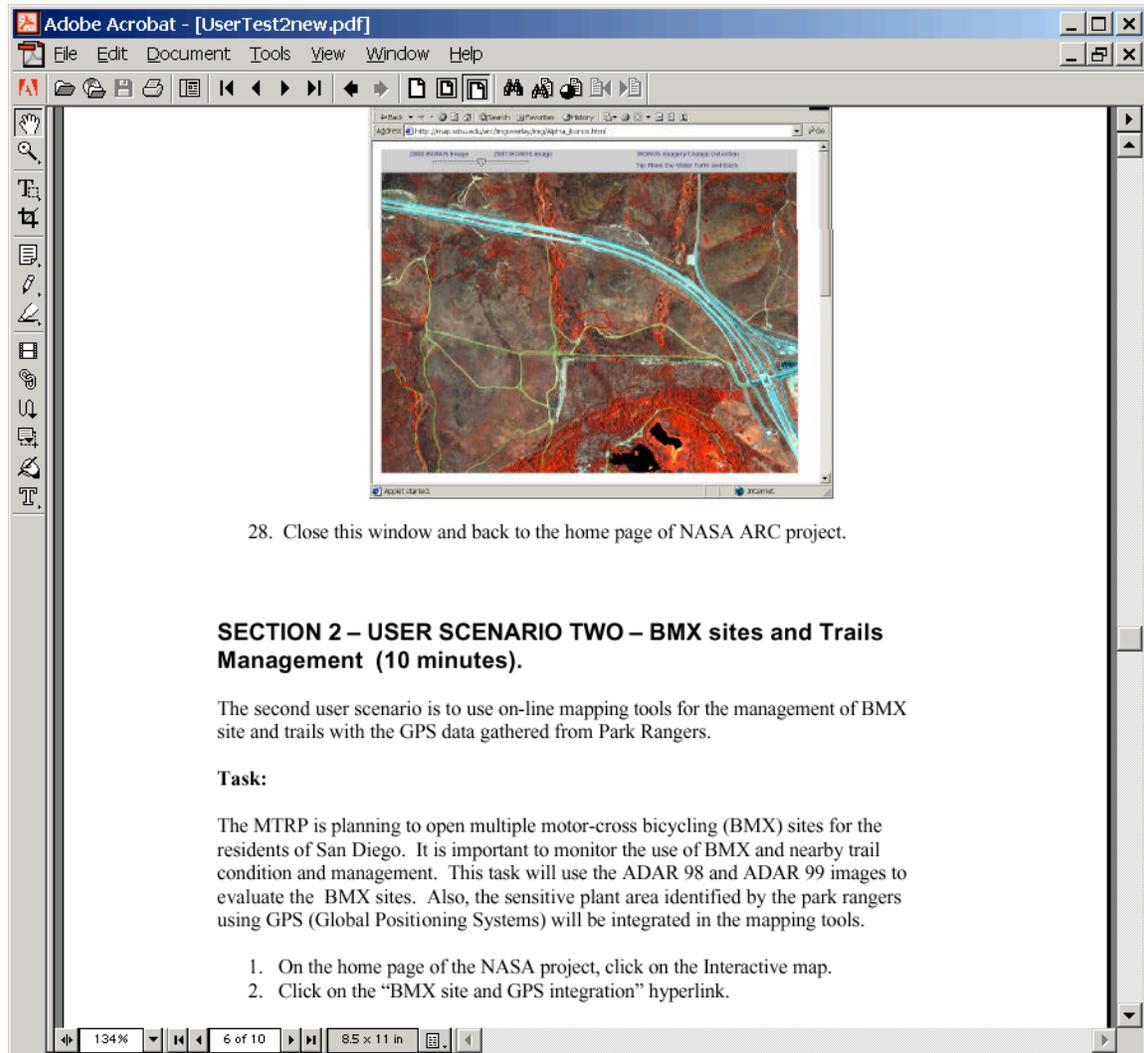


Figure 7. The user scenario and the tutorials of the prototype.

4. Conclusions and Further Developments

This project demonstrates that there is a large potential opportunity for web-based mapping services and image analytical tools applied to natural habitat preservation and environmental resource management. The combined powers of data collection through remote sensing and on-line, geo-spatial analysis tools

through the Internet can significantly reduce the high cost and labor associated with field monitoring. Although Southern California's habitat conservation programs provide the case study for this service, the potential users of these tools extend far beyond the regional community of natural habitat preserve managers.

Two important lessons were learned from the implementation experiences of this project. First, web-based mapping facilities are capable to combine remotely sensed imagery, GPS data, and GIS databases together to provide an integrated framework for natural habitat management and environmental monitoring.

However, the major analytical functions provided in commercial Internet GIS package only focus on the basic GIS query and identification functions. There is a significant limitation (image sizes and formats) to adding very large remote sensing images into the Internet map servers under current software architecture.

The Java applets approach has potential problems of delivering very large remote sensing data due to the lack of appropriate data compression APIs. The average size of images used in the prototype is only 1.7 MB (ADAR images in JPEG format). Hopefully, the future development of Java programming will provide advanced image compression tools for efficient data download and image display functions.

Second, data security and system stability will be the major considerations for the design of web-based remote sensing applications. Many GIS data and remotely sensed images are very sensitive and require protection mechanisms. Currently, very few web-based mapping software or applications can provide a comprehensive security solution or password protection mechanisms for both client-side users and server-side databases.

This research illustrates possible approaches to implement web-based remote sensing applications and demonstrates the potential use for environmental monitoring and management. Future research may focus on the enhancement of web-based remote sensing functions, image compression techniques, dynamic image input/output functions, and mobile device applications, for other public sector applications.

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Java-example1: <<http://map.sdsu.edu/arc/imgview/ImageView.html>>

Java-example2: <<http://map.sdsu.edu/arc/imgcomparison/index.htm>>

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