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# Geospatial Web Services for Environmental Planning

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## Abstract

**Title: Geospatial Web Services in Environmental Planning**



**Keywords:** Geographic Information Systems, Web Services, Environmental Planning, Interoperability, Systems Integration


**Category of paper:** Research paper
**Purpose of the research:** Environmental planning requires integration of disparate geographic database and services in a distributed environment involving multiple stakeholders. As more and more mapping resources are becoming available, the Web is becoming a confluence of collaborative interactions, negotiations and planning platforms. Web services could offer a framework for service integration and composition for collaborative environmental modeling. The objective of this paper is to provide a theoretical framework for understanding how features of Web services can be related to implementation standards and protocols of distributed environmental planning involving geographic information systems.
**Methodology:** Literature review, theoretical analysis and prototype system development
**Findings:** Application of Web services hold promise for distributed resource sharing and collaborative environmental planning. Web services wrap various geo-processing services and avoid problems of tightly coupled distributed object techniques and expose an application programming interface over the Web. Thus, Web service provides promising tools for dynamic composition of complex geospatial services for collaborative environmental planning. By wrapping geo-processing services of interoperable standards of XML and SOAP, we demonstrate a prototype implementation of environmental decision support systems GEO- ELCA (Exploratory Land Use Change Analysis) where Web service-enabled middleware adds core functionality to a Web mapping service. The system demonstrates how geo-processing services can be integrated with environmental simulation models using OGC (Open GIS Consortium) compliant connectors that support WMS (Web Mapping Service) and WPS (Web Processing Services).
**Implications for practice:** The findings will have implications for system analysis and design of Web-based spatial decision support system for decentralized planning and organizational policy formulation e.g., in formulating multiattribute decision rules (discrete choice model) or Data Envelopment Analysis (DEA) for comparing relative efficiencies of different planning units.
**Value of the paper:** The paper will be of interest to academics researcher, urban planners and practitioners.
**Number of pages:** 15
**Number of tables/figures:** 4
**Section headings:** Introduction, Literature Review: Multi-user Context in Environmental Planning, Web Services and Mapping Standards, Research Methods, Web Service Framework for Distributed Collaborative Modeling, Web Services and Mapping Standards, Web Service Framework for Distributed Collaborative Modeling, Service Oriented Architecture: GEO-ELCA, The Collaborative Context of GEO-ELCA, Conclusion.

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# Geospatial Web Services for Environmental Planning

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## Introduction

In the face of the growing trend of organizations moving towards a flatter structure, environmental planners and natural resource managers are facing an increasing need to involve multiple stakeholders in spatial decision-making to bridge the gap resulting from differential access to information and resources. The traditional production of geospatial data and models has been relatively centralized (Pickles 1999). In recent years, there is a growing interest in making access to geospatial information and services available to decision makers and planners to promote Collaborative Spatial Decision Making (CSDM)(Goodchild, Egenhofer, Kemp, Mark and Sheppard 1999). CSDM and public GIS involve a "bottom-up" planning model reflecting the stakeholders' perspective to explore scientifically projected planning scenarios. The vision requires a broad understanding of organizational settings against the backdrop of the distributed information architecture for a closer involvement of multiple stakeholders from different geographic locations and social orientations. It presupposes systems that provide stakeholders with the ability to continuously make plans (Hopkins 1999), have it pre-empted by collaborative actions, and evolve based on any new contexts. This service-oriented approach has triggered a new wave of enthusiasm in the composition of complex services in a meaningful way involving not only traditional alphanumeric data but complex geographic data and services (Sikder and Gangopadhyay 2002).

One of the functional requirements of collaborative modeling is the development of reusable generic geospatial procedures, which can be made to communicate each other in distributed systems in a heterogeneous environment. For instance, the user may wish to view relationships among several geographically separate datasets and perform varying degrees of analysis and invoke different geo-processing services (e.g., perform spatial proximity analysis combined with geocoding procedures and specialized cartographic visualization in a given area). From the planning point of view, comparing individual preferences with the collective scenario is a group process that essentially requires geospatial service composition in a collaborative framework and a distributed environment. Hence, the service-oriented architecture (SOA) becomes inevitable for collaborative GIS systems that would then define the use of services to support the requirements. By having such services distributed all over the Internet and accessible in a uniform standard manner, it is possible to envision the integration of several spatial services (chaining of services) to provide higher levels of functionality to existing services (Balram and Dragic´evic 2006; Peng and Tsou 2003). Equally important is the ability to locate and obtain someone else's data with minimal human intervention in the process of system interoperability. In this respect, the OpenGIS Consortium's endorsed standards and specifications for geographic data encoding GML/Geography Markup Language), geographic data publishing (WFS-Web Feature Service), and map publishing (WMS/Web Mapping Service) and Web Processing Service (WPS) are being received in the industry. These standards are becoming key elements of collaborative planning in urban information systems.

While Web services require minimal standards-based protocols such as HTTP or SMTP for use in other applications, they essentially offer communication among systems without requiring centralized planning or control mechanisms to integrate a heterogeneous mix of platforms (Curbera, Nagy and Weerawarana 2001). Current researchers lack a theoretical framework for understanding how features of Web services can be relate to implementation standards and protocols of distributed planning systems; they also lack a theoretical framework for understanding how such features can be exposed in geospatial service composition for collaborative planning.

## Literature Review: Multi-user Context in Environmental Planning

Collaborative GIS have been used in many planning problems for solving semi-structured or loosely structured decision problems in environmental planning (Angelides and Angelides 2000; Balram and Dragic´evic 2006; Balram, Dragicevic and Meredith 2003; Kingston, Carver, Evans and Turton 2000) The Web GIS implementation area mainly includes environmental planning (Sikder and Gangopadhyay 2002; Tuchyna 2006), data dissemination (Hu 1999; Schuurman and Leszczynski 2006), community planning (Al-Kodmany 2000; MacEachren, Pike, Yu, Brewer, Gahegan, Weaver and Yarnal 2006; Rao, Fan, Thomas, Cherian, Chudiwale and Awawdeh 2007). While researchers continue to argue for an integration and structuring of collaborative mapping and visualization technologies into spatial decision making (Armstrong 1994; Balram and Dragic´evic 2006; Jankowski and Nyerges 2001; MacEachren 2001; Nyerges and Jankowski 2001), a Web-based GIS framework designed to integrate stakeholders into the planning process has yet to be realized. One of the major impediments to developing GIServices for collaborative modeling is the lack of interoperable component technologies. Heterogeneity of geo-spatial systems has plagued GIS since its inception (Goodchild, Hanning and Wise 1992; Stoimenov and Djordjevic-Kajan 2005; Worboys and Deen 1991). Different agencies had built many different geographic data models and systems, following their native organizational interest and problem domain (Egenhofer and Herring 1991). The benefit of collective learning has not yet been fully realized, due to a lack of mechanism for reusable service and models in participatory systems. In view of decision support frameworks, collaborative modeling presupposes multiple parties with different perspectives working together in a complex emergent environment. These parties (henceforth termed as "agent, "decision maker", or "stakeholder" interchangeably) must have integrated data access from heterogeneous sources to integrate with transparent high performance computing resources to compose decision models dynamically. However, in real life situations, it is often difficult to achieve the stakeholders' views or effective patterns of social interactions in the planning process. For example, decisions on how current land use should be changed depend on legal, environmental, and regulatory constraints, as well as on biases and preferences of different groups or institutions. In particular, understanding urban land use dynamics involves consideration of the complex behavior of individual decision makers and the interaction of local and regional institutions in multiple scales. Moreover, such decisions are inherently spatial in nature because the change in a particular parcel may have direct or indirect consequences to the neighboring parcels.

For example, the EPA's Brownfields development program involves the expansion, and redevelopment of urban areas that may be complicated by the potential presence of a hazardous substance, pollutant, or contaminant (EPA 2006). While cleaning up and reinvesting in these properties takes development pressures off of undeveloped, open land and improves the environment, evaluating a candidate property to determine if it meets the criteria for redevelopment is inherently a collective decision process. For instance, an individual landowner may act from his or her individual interest; however, in the long run, the overall land use scenario may be undesirable to everyone. Moreover, changes in land use may create concern for environmental impact in the surrounding region. While land-use changes are often identified as a major driving force of ecological changes, with the conversion of land use from one category to another, there is an overall change of hydrological characteristics resulting from the changes of impervious areas. Consequently, the increase in volume and peak flow means a possible increase in the concentration of pollutants that could potentially cause the environment to deteriorate. Hence, a centralized planning process is essentially inadequate to reflect group dynamics. Such group-individual dilemmas make them ideally suited for collaborative planning in a distributed environment, particularly regarding the integration of Web-services in accessing geospatial data and models for environmental monitoring.

**Web Services and Mapping Standards**

As a precursor to Web services, CORBA and Microsoft's DCOM or Java-based RMI were often used for distributed access and query of spatial data, sometimes integrated with SDSS. However, being "tightly coupled" with native data structure, the broker-based services are unable to make sure that whenever an organization makes changes in its native data structure or services, the corresponding change is automatically reflected in all other organizations sharing the same resource. Moreover, middleware-based access through a broker relies on a standard definition of" interfaces". Geo-processing services can become very cumbersome in the absence of such interface. From the decision support point of view, having data access at the client's end without robust geo-processing capabilities amounts to having little help. In a broker-based solution, the client has to pull a massive amount of data at his/her end and manage it locally. Such approaches assume the client's explicit ability to manipulate the server connection and remote objects. Thus, frequent spatial processes, such as spatial join between data from two different servers, need to be coordinated at the client's end. Such object-level manipulations of spatial process often fail to provide high-level views to application developers. Paradoxically, in a spatial decision support system, the user's or decision maker's view on spatial features or geometry needs to be realized at a higher level of abstraction while at the same time maintaining the transparency of system processes.

In Web services, a series of protocols such as eXtensible Markup Language (XML); Simple Object Access Protocol (SOAP); Web Service Description Language (WSDL); and Universal Description, Discovery, and Integration (UDDI) provides standards for communication and collaborative processing capacity among Web-service compliant architecture. A key advantage is that various GIS layers can be dynamically queried and integrated while still maintaining independence in a distributed environment. From an organizational point of view, this feature may be very appealing; for local governments, such as counties and other organizations, can still independently collect and manage data locally and still integrate information and services using Web services. A client, for example, like a transportation company, could directly access a local government's base map without maintaining its own. At the same time, the client can update the local government's data from its own record. As far as data interoperability is concerned, extended collaboration and partnerships using Web Services could provide opportunities to open interfaces and communication mechanisms for distributed computing.

Open GIS Consortium (OGC) has been in the forefront of developing a set of interoperability standards to guide the development of web mapping programs. All service specifications of OGC are collectively known as OGC Web Services (OWS) and adhere to the same communication protocol of HTTP. OWSs are subject to somewhat similar operational interfaces. The interfaces have common operations such as GetCabalities, which provide service level information; Get operation allows users to access data in a given context and Describe operation provides a description of data or attributes. OGC's Web Map Server (WMS) implementation information specifies that a mapping service should be able to at least produce a map (as a picture, series of graphical elements, feature data) and answers basic queries and finally inform other programs about its capabilities The three operations defined for a Web Map Service are as follows:

GetCapabilities – obtains machine-readable service metadata

GetMap - returns a map upon receiving request

GetFeatureInfo – optional operation that provides additional feature information (e.g., more information about features in the pictures of maps that were returned by previous map requests).

The Web Processing Service (WPS) interface specifies WPS operations that can be requested by a client and performed by a WPS server. The GetCapabilites and DescribeProcess of WPS are implemented through WSDL which is an XML format for describing Web Services.

## Research Methods

The research methodology involves literature review, theoretical analysis and prototype system development and application of an environmental simulation model in the prototype. The literature review includes extensive study of current developments of distributed geospatial service standards and specifications focusing on evaluation of specifications provided by OGC with respect of OWS. The research explores the issues involved in syntax and semantics requirements of system implementation and how geospatial services are rendered interoperable in a distributed environment. Specifically, this entails examining the requirements operations defined for a Web Map Service, namely GetCapabilities, GetMap, GetFeatureInfo. We also explore how to integrate distributed services with a local mapping applications and how to wrap an application with a SOAP API to invoke a request. The research also includes characterization of OGC compliant middleware for integrating services that supports access to the Web Mapping Service (WMS) and Web Processing Service (WPS) or Web Feature Services (WFS). Within this context a service integration framework is proposed that can be realized by implementing In Particular, the scope of the middleware includes the evaluation of following services:

a) Geoprocessing services
b) Feature update services
c) Parameter-based map rendering services
d) Spatial query processing services
e) User-specific data profile management services

As proof of concept, an implementation of these services is realized in GEO-ELCA, which compiles with OGC specification and the proposed service integration framework. The system allows user to run an environmental simulation model to explore the consequences of land use changes (i.e., feature update services). Moreover, the collaborative aspect of planning is explored by means of use profile management through an implementation of "virtual private network" to compare planning profiles.

## Web Service Framework for Distributed Collaborative Modeling

GIS Web Services is a fast growing field. However, most GIS applications still remain as traditional distributed object systems. The GIS service providers still need to realize the critical issues of interoperability and the obvious benefits of interoperable GIS applications which expose functionality through Web services. In a distributed planning environment, the server side component can exposes its functionality through web services, which could provide the benefits of interoperability and open standards. Figure 1 illustrates a stranded-based framework for integrating collaborative models using Web services. In such a system, UDDI will allow any client to discover spatial services (e.g., using the UDDI nodes as FGDC compliant geospatial metadata servers for registered Web services). Typical geo-processing services may include data management tools like projection and transformation, or topology manipulation, indexing and spatial join, etc.

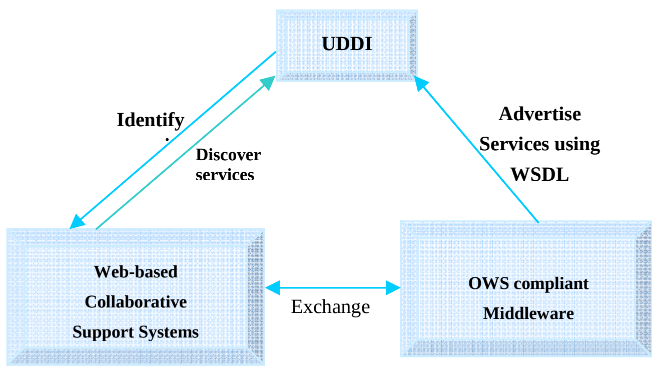


**Figure 1 Standard-based Web-service integration framework for collaborative support**

(Source: Developed for this research)

Analytical services may include spatial proximity analysis, spatial overlay, feature extraction, geo-statistical analysis services, and so forth. Each geo-processing service can advertise its XML protocol or SOAP API using WSDL for discovery. To integrate these services with a local application, the Web application developer needs to wrap an application with a SOAP API to invoke or serve a request. Integrating services can be realized by developing OGC compliant middleware that supports access to the Web Mapping Service (WMS) and Web Processing Service (WPS) or Web Feature Services (WFS). Since Web services build stateless or loosely coupled environments, nodes can be dynamically connected whenever needed, thus multi-user access to data and services are basically "just in time".

### Service Oriented Architecture: GEO-ELCA

What follows is an illustration of a prototype implementation of a Web service-based spatial decision support system for collaborative planning of urban land use change. GEO-ELCA (Exploratory Land Use Change Analysis) offers a collaborative platform for multiple stakeholders with exploratory tools to evaluate the environmental consequences of land use changes. GEO-ELCA supports the evaluation of the pollutant flow as a consequence of land use changes. The system allows an exploratory model to evaluate the hydrological scenarios in response to land use changes as a result of stakeholders' different options. The Web interface allows a user to select graphically a land use type and change it to a different category and then visualize the effect of different pollutants. The system allows the dynamic selection of a feature type (i.e., polygon – land use class) interactively so that a user can change attribute items and identify a feature property. A user can initiate a change in land use type by graphically selecting a polygon. The server side application processes the request and makes necessary updates in the database to reflect the corresponding changes of the pollutant coefficients. Every request to change in land use type results in the recalculation of the mass export of pollutants and corresponding statistics. The processed result is sent back to the Web server and then to the client side. The consequences of user decisions initiate the simulation model to estimate the yearly pollution load. The system integrates a simulation model commonly used in urban hydrology--the so-called “Simple Method”(Schueler 1999) for estimating exports of various pollutants’ runoff from different land uses. The resulting pollution map can be visualized with multiple theme overlay. The system logs individual user’s input preferences into mediating algorithms to resolve conflict among user preferences of land use choice.

GEO-ELCA uses ArcXML (native XML encoding of spatial object) to communicate between the custom middleware and the Web mapping server of the client (which is typically a light viewer such as a browser); the Web mapping server sends WMS Request (GetMap, GetCapabilities, GetFeatures) and WPS Execute Operation (changeLandUsageType) messages which are XML encoded and enclosed in SOAP 1.1 messages. The construction of SOAP messages is accomplished using client side scripting such as JavaScript, VBScript and can also makes use of advanced features such as AJAX. These messages are received by the web server which exposes a web service interface and has already published its service end point interface in a WSDL file. The SOAP message is decoded and passed on to the middleware solution. The middleware is responsible for decoding the request messages which were in OGC Compliant message formats into a format understood by the web mapping server (see Figure 2). In our case, since the web mapping server is ArcIMS, we need to communicate with it using ArcXML..

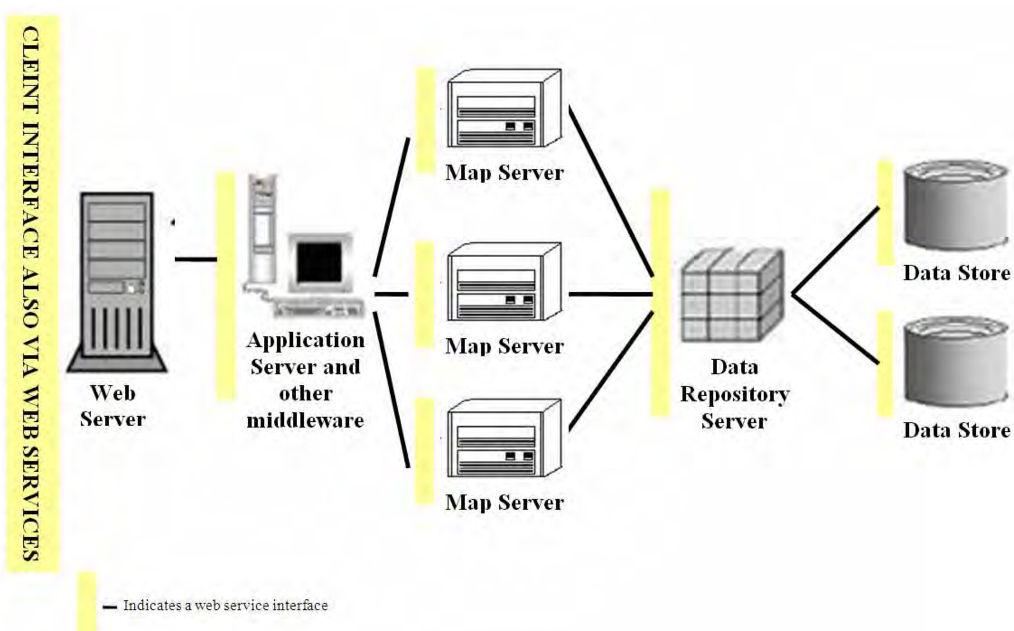


**Figure 2 Service Integration Framework in GEO-ELCA**

(Source: Developed for this research)

Hence the middleware solution provides a mapping from the OGC WMS Request message to appropriate ArcXML requests Figure 3 shows the sequence diagram for implementing the

GetMap Capability. The ArcXML equivalent of OGC Web Mapping Service Operations is shown in Table 1.

**Table 1 OGC's WMS operations and their mapping with ArcXML request**

| OGC WMS Operation | ArcXML Request Operation |
|---|---|
| GetCapabilities | GET_SERVICE_INFO |
| GetMap | GET_IMAGE |
| GetFeatures | GET_FEATURES |

(Source: Developed for this research)

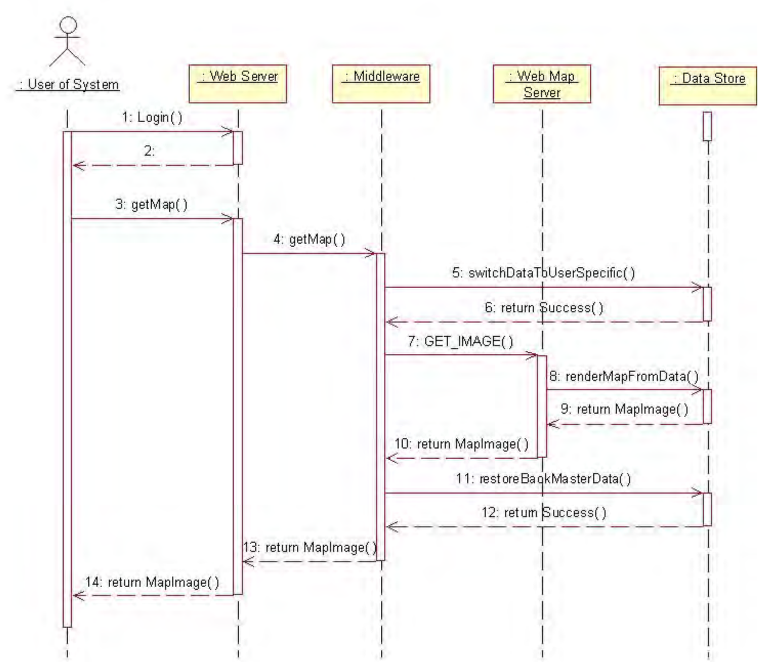


**Figure 3 Sequence diagram for implementing *GetMap* capability**

(Source: Developed for this research)

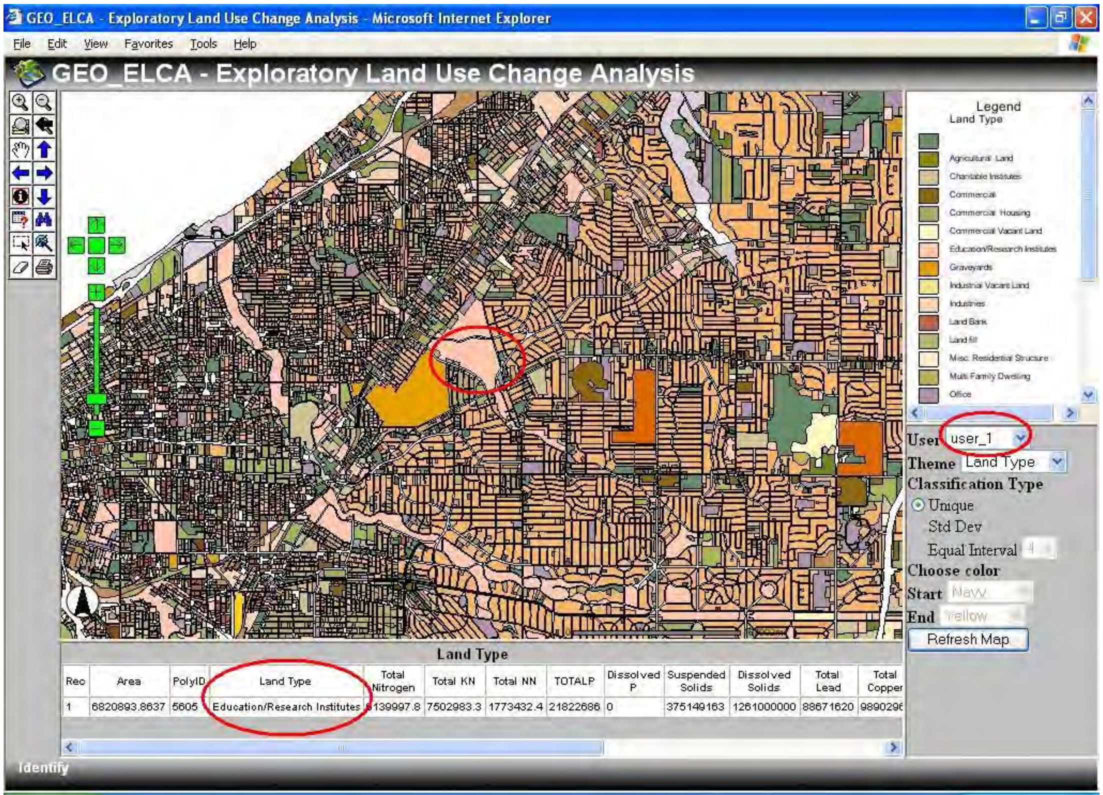


**Figure 4 User specific planning scenario of land use change analysis**

(Source: Developed for this research)

The response received from the web mapping server is also in ArcXML and needs to be converted into a format compliant with OGC WMS Response message format. The middleware solution performs this mapping. Hence the request issued to the web map server is a GET_IMAGE request (as always in ArcXML). The web map server renders the map based on the specific user's state of data and this Map Image is returned all the way back to the user. Hence the client visualizes user specific maps. Once again the middleware solution is responsible for ensuring that the response from the web map server (URL of Map Image encoded within an ArcXML response) is returned back to the client in an OGC GetMap compliant response. The mapping performed for WPS messages is similar to that performed for WMS messages with the tasks performed being the same.

## The Collaborative Context of GEO-ELCA

The"virtual" private user workspace provided by GEO-ELCA offers a mechanism to log an individual user session. An individual user session is achieved by means of a relational data model that provides each user a 'virtual private' workspace. Each individual user is associated with a native profile database, while, in fact, the actual visualization is rendered from a single dataset. Thus, user specific visualization and data editing is possible in real time. For example, when a user's request to change a land use type is received by middleware, it updates the specific user's data. Then it forwards the request for a map to the web map server after converting the request to ArcXML-- a format understandable by the web map server. The web map server queries the data store to retrieve the data it needs to generate the map. The records returned consist of the current user's data and the map. Then a map image is generated using the updated (current user's) data and the map image is returned to the middleware solution, while the master data is restored to original values by updating records from backup data store. Finally, the middleware returns the map image (or URL) of the newly generated user specific map.

The algorithm for land use change performed by the middleware solution is as follows. Note that the response to the WPS changeLandUsageType request is a generated map image:

*Begin*

*Receive the OGC Compliant WPS request along from client.*
*Extract the current user from input parameters.*

*Create a web mapping server request to find out which polygons are affected (i.e Polygons contained within the co-ordinates [minx,miny], [maxX,maxY]) .*
*Send the request to the web mapping server.*
*Decode the web map server response to get the list of polygons affected.*
*If there were affected polygons*
*For each of the affected polygons update users table to reflect the changes.*
*End if*

*Backup Master Data. Save only polygons which will be affected.*
*Update Master Data with specific current user data.*

*Create a GET_MAP request in a format understandable by the web mapping server.*
*Forward the request for Map to web mapping server.*
*Receive the response from the web mapping server*

*Restore Master Data.*

*Convert the web mapping server response to a format expected by the client. (OGC Compliant WPS response) and return it back to client.*

*End*

Thus, user specific planning profiles can be achieved and communicated in real time. As illustrated in Figure 3., the Web-based planning interface offers user-specific individualized explorative options where a user graphically selects a polygon and chooses a land use category from the pop up list to change its category and simulate the "what if" kind of pollution scenario. The simulation model estimates the pollution potential (e.g., total nitrogen, BOD load, etc.) resulting from a user's decision to change land use and graphically display the estimated pollutant. In a multi-user context, each user's planning scenario and corresponding simulation result are achieved in a relational table. As a result, cartographic visualization and representation can be locally customized by user. For example, the same area can be visualized by different user with different options. A user has the option to visualize the confidence limit and standard deviation classification of selected pollutant categories and choose the color scheme or color ramp for classification and hence dynamic map legend rendering. A color ramp is calculated on the fly and a corresponding visualization of the map and the accompanying legend is generated. At present, the system does not offer any group negotiation tool that allows the convergence of a consensus decision. However, such utilities can be easily implemented in the given architecture by integrating multi-objective optimization services (e.g., a discrete decision choice model like the Analytic Hierarchic Process or evolutionary algorithm for group decision making).

## Conclusion

Since Web services avoid problems of tightly coupled distributed object techniques and expose an application programming interface over the Web, they hold promise for distributed resource sharing and collaborative environmental planning. By wrapping and dynamically integrating remote geo-processing services from multiple sources, one can develop an emergent collaborative system using interoperable standards of XML and SOAP. We introduced some architecture for Web service-based collaborative modeling applications for environmental planning. The prototype system is based on the conversion of the OGC compatible GIS services to Web Services for flexible collaboration. The significant advantage of the architecture is that it provides a means for self-describing services in which end users through any WMS/WPS client can invoke a set of services (e.g., catalog services of spatial map). Consequently, user specific plan profiling and customized cartographic visualization are rendered dynamically. The consequence of a user's decision is simulated graphically to estimate the yearly pollution load as a result of individual decision. Each user's planning profile can finally be compared for further modification. The collaborative model suggested here is geared towards archiving different opinions in a manner suited to visualization and negotiation. The service integration framework proposed in this paper has significant implications in developing spatial decision support systems for natural resources planning, multicriteria-spatial DSS(MC-SDSS) for site selection (e.g., spatial group choice based habitat restoration). Moreover, in group environment one can implement multiattribute decision rules (e.g., Analytic Hierarchic Process (Saaty and Vargas 2001) for discrete choice model), Data Envelopment Analysis (DEA) for comparing relative efficiencies of different planning units.

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