Assessing the Robustness of Web Feature Services Necessary to Satisfy the Requirements of Coastal Management Applications

by

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Abstract

Ever expanding pressures on the health and productivity of our oceans and coasts from threats such as coastal development and climate change are stressing the need to consider the full spectrum of factors, scales, dataset, opinions, and trade-offs for current and future coastal management actions (Guerry 2009; McLeod and Leslie 2009; Rosenberg and Sandifer 2009). Web-based GIS tools including coastal web atlases (CWAs) and geospatial web services are rapidly being developed to assist managers, decision-makers, and scientists with the creation, implementation, and evaluation of coastal management options. Numerous web atlases are incorporating web feature service (WFS) standards into their website to provide critical datasets on-the-fly for use in spatial decision support tools to assist with management and policy decisions. However, with this increased use of WFSs in CWAs it's critical to understand how the various components used to create robust WFSs can affect its performance and ability to successfully execute complex spatial queries that are utilized to assess management options. A subset of county land parcel data from Wisconsin was utilized to assess how various software, hardware, and data characteristics can affect WFSs overall robustness, and how these components impact its ability to execute accurate, timely complex spatial queries consistently and their ability to meet the demands of managers, decision-makers, and scientists. Results suggest that WFSs, with varying levels of robustness, can successfully perform accurate, reliable spatial queries on datasets to extract relevant information pertaining to coastal management concerns, which could impact CWAs by increasing their functionality and range of potential applications provided to users.

This research paper follows the style guidelines of the *Annals of the Association of American Geographers*

Introduction

The severity and scale of threats challenging the health and productivity of coastal ecosystems are increasing at an unprecedented rate (e.g., McLeod and Leslie 2009). The range of pressures faced by these ecosystems are diverse, including threats from point and nonpoint source pollution, habitat loss and fragmentation, climate change, ocean acidification, sea level rise, shoreline erosion, and coastal development (McLeod et al. 2005; Lubchenco 2009). Research has shown that the impacts from these threats are often widespread and adverse (Feeley et al. 2008; Lubchenco 2009; McLeod and Leslie 2009; FAO 2010). Examples include estimates that 85% of the world's fish stocks are at or above maximum sustainable yield, over 20,000 acres of critical habitat including wetlands and mangroves disappear annually, and over 150 invasive species have been introduced to U.S. waters since 1970 (Pew Ocean Commission 2003; FAO 2010).

However, impacts from these threats aren't limited solely to coastal ecosystems, but also affect human society and culture. The coasts are home to 50% of the global population, with suggestive estimates that by 2020 approximately 75% of the global population will live within 60km of the coast, and over a billion people rely on fisheries as their major source of protein in their diet (Feeley et al. 2008; FAO 2010; McGlade 2011; Wright, Dwyer, and Cummins 2011). Humans are also reliant upon other services these ecosystems provide including transportation, water filtration, renewable energy, carbon sequestration, erosion control, and various recreational usages (e.g., McLeod and Leslie 2009). This intrinsic complexity between humans and coastal ecosystems, in combination with numerous threats they face, pose a unique challenge to managers, decision-makers, and scientists tasked with developing new, effective management strategies.

Traditional management strategies, which focus on individual sectors of coastal ecosystems, such as managing single species, habitats, or areas, have failed to address these intricate relationships between humans and coastal ecosystems. Therefore, numerous national and international bodies are developing and applying more comprehensive and integrated management strategies for our oceans and coasts (Jones and Ganey 2009). As a result, ecosystem-based management (EBM) has developed as a key management framework since it seeks to achieve the conceptual goals of maintaining a "healthy, productive, and resilient" ecosystem while still providing "the services humans want and need" (McLeod and Leslie 2009). An EBM approach stresses collaboration and integration across multiple scales, agencies, scientific disciplines, and jurisdictions to result in, ideally, more effective and successful coastal management and planning (McLeod and Leslie 2009).

Since the integrated approach of EBM requires managers, decision-makers, and scientists to collaborate with numerous individuals representing multiple agencies, institutions, organizations, stakeholders, and disciplines, it's critical that methods can incorporate the full spectrum of factors, scales, dataset, opinions, and trade-offs into planning, implementing, and evaluating current and future management actions (Guerry 2009; McLeod and Leslie 2009; Rosenberg and Sandifer 2009). Numerous tools are being developed and applied to assist managers, decision-makers, and scientists with facing these challenges. Methods applying coastal mapping, with the assistance of geographic information systems (GIS) have become a popular tool for data exploration, visualization, analysis, and interpretation to aid with the planning, implementation, and evaluation stages of management actions (Dragicevic 2004; Simao, Densham, and Haklay 2009; O'Dea et al. 2011b*,* Wright, Dwyer, and Cummins 2011*)*. However, the development of effective and successful management strategies is also dependent upon access to complete and up-to-date information, which is often limited by numerous factors including data, analysis methods, organizations that hold the data, and the chosen presentation method (conference presentation, journal article, poster, website, etc.; Zhang and Li 2005; Best et al. 2007; O'Dea et al. 2011b). The World Wide Web (henceforth referred to as the Web) and Internet are valuable resources for managers, decision-makers, and scientists because they can provide quick, flexible, and ubiquitous access to a range of data. The growth and accessibility of the Web and Internet has facilitated a shift from traditional desktop GIS applications to the development and increased use of web-based GIS technologies.

Utilization of web-based GIS can provide managers, decision-makers, and scientists access to up-to-date and accurate information from multiple sources, including the government and academia, and across multiple spatial scales that are essential to informed decision-making. The pertinence of web-based GIS to coastal management has resulted in the creation and increasing popularity of a new web-based GIS tool, coastal web atlases (CWAs; e.g., O'Dea et al. 2011a; Wright, Dwyer, and Cummins 2011). CWAs are defined as "a collection of digital maps and datasets with supplementary tables, illustrations and information that systematically illustrate the coast, oftentimes with cartographic and decision support tools, and all of which are accessible via the Internet" (O'Dea et al. 2007, 1). The increasing popularity of CWAs with managers, decision-makers, and scientists is due largely to their inherent ability to be customized to meet the specific needs of various user groups, deal with a variety of coastal thematic properties (e.g., oil spills or coastal erosion rates), and facilitate and support collaboration amongst users (Simao, Densham, and Haklay 2009; Wright, Dwyer, and Cummins 2011). Utilization of CWAs can also bolster accessibility to and efficiency of finding up-to date information by acting as data portals or as searchable data catalogues and benefit managers, decision-makers, and scientists by providing access to spatial decision support tools, assisting with spatial planning, and serving as an educational resource (Wright, Dwyer, and Cummins 2011).

Advances in technology are being applied to web-based GIS components, including CWAs, to create more accessible, comprehensive, and flexible services and applications. Web services are a focus of development as they can be created to perform a wide variety of functions that can be published, located, and invoked across the Web (Vasudevan 2001). Once web services are published, or made accessible, they can be called and invoked by other applications, like CWAs and web sites, and combined with other services to create larger, more comprehensive services and/or applications (Anderson and Moreno-Sanchez 2003). Geospatial web services provide a framework for the acquisition and dissemination of spatial information and are being used to help address a major problem with web-based GIS technology, interoperability.

Interoperability, or the ability for heterogeneous systems or system components to communicate, exchange resources, or work together, is often limited by the heterogeneous nature of spatial datasets (Anderson and Moreno-Sanchez 2003; Lassoued et al. 2011). Heterogeneity can be the result of data collection methods, analysis methods, file formats, or the software used to create, store, and make the datasets available online. Differences in heterogeneity can pose a major problem in spatial data sharing and data interoperability, as well as the functionality of CWAs (Zhang et al. 2010; Lassoued et al. 2011). However, the creation of open-source geospatial web services and standards provide the framework for the incorporation and exchange of heterogeneous spatial datasets and overcoming interoperability and data-sharing problems (Zhang and Li 2005; Moses 2011).

The rapid development and adoption of open-source services and standards provides a stable foundation for the development, growth, and use of web services (Zhang and Li 2005). The enabler of open-source geospatial web services is the Open Geospatial Consortium (OGC). The 400+ members, from geospatial technology software vendors, government agencies, and universities, of the OGC participate in the development, testing, and documentation of a suite of open source standards, protocols, and services that support the interoperable exchange of geospatial information (Best et al. 2007; Reed 2011). Three main OGC standards, web map service (WMS), web feature service (WFS), and web coverage service (WCS) are used for visualizing, accessing, and editing geospatial content (Reed 2011). All three services are used to visualize spatial information but vary based on their inputs, outputs, and inherent client functionality (Table 1).

Table 1. Comparison of three popular OGC web services.

Service Interface Standard	**Input(s)**	**Output(s)**	**Client Functionality**
Web Map Service (WMS)	Map (created from vector and/or raster datasets)	Image (GIF, JPEG, etc.)	Request
Web Feature Service (WFS)	Vector datasets (points, lines, polygons)	XML data (or GML) that includes spatial, metadata, and attribute information	Request, query, and manipulate
Web Coverage Service (WCS)	Raster datasets (pixel-based or features bounded in space)	Encoded binary images (GeoTIFF, NetCDF, etc.) and metadata	Request and query

A WMS provides an interface for users to request an image of a map based off a spatial bound dataset created from vector and/or raster datasets that has been published from an internet connected server. WFSs allow users to request, query, and manipulate vector datasets, including their spatial information, metadata (data about the data), and attributes which are all returned from a server encoded in XML or GML (markup languages that define a specific method for encoding data). WCSs provide either a portion of or an entire raster or spatially bound feature dataset, including the metadata, from a server based off a user's request or query (Reed 2011).

Web services can be utilized in CWAs to create coastal maps, download data for a user specified area of interest, and perform basic spatial queries. As a result, CWAs and geospatial web services are frequently combined to assist with the creation, implementation, and evaluation of coastal management issues. WFSs are becoming increasingly incorporated into CWAs to allow users to perform spatial queries on datasets on-the-fly to extract relevant data pertaining to their specific management concerns or questions. Therefore, with the increasing use of WFSs in CWAs, what components are necessary to create a robust WFS that meets the demands of managers, decision-makers, and scientists to perform critical coastal spatial queries? And consequently, how does the robustness of a WFS affect its performance in executing complex spatial queries?

This study will attempt to assess the necessary components to create a robust WFS and the sequential affects robustness can have on performing a spatial query. To conduct this analysis the Wisconsin Coastal Atlas (WCA) will be utilized as a case study (Figure 1). The framework for the WCA is modeled off the Oregon Coastal Atlas, a well-established, successful, robust CWA developed by the Oregon Coastal Management Program, Oregon State University, and Ecotrust (Haddad, Bailey, and Wright 2011; Hart 2011). Utilizing the successful framework, as well as incorporating the technical lessons learned throughout the development, of the Oregon Coastal Atlas the WCA received funding in 2010 from the University of Wisconsin Sea Grant College Program to develop a statewide resource to address coastal hazards on the Great Lakes, by providing maps, data, and decision support tools (Ventura et al. 2009; Hart 2011).

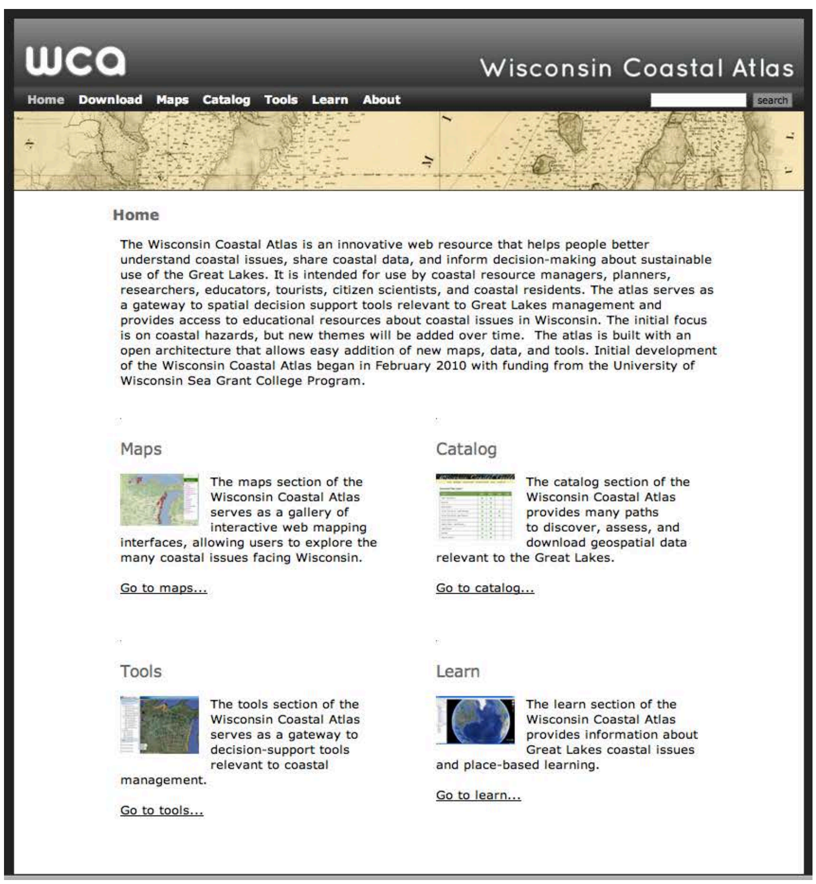

Figure 1. Home page of the Wisconsin Coastal Atlas. Available at http://wicoastalatlas.net.

This study is an outcome of a collaboration between the University of Wisconsin Sea Grant Institute and Oregon State University to evaluate WFSs potential application in CWAs. The primary goal of this study was to evaluate potential benefits and limitations of interfacing WFSs into the WCA, and therefore other CWAs, by determining their ability to meet user needs while still efficiently providing accurate, up-to-date spatial information (Ventura et al. 2009). Initially, multiple hardware, software, and data components were installed and utilized to create, author, and access WFSs. Next, individual components and combinations of components were tested to quantify their effects on WFS robustness. Robustness, in this paper, refers to WFSs ability to provide accurate and precise data on-the-fly in a timely manner and in its entirety for a user, consistently. Finally, the consequent effect of WFS robustness was tested in a distributed spatial query to calculate the economic value of coastal properties in four counties along the Lake Superior coast of Wisconsin. These results can identify the robustness of WFS necessary to meet user's needs by providing assistance with coastal hazard management decisions and, therefore, the potential implications of interfacing WFSs in CWAs.

Methodology

With the increased use of WFSs in CWAs, it's critical that WFSs are robust enough to meet user requirements by providing access to relevant, reliable, and interoperable data for utilization with various management and decision making applications. Multiple factors can impact WFS robustness since they are open-source services and therefore can be utilized in numerous software applications and incorporate different data formats at various levels of completeness. To assess WFS robustness and its ability to meet user requirements this study performed two phases of analysis. The first phase evaluated how different software, hardware, and data components used to create, publish, and access WFSs effect WFS robustness. The second phase focuses on assessing how the various components tested in phase one can impact a WFS's ability to perform on-the-fly spatial queries to calculate the economic value of coastal properties along the Lake Superior coast of Wisconsin.

Evaluating Web Feature Service Components

Software

The core functions of geospatial web services, CWAs, and the Internet operate off a client-server architecture, where information is exchanged between a client and a server over a network (Figure 2A). This exchange of information occurs when a user makes a request from a client machine to a server which finds the appropriate information from an installed application, program, or service to fulfill the request, and then the server returns the request back to the client machine. The basic components for a client-server architecture include a machine that acts as a server, software installed on the server that is specific to the desired task, information stored either on the server or somewhere the server can access, a network connection, and a method (e.g. a website or specific software) where a client can form a request, call the server, and access the returned request. WFSs incorporated in CWAs utilize this client-server architecture to provide users access to spatial information over a distributed network, but require additional software components to create, author, and allow users to access the WFS online.

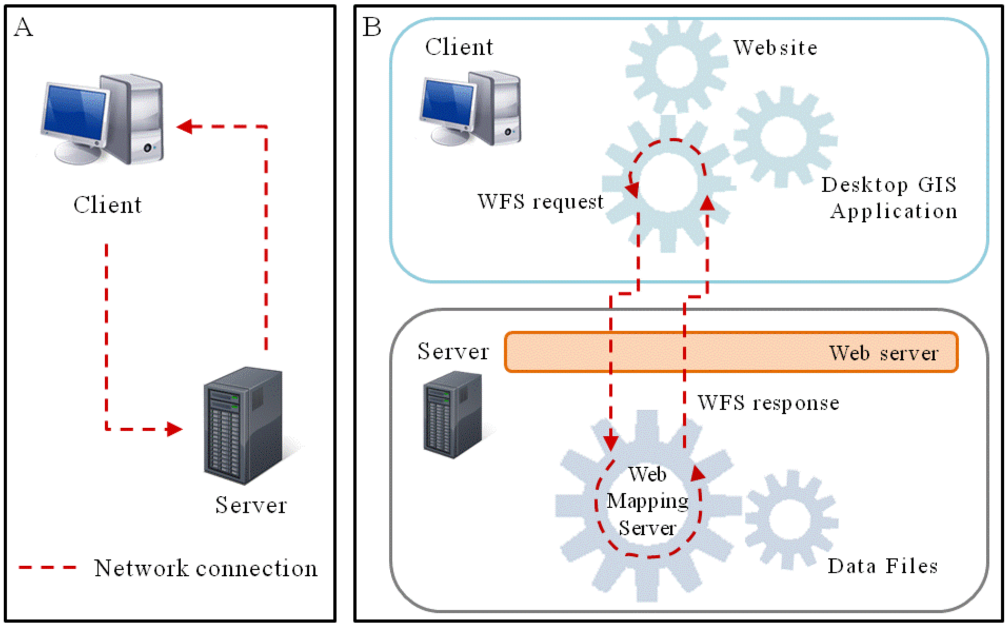

Figure 2. Example of a basic client-server architecture (A) and a client-server architecture for a WFS (B).

The software components utilized to create, publish, and access a WFS predominantly include web servers, web mapping servers that can interface with WFSs, and web mapping applications to request and access the WFS (Figure 2B). WFSs are created on a server with a web mapping server application, such as MapServer, from spatial data stored directly on or that can be accessed from that server. WFS requests to web mapping servers generate spatial information from the dataset, in the form of an XML document (Figure 3), on-the-fly, which is made available from a web server, like Apache HTTP server or Microsoft Internet Information Services (IIS), which make the WFS available on the Internet through a URL. Clients, whether through a website or a desktop GIS application, call the URL with a specific request to access a WFS.

OGC WFS standards allow users to request certain information about a WFS using one of three basic operation requests; get capabilities, describe feature type, and get features (Reed 2011). These requests tell the web mapping server what components of the WFS to return to a user. A get capabilities request returns a WFS XML document that lists all the features available to a user from that URL and a describe feature request returns descriptions of the requested features properties, including its attributes and spatial reference system. Get feature requests allow a user to query components of a WFS to satisfy their specific needs, such as limiting the number of features, the spatial extent returned, etc. (more information about WFS requests can be found at http://www.opengeospatial.org/standards/wfs).


```
<?xml version="1.0" encoding="ISO-8859-1"?>
- <WFS_Capabilities xsi:schemaLocation="http://www.opengis.net/wfs http://schemas.opengis.net/wfs/1.0.0/WFS-
capabilities.xsd" xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" xmlns:ogc="http://www.opengis.net/ogc"
xmlns="http://www.opengis.net/wfs" updateSequence="0" version="1.0.0">
    <!-- MapServer version 5.4.2 OUTPUT=GIF OUTPUT=PNG OUTPUT=JPEG OUTPUT=WBMP OUTPUT=SWF OUTPUT=SVG
    SUPPORTS=PROJ SUPPORTS=AGG SUPPORTS=FREETYPE SUPPORTS=ICONV SUPPORTS=WMS_SERVER
    SUPPORTS=WMS_CLIENT SUPPORTS=WFS_SERVER SUPPORTS=WFS_CLIENT SUPPORTS=WCS_SERVER SUPPORTS=GEOS
    SUPPORTS=RGBA_PNG INPUT=EPPL7 INPUT=POSTGIS INPUT=OGR INPUT=GDAL INPUT=SHAPEFILE -->
  - <Service>
    <Name>MapServer WFS</Name>
    <Title>Parcels of Iron County, WI</Title>
    <Abstract>This WFS contains spatial information for parcels in Iron County, Wisconsin. Includes acres (TOTACRES),
      total land value (TOTLAND) and total impervious value (TOTIMP) attributes for each parcel.</Abstract>
    <OnlineResource> http://webserverURLaddress/locationOfDataStoredAsWFS
                                                  </OnlineResource>
  </Service>
  - <Capability>
    - <Request>
      - <GetCapabilities>
        - <DCPType>
          - <HTTP>
              <Get onlineResource=" http://webserverURLaddress/locationOfDataStoredAsWFS
                                                  "/>
            </HTTP>
          </DCPType>
        - <DCPType>
          - <HTTP>
              <Post onlineResource=" http://webserverURLaddress/locationOfDataStoredAsWFS
                                                  "/>
            </HTTP>
          </DCPType>
        </GetCapabilities>
      - <DescribeFeatureType>
        - <SchemaDescriptionLanguage>
            <XMLSCHEMA/>
          </SchemaDescriptionLanguage>
        - <DCPType>
          - <HTTP>
              <Get onlineResource="http://webserverURLaddress/locationOfDataStoredAsWFS
                                                  "/>
            </HTTP>
          </DCPType>
        - <DCPType>
          - <HTTP>
              <Post onlineResource="http://webserverURLaddress/locationOfDataStoredAsWFS
                                                  "/>
            </HTTP>
          </DCPType>
        </DescribeFeatureType>
      - <GetFeature>
```


Figure 3. Example of a <get capabilities> WFS response from MapServer. The WFS is returned in an XML format, which can be viewed in an internet browser.

Since WFSs are open source, there are multiple proprietary and open-source client and server software applications that have the capabilities to create, publish, or access WFSs. This variety creates a broad range of interfaces for the creation and use of WFSs, and can impact the resulting robustness of the service since each software application has its own unique specifications for creating, publishing or accessing a WFS. Three popular web mapping servers and desktop GIS applications are evaluated to determine how the software impacts a WFS robustness.

Web Mapping Servers

There are numerous web mapping servers that can create and publish WFSs. To understand how a web mapping server impacts a WFS robustness three popular web mapping servers were tested and compared; two open source and one proprietary, MapServer (version 5.4.2), GeoServer (version 2.1.3), and ArcGIS 10.0 for Server (henceforth referred to as ArcServer) respectively. These three servers are popular software's frequently utilized by CWAs and work with most major operating systems and support a variety of vector file formats to create WFSs (Table 2).

Table 2. Comparison of MapServer, GeoServer, and ArcServer. All information seen below is available on their websites.

Category	MapServer	GeoServer	ArcServer
Website	http://www.mapserver.org/	http://geoserver.org/	http://www.esri.com
Supported Operating Systems	Windows, Linux, Mac OSX, Solaris, etc.	Windows, Linux, Mac OSX	Windows, Linux
License Type	Open Source	Open Source	Proprietary
Software Interface	Command line or separately installed graphical user interface	Graphical user interface	Graphical user interface
Supported Input File Formats	• Vector: shapefile, TIGER, etc. • Raster: TIFF, GeoTIFF, JPEG, GIF, PNG, etc. • Databases: Microsoft SQL, Oracle, PostGIS/PostgreSQL, etc.	• Vector: shapefile, TIGER, etc. • Raster: TIFF, GeoTIFF, JPEG, GIF, PNG, etc. • Databases: Microsoft SQL, Oracle, PostGIS/PostgreSQL, etc.	• Vector: shapefile, TIGER, etc. • Raster: TIFF, GeoTIFF, JPEG, GIF, PNG, etc. • Databases: Microsoft SQL, Oracle, PostGIS/PostgreSQL
Supported output OGC web services	• WMS • WFS • WCS	• WMS • WFS • WCS • Etc.	• WMS • WFS • WCS • Etc.

Since each server provides its own method to create and publish WFSs, which can affect WFS robustness, four WFSs were created on each server from the land parcel data for the four counties, Ashland, Bayfield, Douglas, and Iron, on the Lake Superior coast in Wisconsin (Figure 4). To assess the web mapping servers effects on WFS robustness, first all three web mapping servers' integrated WFS capabilities were compared to determine the level of customization and ease of use they provided to users when generating WFSs. Next, all four datasets on each server were requested using a Python script from a desktop computer with high speed network access (100 Mbps) to assess which WFS XML tags were included from each server for all three OGC operations, get capabilities, describe feature type, and get feature. This script was also used to calculate the file size (Megabits (Mb)), WFS response time (s), and average download speed (Megabits per second (Mbps)) for each WFS request created (*n*= 30).

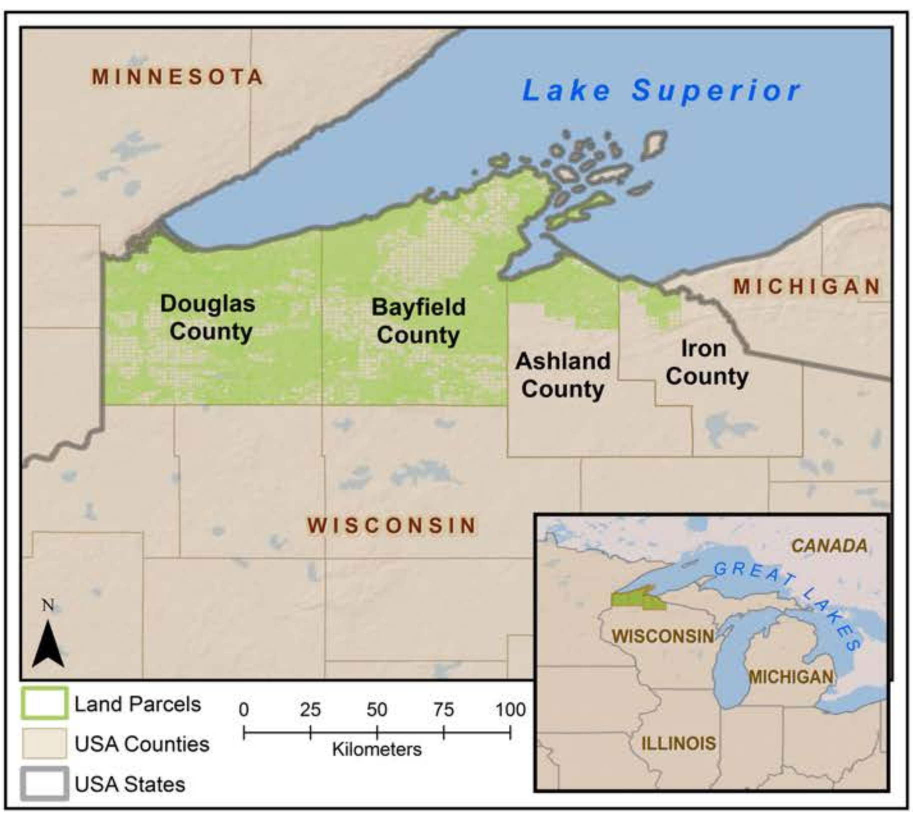

Figure 4. Study area of Douglas, Bayfield, Ashland, and Iron Counties in Wisconsin. Data sources include Ashland County, Bayfield County, Douglas County, Iron County, Wisconsin Coastal Atlas, and Esri.

Desktop GIS Applications

Three desktop GIS applications were tested and compared: two open source and one proprietary, QuantumGIS (version 1.7.4), gvSIG (version 1.11.0), and ArcGIS for Desktop (version 10.0; henceforth referred to as ArcGIS) respectively, to evaluate how their software specifications and integrated WFS capabilities can impact WFS robustness (Table 3). Each desktop GIS application was used to call the WFSs created for Ashland, Bayfield, Douglas, and Iron counties from each of the three web mapping servers, MapServer, GeoServer, and ArcServer. The process of requesting a WFS for each application was compared from a desktop computer with high speed network capabilities (100 Mbps) to determine the level of customization and ease of use they provided to users. Each OGC get feature WFS request (n=10) was then evaluated to determine file size (Mb), average download time (s), download speed (Mbps), and the number of features, attributes, and metadata returned for each WFS operation request.

Table 3. Comparison of Quantum GIS, gvSIG, and ArcGIS. All information seen below is available on their websites.

Category	Quantum GIS	gvSIG	ArcGIS
Website	http://www.qgis.org	http://www.gvsig.com	http://www.esri.com
Supported Operating Systems	Windows, Linux, Mac OS X, Android	Windows, Linux, Mac OS X	Windows, Linux
License Type	Open source	Open Source	Proprietary
Software Interface	Graphical user interface	Graphical user interface	Graphical user interface
Supported Input File Formats	• OGC WMS, WFS, etc. • Vector: shapefile, TIGER, etc. • Raster: TIFF, GeoTIFF, JPEG, GIF, PNG, etc. • Databases: Microsoft SQL, Oracle, PostGIS/PostgreSQL, etc.	• OGC WMS, WFS, WCS, etc. • Vector: shapefile, TIGER, etc. • Raster: TIFF, GeoTIFF, JPEG, GIF, PNG, etc. • Databases: Microsoft SQL, Oracle, PostGIS/PostgreSQL, etc.	• OGC WMS, WFS, WCS, etc. • Vector: shapefile, TIGER, etc. • Raster: TIFF, GeoTIFF, JPEG, GIF, PNG, etc. • Databases: Microsoft SQL, Oracle, PostGIS/PostgreSQL,

Hardware

Since CWAs can reach a broad audience, chances are that not all users will have access to high speed internet. A user's satisfaction can be heavily influenced by the download time and can impact their likelihood to use a WFS (O'Dea et al. 2011a). To evaluate how network speed can impact the timeliness and reliability of a WFS, all three OGC operation request for all four counties were called from the three web mapping servers with a desktop computer connected to a high speed internet connection (100 Mbps) and a lower speed internet connection (15 Mbps) from a Python script (n=30). Results were timed to compare how network speed impacted the download time of each WFS from all web mapping servers and desktop GIS applications from a high speed and lower speed internet connection.

Data Characteristics

CWAs are contributing to the increasing amount of spatial data available across the Internet. Since these datasets can come from various sources, including governments, universities, researchers, and the general public, WFSs have to be capable of incorporating numerous data formats and file sizes, with varying numbers of features, attributes, and metadata. However, since WFSs are transferred over the internet on-the-fly, the amount of data incorporated can impact its robustness effecting its reliability and timeliness. Therefore, the land parcel datasets from Ashland, Bayfield, Douglas, and Iron counties will be altered and compared to evaluate how the number of features, attributes, and level of metadata included in a WFS can impact its robustness from the web mapping servers and desktop GIS applications.

Number of Features

Since WFSs access data and provide it on-the-fly to a user, it's important to understand how the number of features incorporated in a WFS impacts its performance. To evaluate how the number of features impacts a WFS the four datasets from each county along Lake Superior in Wisconsin were compared. Each county's data had the same number of attributes for each feature and the same level of metadata but varied in the number of land parcels. This study used the full number of land parcel features for Douglas and Bayfield counties and a subset of coastal land parcels from Ashland and Iron counties to vary the number of features tested (Table 4). Get feature WFS requests from all web mapping servers were performed in each desktop GIS application to evaluate how the number of features impacts the accuracy, timeliness, and consistency of each WFS.

Table 4. Number of features included in each county's WFS.

	Counties			
	Ashland	**Bayfield**	**Douglas**	**Iron**
Number of Features	9192	32843	47224	1059

Feature Attributes

Attributes, characteristics of a feature (e.g. total tax value of a land parcel or median household income for each zip code), provide additional information about a spatial dataset and are frequently used by coastal managers, decision-makers, and scientists to analyze data, identify trends, and evaluate management options with spatial queries. Datasets can contain unnecessary attribute fields or unique values that may not be necessary to the general users of a CWA. Sometimes, certain feature attributes might contain sensitive information that isn't allowed to be made public, like land owner names, and would need to be removed before being published on a CWA. Reducing the number of feature attributes can reduce the size of a WFS request and therefore, impact the robustness of a WFS in terms of timeliness and may impact the consistent, complete download of all features and their attributes. To test how the number of attributes impacts a WFS, two different WFSs were created from the Douglas County land parcel data, with the same number of features (47,224) and level of metadata, but with varying attribute quantities, one with 33 attributes and the other with 6 attributes. The two datasets will be used to create WFSs from each of the three servers and requested from all three desktop

GIS applications and a Python script to determine how the number of attributes impacts file size (Mb), download time (s), download speed (Mbps), and evaluated to determine if there is any impact on the completeness of spatial features or attributes for each WFS.

Metadata

Metadata, or data about the data, provides necessary information for users about the data, including information about collection and analysis methods, sources of error, spatial reference systems, and contact information (e.g., FGDC 2011). However, the amounts of metadata included with spatial data vary, from none to full documented metadata that meets a metadata standard. There are several national and international metadata standards in use, typically by government agencies, corporations, and institutions. In the United States, most federal and state agencies follow the Federal Geographic Data Committee (FGDC) metadata standards which can provide significant information for a user (a complete list of FGDC metadata attributes is available online at http://www.fgdc.gov/metadata/geospatial-metadata-standards). To test WFS robustness in regards to metadata, the land parcels data from Douglas County will be duplicated with various levels of metadata; no metadata, basic metadata, mandatory FGDC metadata, and full FGDC metadata (Table 5). These WFSs were created in all three web mapping servers and requested from each desktop GIS application and a Python script with a get feature operations request to determine how the level of metadata detail impacts file size (Mb), download time (s), download speed (Mbps), and if there are any impact on the completeness of spatial features or attributes for each WFS.

Table 5. Metadata components included in each WFS for Douglas County.

WFS Metadata	Metadata components
No Metadata	Basic information generated directly from the data, such as data sources and information about the attributes (names and data formats)
Basic Metadata	File name, keywords, summary, description, spatial reference system, basic attribute information, credits, and access and use limitations for the data
Mandatory FGDC Metadata	All mandatory FGDC fields including basic information (e.g. abstract, keywords, supplementary information, data citation, contact information) and information about data quality, data organization, spatial reference, attributes, and its distribution
Full FGDC Metadata	All mandatory and optional FGDC fields including basic information (e.g. abstract, keywords, supplementary information, data citation, contact information) and information about data quality, data organization, spatial reference, attributes, and its distribution

Distributed Spatial Queries

To contribute to the conceptual framework for utilizing web services in CWAs and their ability to assist with coastal management actions, WFSs were tested to determine their ability to provide methods for WCA users to evaluate coastal hazards. To achieve this, WFSs were utilized in spatial queries to calculate the economic value of coastal properties for the four counties in Wisconsin on the shore of Lake Superior; Ashland, Bayfield, Douglas, and Iron. Spatially-explicit tax assessment data were made available from each county that included attributes such as land parcels identification number, tax value of each parcel, and size (in acres) of each parcel for all four counties. All four counties WFSs were requested and downloaded from all three web mapping servers into all three desktop GIS applications. Once each WFS loaded, spatial queries were performed on the land parcel data to identify which parcels intersected the 1,000-ft jurisdiction of the state shoreland zoning rules. The total land value of all the impacted land parcels from all four counties was calculated to estimate the total assessed value of property, in dollars, within each desktop GIS application. These results were compared across the web mapping servers and desktop GIS applications to the results from the same query performed in all three desktop GIS applications using local data instead of on-the-fly data from a WFS to determine if the WFS introduced any error into the spatial query that would impact the accuracy of the query.

Results

Software

The returned WFSs created from all three OGC operation requests with all three web mapping servers produced accurate spatial data, with each request consistently returning the correct number of features, attributes and level of metadata for each county's WFS as compared to the original datasets. Variance in the WFS robustness was introduced by the file size and download time of each WFS across all three web mapping servers (Table 6). The most significant file size differences occur with get capabilities request between GeoServer and the other two web mapping servers. The file size generated across all web mapping servers for the describe feature type and get feature request are similar with slight variations, with the WFS files created by ArcServer larger than those created with MapServer and GeoServer.

Table 6. Average file size (Mb) and download time (s) for WFS's distributed by MapServer, GeoServer, and ArcServer. Results for all three OGC operations (get capabilities, describe feature type, and get feature) from all four counties as calculated with a Python script.

		WFS Requests average file size (Mb) and download time (s)					
Web Mapping Server	**County**	**Get Capabilities**		**Describe Feature Type**		**Get Feature**	
		file size (Mb)	time (s)	file size (Mb)	time (s)	file size (Mb)	time (s)
MapServer	Ashland	0.03	0.117	0.01	0.096	89.26	1.405
	Bayfield	0.03	0.097	0.01	0.095	293.61	8.813
	Douglas	0.03	0.099	0.01	0.095	456.72	5.472
	Iron	0.03	0.098	0.01	0.096	3.93	0.204
GeoServer	Ashland	0.10	0.011	0.01	0.007	78.97	0.536
	Bayfield	0.10	0.012	0.01	0.010	263.02	1.676
	Douglas	0.10	0.012	0.01	0.009	427.96	3.041
	Iron	0.10	0.010	0.01	0.008	6.77	0.048
ArcServer	Ashland	0.02	0.403	0.01	0.397	58.52	4.734
	Bayfield	0.02	0.402	0.01	0.400	342.04	24.931
	Douglas	0.02	0.396	0.01	0.417	538.88	38.738
	Iron	0.02	0.423	0.01	0.411	8.26	1.096

The average download times also varied across the web mapping servers with GeoServer predominantly returning WFSs the faster across all OGC requests and for every county's WFS. A linear regression of the average download time (s) and file size (Mb) for each county's WFS across all OGC operation requests shows a linear relationship between the two variables for all three web mapping servers (Figure 5). All three web mapping servers average download speeds are best described by a linear regression (R^2 values seen in Table 7), the main difference between the servers lies in the slope of the calculated regression line, with MapServer and GeoServer having low slopes, at 0.0116 and 0.0061 respectively and ArcServer having a higher slope, with a value of 0.0661 (Table 7).

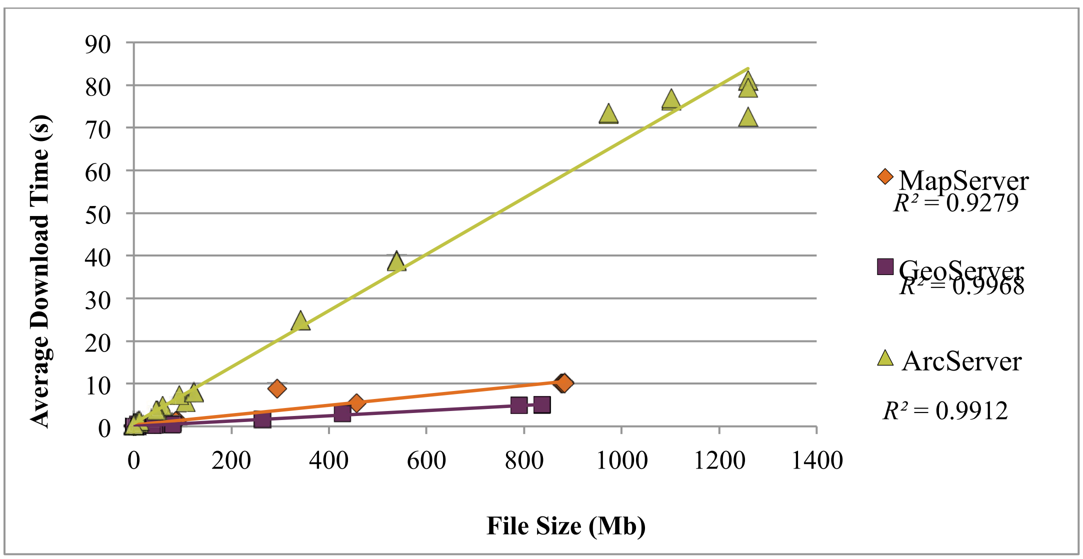

Figure 5. Comparison of average download time (s) and file size (Mb) for WFS requests to MapServer, GeoServer, and ArcServer from a Python script (*n*=30).

Table 7. Simple linear regression results for average WFS download time (s) and file size (Mb) from all three web mapping servers.

Web Mapping Server	Linear Equation (y= mx+b)	Slope (m)	R^2
MapServer	0.0116x+0.3225	0.0116	0.9279
GeoServer	0.0061x+0.0335	0.0061	0.9968
ArcServer	0.0661x+0.6931	0.0661	0.9912

Variance in the WFS robustness was introduced predominantly from the download time of each WFS across all three desktop GIS applications. Results show that all the desktop GIS applications accurately downloaded each WFS and all its features, attributes, and level of metadata. Results also showed that none of the desktop GIS applications alter the file size of the WFS as the file sizes were the same as seen from the WFS evaluation of the web mapping servers with a Python script (Table 8). The Ashland County WFS created from ArcServer is not available (n/a) since errors generating a attribute table for the WFS prevented successful operation requests to that WFS from all three desktop GIS applications. In regards to download speeds, it appears the download times varied across all three desktop GIS application and web mapping server combinations (Table 8, Figure 6).

Table 8. Average file size (Mb) and download time (s) for WFS accessed with Quantum GIS, gvSIG, and ArcGIS. Results compared for <get feature> request from all four counties published from MapServer, GeoServer, and ArcServer.

		WFS get feature requests for each web mapping server average file size (Mb) and download time (s)					
Desktop GIS Application	**County**	**MapServer**		**GeoServer**		**ArcServer**	
		file size (Mb)	time (s)	file size (Mb)	time (s)	file size (Mb)	time (s)
Quantum GIS	Ashland	89.26	3.67	78.97	3.08	n/a	n/a
	Bayfield	293.61	11.20	263.02	9.11	342.04	34.23
	Douglas	456.72	15.75	427.96	16.49	538.88	52.63
	Iron	3.93	0.97	6.77	0.57	8.26	2.45
gvSIG	Ashland	89.26	3.10	78.97	5.16	n/a	n/a
	Bayfield	293.61	14.00	263.02	9.84	342.04	19.50
	Douglas	456.72	15.53	427.96	14.32	538.88	32.54
	Iron	3.93	1.49	6.77	1.34	8.26	2.43
ArcGIS	Ashland	89.26	5.20	78.97	5.18	n/a	n/a
	Bayfield	293.61	8.34	263.02	9.33	342.04	11.15
	Douglas	456.72	10.41	427.96	11.87	538.88	15.07
	Iron	3.93	2.83	6.77	4.25	8.26	3.96

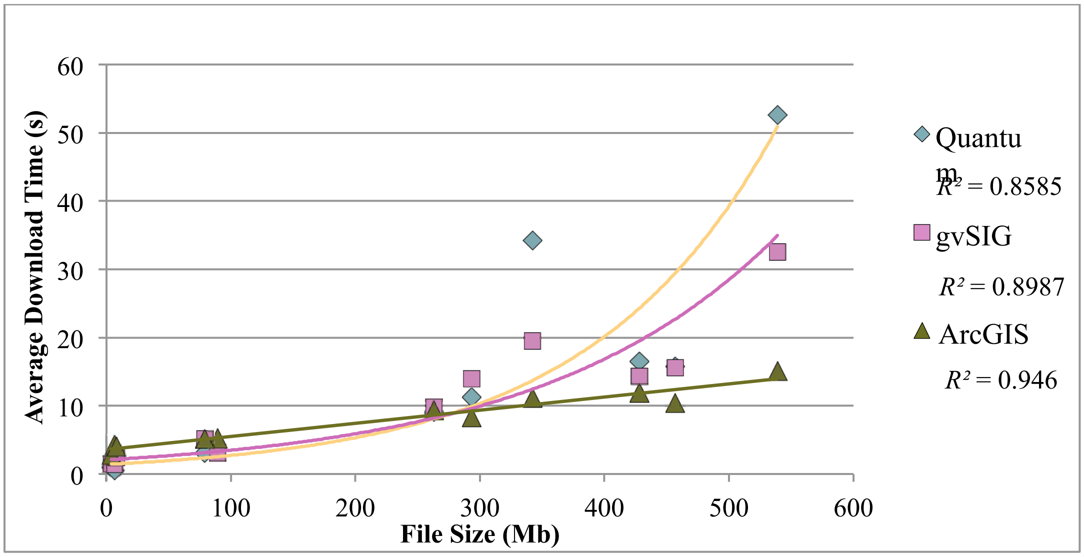

Figure 6. Comparison of average download time (s) and file size (Mb) for WFS requests from Quantum GIS, gvSIG, and ArcGIS (*n*=10).

The average download speed (Mbps) trend (Table 9) for ArcGIS is still best explained by a linear function (R^2 value of 0.946), while variability in download speeds in Quantum GIS and gvSIG appear to better explained by exponential functions (R^2 value of 0.8585 and 0.8987 respectively).

Table 9. Regression analysis results for average WFS download time (s) and file size (Mb) from all three desktop GIS applications.

Desktop GIS Application	Regression Equation	R^2
Quantum GIS	$1.3964e^{0.0067x}$	0.8585
gvSIG	$2.0586e^{0.0053x}$	0.8987
ArcGIS	0.0193x+3.5681	0.946

Hardware

Comparing the download time (s) for WFSs created in MapServer, GeoServer, and ArcServer showed that the timeliness of WFS was greatly impacted by a user's network speed. Download times for a high network speed (100 Mbps) allowed all servers WFSs for all OGC requests to be download in less than 90 seconds, while the lower network speed (15 Mbps) increased download times for all OGC operation request made from all web mapping servers (Figure 7). For MapServer WFS requests, the average download time with a low speed network connection for get capabilities and describe feature type request was double the download time, while get feature requests average download time was 5 times greater than download times with a high network speed capability. ArcServer WFS response time for get capabilities and describe feature type requests remained similar to the same requests called through a high speed network connection, but on average, the get feature request download time was 3 times the duration of the same download from a high speed network connection. GeoServer had the largest variance in download time with get capabilities and describe feature types increased by a factor of 16 and get feature requests increased by an average factor of 34 compared to download times with a high speed network.

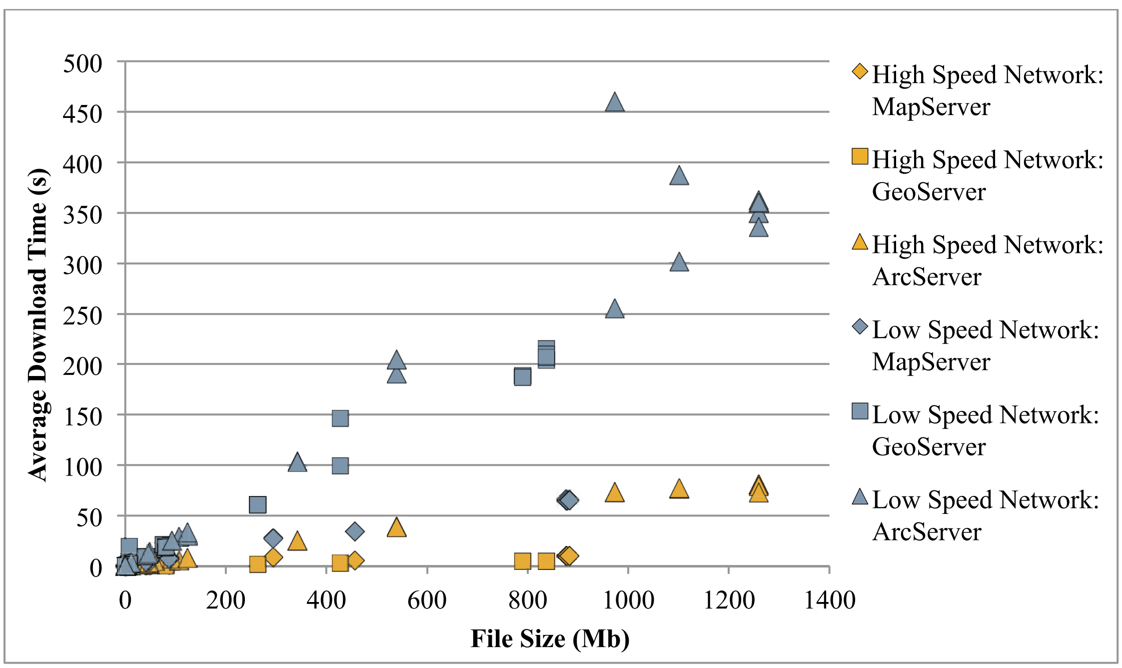

Figure 7. Comparison of average WFS download time (s) and file size (Mb) across different network capabilities. All WFS OGC operation request from MapServer, GeoServer, and ArcServer (*n*=30) were made across a high speed network connection (100 Mbps) and a low speed network connection (15 Mbps) with a Python script.

Data Characteristics

Earlier results for WFS requests from all three web mapping server and desktop GIS applications (Table 6 and Table 8) displayed that WFS file size and download time increases as the number of features increase. The number of attributes appears to impact the timeliness of WFS robustness, as seen in Figure 8, with additional attributes creating larger WFS responses and decreasing the download time in a linear function. This linear relationship between file size and download time doesn't appear when changing only the level of metadata for a WFS (Table 10).

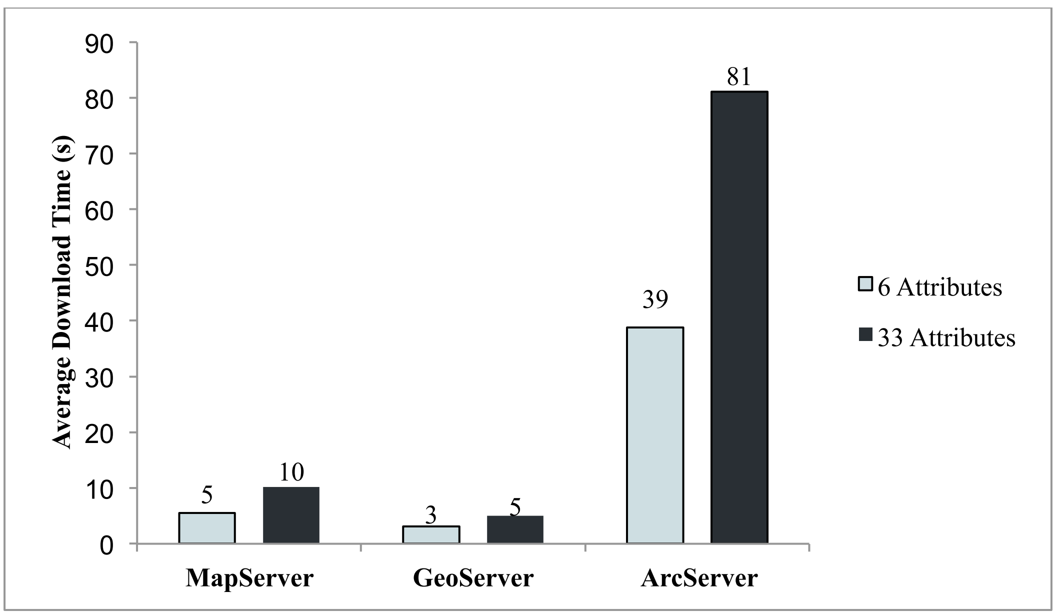

Figure 8. Average download time (s) for <get feature> WFS requests created with various data attribute quantities. Results from each WFS <get feature> request from MapServer, GeoServer, and ArcServer for Douglas County land parcel data with different numbers of attributes, 33 attributes and 6 attributes for all 47,224 features.

Table 10. Average WFS download time (s) and file size (Mb) from MapServer, GeoServer, and ArcServer for WFS's created with various levels of metadata.

WFS	MapServer		GeoServer		ArcServer	
	file size (Mb)	time (s)	file size (Mb)	time (s)	file size (Mb)	time (s)
No Meta	876.18	10.03	789.53	4.92	1101.85	77.02
Basic Meta	878.34	10.06	836.59	5.11	973.59	73.53
Mandatory FGDC Metadata	882.67	10.15	836.59	5.03	1258.94	81.13
Full FGDC Metadata	882.67	10.11	836.59	5.11	1258.94	72.62

Distributed Spatial Query

The original land parcel data for Ashland, Bayfield, Douglas, and Iron counties was queried to identify the number of parcels that were within a 1,000-ft buffer of Lake Superior, which is jurisdictional range of the state shoreland zoning rules. The selected parcels were then queried to calculate their total assessed value (Table 11). To evaluate how the different web mapping servers and desktop GIS application can effect WFS robustness and their impact on a WFS's performance in executing complex spatial queries, the same spatial query was performed on all WFSs from Ashland, Bayfield, Douglas, and Iron counties for each web mapping server within each desktop GIS application. Results showed that the calculated land loss was accurate for all county's WFSs from all servers and within all desktop GIS applications. The only variability introduced from robustness impacted the time spent performing the query and the tool interface provided to a user to develop a query.

Table 11. Spatial query results utilizing WFSs to calculate the economic value of coastal properties along the Lake Superior coast of Wisconsin. The table lists the number of selected parcels and total assessed value of those parcels near the coast in Ashland, Bayfield, Douglas, and Iron Counties.

County	Number of selected features	Total Value (dollars)
Ashland	1,787	158,419,410
Bayfield	2,441	108,622,950
Douglas	1,671	39,260,500
Iron	91	780,500

Discussion

The strengths and weaknesses of WFSs seem to corroborate with the components used to create, publish, and access them. The three tested web mapping servers, MapServer, GeoServer, and ArcServer, provided a user with various levels of customization when creating a WFS. MapServer, which lacks a graphical user interface, develops WFSs from Map Files, a data format specific to MapServer (Figure 9). Map files outline the WFS XML document that is created, pointing a WFS request to the proper data source and location, defines the data's spatial reference system, and includes additional tags for information about the WFS and the data.

Through the creation of multiple WFSs for this study it was determined that the lack of a graphical user interface and the distributed online resources made it difficult to determine the minimum tags required for a MapServer WFS Map File, as well as identifying optional tags that could be included to bolster a WFS's metadata. Problems would also occur since the Map File's document tree, or structure, is extremely rigid, and misplacing tags, spelling errors or additional spaces could prevent a WFS from working properly. This and the lack of error handling made it difficult to troubleshot problems when they arose. These obstacles make it more challenging to build a robust WFS for an inexperienced or time pressed developer, creating less robust WFSs with only the required WFS tags and limited metadata, potentially limiting the usage and incorporation of these services in CWAs. Both GeoServer and ArcServer provided graphical user interfaces for the creation of WFSs which made it easy to select data sources, select spatial reference systems, and add additional metadata descriptions, thus making it easy for users to create and publish WFSs that provide detailed descriptions and sufficient metadata to meet a broader range of user needs.

```
MAP

NAME WFS_Server
STATUS ON
EXTENT -92.3 46.6 -91.9 46.8
SIZE 800 800
SHAPEPATH   "/LocationofData"
IMAGECOLOR 255 255 255

WEB
 IMAGEPATH   "/LocationofMapServer"
 IMAGEURL   "/LocationofMapServer/TemporaryFoldertoCreateWFS"
 METADATA
  "wfs_title"           "WFS Demo Server for MapServer" ## REQUIRED
  "wfs_onlineresource"  "http://webserverURLaddress/locationOfDataStoredAsWFS" ## Recommended
  "wfs_srs"             "EPSG:4326 EPSG:4269 EPSG:3978 EPSG:3857" ## Recommended
  "wfs_abstract"        "This text describes my WFS service." ## Recommended
 END
END

PROJECTION
 "init=epsg:4326"
END

LAYER # Parcels polygon layer begins here
 NAME Parcels_poly
 METADATA
  "wfs_title" "Parcels"
  "gml_featureid" "REFNAME"
  "gml_include_items" "all"
 END
 STATUS ON
 TYPE POLYGON
 DATA Parcels_project

 PROJECTION
  "init=epsg:4326"
 END
 DUMP TRUE

 CLASS
  NAME "Parcels"
  STYLE
   COLOR 245 222 179
  END # End style
 END # End Class
END # Parcels polygon layer ends here
END # End Map
```

Figure 9. Example of a MapServer Map File. Information is designated by tags, seen in all caps, with the corresponding information next to each tag.

All three servers were able to produce accurate, complete WFSs for majority of the OGC operation request returning all the requested features, attributes, and the correct level of metadata. The only problems encountered that affected a server's ability to produce reliable, complete WFSs were the result of the WFS's creation, although problems were observed in all three tested servers. As noted in the results, ArcServer failed to provide a working WFS for Ashland County when a get feature request was sent to the server from each three desktop GIS applications. ArcServer provided a generic error message regarding an error finding the data table. A basic internet search failed to elicit a solution to the problem; however, since ArcServer is proprietary software, CWA developers that ran into similar problems could contact the software developers, Esri, directly for support. Problems encountered with MapServer pertained mainly to the creation of the Map Files as described above. The process of publishing WFSs from GeoServer encountered the fewest problems, all of which pertained to publishing the data and had simple, quick solutions that were described sufficiently through the server's online resources.

The resulting WFS robustness created through these three web mapping servers varied most in the file size generated from a WFS request and the download time. File size seemed to be influenced most by the web mapping server used to generate the WFS and the OGC operation request used to access the WFS. If the web mapping server provided a user friendly interface to create a WFS, like GeoServer and ArcServer, it made it easy for a user to incorporate additional information which increased the average file size. GeoServer also incorporated additional information in its get capabilities WFS requests by listing the query functions available to a user, which tripled the average WFS file size for GeoServer in comparison with the file size from MapServer and ArcServer. Although results showed that the file size generated across all web mapping servers for the describe feature type and get feature request were similar, ArcServer generated slightly larger files which is a result of additional attribute fields ArcServer automatically adds to a WFS. These attribute fields included a unique object ID, geometric shape, shape area, and shape length for every feature and additional information about each attribute's data format (e.g. string, text, and integer).

Download time and speed of WFSs appears to be heavily influenced by numerous WFS components, including the server hardware, web mapping server, and network connection capabilities of both the server and the user. Comparison of WFS download time for all three servers showed a significant difference between the average download time of ArcServer to those from MapServer and GeoServer, with ArcServer performing on average five to ten times slower than MapServer and GeoServer, respectively. Average download time results comparing a high and low network speed connections suggest that MapServer had the most precise download times, while GeoServer had the least precise download times with a wide variance of download times seen between high speed and low speed network connections. However, since each web mapping server was installed on different server hardware, it's hard to identify how much of the download time variance is the result of the user or server network speed, the web mapping server, or the server hardware components. To effectively evaluate the relationship between these components and WFS download time and speed, additional studies would need to be performed with all web mapping servers installed on the same server hardware. Furthermore, since CWAs provide access to users from around the world, with a wide variety of network capabilities, it's critical for CWA developers to consider who and how a WFS might be used and sufficiently increase the network capabilities of the server to improve WFS robustness from the server side.

Results showed that desktop GIS applications had the smallest impact on WFS robustness in comparison to web mapping servers, network connection capabilities, and data characteristics. Majority of the impacts of WFS robustness were limited to the user interface provided to access WFSs by each application. All three desktop GIS applications allowed a user to easily request and access a WFS if they had the URL link to the data. The URL requests made in gvSIG and Quantum GIS could then be view directly in the software, while in ArcGIS a user would build the request first in

ArcCatalog using the Data Interoperability Extension and then could visualize the WFS in either ArcCatalog or ArcMap. ArcGIS and gvSIG provided a user with a graphical user interface to help build a WFS request. Users could restrict the number of features, change the spatial reference, limit the number of attributes, and create queries to restrict the returned WFS. Quantum GIS did not provide an easy method for a user to restrict or change a WFS, and therefore users could only restrict a WFS by directly altering the WFS request in its URL. This method can be frustrating for users if they aren't sure how to structure the WFS query and how to respond to any errors they might receive.

If the same request was called from all three desktop GIS applications, whether through a URL or a user interface, they all displayed spatially accurate and complete WFSs with all the requested features, attributes, and the correct level of metadata. The difference between the return WFS requests was the time to contact the web mapping server, access the results, and spatially reference the feature. Results showed that the WFS download times requested from ArcGIS had a fastest download time on average across a range of file sizes, especially for files larger than 300 Mb. This is likely the result of a unbroken connection between ArcGIS and a WFS, which appears to remain linked to a WFS after the first initial use until the programs are closed. Quantum GIS, which displayed a exponential trend to download time and file size, would established a new connection with a WFS even if the file was previously loaded, which could have resulted in the exponential trend between file size and download time. The variance seen in gvSIG average download time and speed, which also displayed an exponential trend, is likely due to a combination of these factors, since gvSIG also remains connected to a server until the application is closed. However, gvSIG has a limited amount of Java heap space memory, that when the maximum load is filled, gvSIG will fail to load any additional datasets and ask a user to restart the application. This restricts a user's ability to perform spatial queries on large WFS datasets since gvSIG may be unable to load all features necessary for the query at one time.

The number of features and attributes had the expected effect on WFS robustness, with an increase in features or attributes increasing the file size and slowing the WFS download time. However, the level of metadata didn't display a similar linear relationship between file size and download time that was seen with changes to the number of features and attributes of a WFS. This could be a result of the built-in WFS metadata fields each server generates automatically when creating the WFS within the web mapping servers. The small impact of metadata on the WFS robustness means that CWAs don't need to sacrifice incorporating proper metadata for users to prevent slow, inconsistent WFS performance. Although file size can be reduced by limiting the number of data features and attributes, CWA developers need to consider their users' needs to make sure the necessary data components are including while minimizing unnecessary components to optimize the performance capabilities of a WFS.

All the components of a WFS tested in this study seemed to have an impact on WFS robustness. The results of this study suggest that the best combination of components to easily create and publish reliable, robust WFSs would be to utilize GeoServer as a web mapping server due to its ease of use, interoperability, cost, sufficient online documentation, and reliable performance throughout the duration of this study. Results show that network capabilities impact the reliability and timeliness of a WFS, therefore, it's suggested to use a server with high network speed capabilities. Concerns about GeoServer network capabilities for users with various network capabilities would need to be addressed, and should be improved with the use of a more robust server hardware, although more testing would be required to determine the level of improvements this would have on WFS download time and speed. As for a suggested desktop GIS application to access WFS's this study would suggest ArcGIS due to its reliability, built-in spatial tool capabilities, and user interface. However, if costs restrict users to open-source software, results show that Quantum GIS was able to to interface with numerous WFSs in an accurate, timely, reliable manner and should sufficiently meet a user's needs as well.

Results evaluating how the various components of WFS's affect the outcome of a spatial query by calculating the total assessed value of properties intersecting a 1,000-ft. buffer from the coast, showed that all combinations of software, hardware, and data components produced accurate query results. All WFS queries produced accurate land value loss, matching the predicted values calculated with locally available datasets, as seen in Table 11. The only impact was on the time to perform the query, with larger WFS files requiring additional calculation time. These results suggest that WFS robustness does not significantly affect a WFS ability to successfully execute complex spatial queries relevant to coastal management decisions.

Conclusions

Although WFSs can require sufficient time to create and troubleshoot and are unable to incorporate raster data, this study recommends incorporating WFSs into CWAs since they can provide reliable, on-the-fly access to critical dataset that can be incorporated into decision support tools, help analyze and assess potential management actions, and can provide their results to a variety of users, including stakeholders, researchers, NGOs, government employees, decision-makers, and the general public. Due to their interoperability, WFSs provide CWAs the ability to incorporate vector datasets from various data sources, on-the-fly, without having to locally store all the datasets and slow down the response time of their servers. In addition, the WFS's ability to interface with numerous open-source and proprietary software prevents CWAs from having to constantly reformat their data and update links. Furthermore, WFS's can prevent CWAs from having to include numerous spatial decision support tools, since users can access basic tools to help visualize, analyze, and utilize the data through numerous open-source and proprietary desktop GIS applications, thus limiting the number of decision support tools a CWA needs to integrate, allows a CWAs to focus development on more specific tools that address their user's specific needs. WFSs can also provide access to datasets through CWAs and make the necessary data available to all parties invested in planning, implementation, and evaluation of coastal management strategies.

As CWAs develop to provide critical, up-to-date information pertinent to coastal issues worldwide, it's critical that CWAs provide users quick, flexible, and ubiquitous access to a range of data. WFSs allow CWAs to provide a range of spatial datasets on-the-fly that can be utilized by coastal managers, decision-makers, and scientists to analyze data, identify trends, and evaluate management options. This study provides an applied example of the capabilities of WFSs to perform spatial queries on datasets on-the-fly to extract relevant data pertaining to a common coastal management concern of coastal flooding and erosion. This suggests that WFSs can successfully be used to assist with the creation, implementation, and evaluation of coastal management strategies by various CWA users, and highlights the benefits and capabilities interfacing WFS with CWAs can provide.

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