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GIS Server Application for Avalanche Studies

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GIS Server Application for Avalanche Studies

A Major Individual Project submitted in partial satisfaction of the
requirements
for the degree of Master of Science in Geographic Information Systems

by
Bryan Joseph Raymer

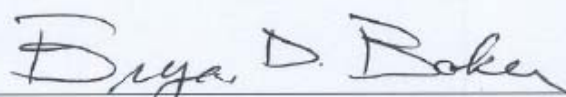Mark P. Kumler, Ph.D., Chair
Bryan D. Baker, Ph.D.

December 2007

"GIS Server Application for Avalanche Studies"

The report of Bryan Joseph Raymer is approved.

Bryan D. Baker, Ph.D.

Mark P. Kumler, Ph.D., Chair

December 2007

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ABSTRACT

"GIS Server Application for Avalanche Studies"

by
Bryan Joseph Raymer

Forecasting avalanches is a complex task that the "GIS Server Application for Avalanche Studies" project prototype attempts to address. This server application provides detailed information -- such as name, average activity rate, elevation, and aspect -- on each known avalanche path within this study area. The prototype serves as a tool for forecasters to share their knowledge with other civilians who frequent the study area, as well as other forecasters.

The primary goal of this project was to establish a tool that utilizes historical weather and avalanche activity data to determine areas where avalanches have occurred in the past and are most likely to occur again, based on forecasted weather conditions. The creation of this GIS model to process data and determine focus areas would allow forecasters to spend more time in the field by eliminating land areas of less concern. This type of model would be valuable for forecasters when they are asked to make predictions for unfamiliar regions, such as forecasting for international events like the winter Olympics or foreign countries to support military efforts.

In order to accomplish this, an Arc model was created which allows individuals to enter predicted weather values such as temperature and precipitation. The tool then executes a query on historical information to find other dates with very similar conditions. Upon completion of this query, a secondary query is conducted to determine what avalanche activity occurred on those days. This information is then transferred to a shapefile with the same color scheme as the Colorado Avalanche Information Center's (CAIC) avalanche probability Danger Rose, which is used by forecasters to communicate

avalanche probability. Avalanche areas are symbolized as green, yellow, or red depending on whether the most similar days had zero, one, or more than one avalanche, respectively. This feature gives forecasters and other individuals access to tools to examine potential avalanche danger without accessing the areas themselves.

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List of Acronyms

CAIC   Colorado Avalanche Information Center

DEM   Digital Elevation Model

ESRI   Environmental Systems Research Institute

GIS   Geographical Information System

GUI   Graphical User Interface

MXD   Map Document extension

NAD   North American Datum

SOC   Server Object Container

SOM   Server Object Manager

TOC   Table of Contents

UTM   Universal Transverse Mercator

WAN   Wide Area Network

1. Introduction

Avalanches affect mountainous regions around the world, taking lives and destroying property. The amount of damage caused by avalanches is predicted to rise due to the increasing popularity of winter sports. As interest in winter sport grows, new infrastructure such as roads, power lines, and buildings are built in avalanche prone areas to support the volume of people traveling in the region. By being more aware of the conditions that could lead to avalanches, individuals may avoid these areas or experts can intentionally trigger avalanches before they become large enough to cause significant damage to infrastructure.

By definition, an avalanche is any amount of snow, ice, earth, or rock, moving in swift motion down a slope (Merriam-Webster, 2007, para. 1). The two types of avalanches that will be analyzed for this project are loose snow avalanches and slab avalanches. Slab avalanches are the most dangerous and cause substantially more damage.

In order to avoid the dangers of these types of avalanches, people have to know what conditions cause avalanches and their triggers. The two most important factors in predicting avalanches are terrain (slope) and snow stability. Avalanches are most common in areas where the slope is between 30 and 45 degrees (Colorado Avalanche Information Center [CAIC], 2007). However, if conditions are perfect, avalanches may occur on different degree slopes, but they are much less common.

Other than slope, the next most significant factor is snow stability. Snow stability is the potential for snow to slide (unstable) or not to slide (stable) relative to a given load (Greene et al., 2004). The difficulty in gauging snow stability is that it may change frequently, sometimes on an hourly basis. Many temporal factors affect the stability, and

if analyzed properly these factors can be used to predict the snow stability (Kozak, Elder, Birkeland, and Chapman, 2003).

The first factor when considering stability is temperature. Snowpack becomes more stable as snow melts and refreezes. However, rapid increases in temperature may cause snow to become unstable and increase the risk of an avalanche. Another factor that must be accounted for is new snowfall. Avalanches are far more likely to occur shortly after new snowfall (LaChapelle, 1980). Additionally, wind must be considered. Both wind speed and direction are important to the probability of an avalanche occurring, due to the transferring of snow from one area to another adding new weight to the snowpack. This process is known as wind loading (LaChapelle, 1980). If the snowpack is unstable, the weight of the new snow can cause the snowpack to fail, resulting in an avalanche.

One further fact that has to be considered is the orientation of the slope. For an avalanche to occur there must be snow accumulation. Snow typically accumulates in more shaded areas that do not have extreme amounts of direct sun light. Consequently, slopes with a northeast aspect (in the northern hemisphere), can be expected to generate avalanches on a more frequent basis.

Lastly, the amount of vegetation can give great insight to the probability of avalanches. If there is a sudden gap in a patch of trees along a mountain side, it may be inferred that avalanches happen quite regularly in that area. Conversely, expansive areas with unbroken, mature vegetation are much less likely to slide.

Now that the conditions that lead to avalanches are known, the problems associated with their prediction can be examined.

1.1. Problem Statement

The copious amounts of data and the frequency at which the data may change make forecasting avalanches a very complex task. Scientific understanding of avalanches, as well as knowledge of the local patterns of avalanche activity (gained through experience), are crucial for avalanche forecasting (McClung 2002a). This criteria limits avalanche forecasting to a few highly trained professionals. Consequently, there are vast areas where avalanches may occur but there are very few people qualified to predict them. Currently, there are no methods other than experience to determine focus land areas for avalanche forecasters. This means that forecasters are required to be involved in every phase of avalanche forecasting, limiting the amount of time that they may spend in the field doing research where their expertise may be most utilized. The creation of a GIS model to process data and determine focus areas would allow forecasters to spend more time in the field by eliminating land areas of less concern. This type of model would be very valuable for forecasters when they are asked to make forecasts for unfamiliar regions, such as forecasting for international events like the winter Olympics or forecasting in foreign countries to support military efforts.

Figure 1.1 Avalanche Path "Cement Fill" passing over Highway 550, San Juan Mountains, Colorado. Photo by Jerry Roberts, CAIC.

1.2. Study Area

The study area for this project is located in the southern San Juan Mountains just north of the town of Silverton, Colorado. It consists of 26 avalanche paths that come in contact with Colorado Highway 550, the only direct connection to Silverton (Figure 1.2).
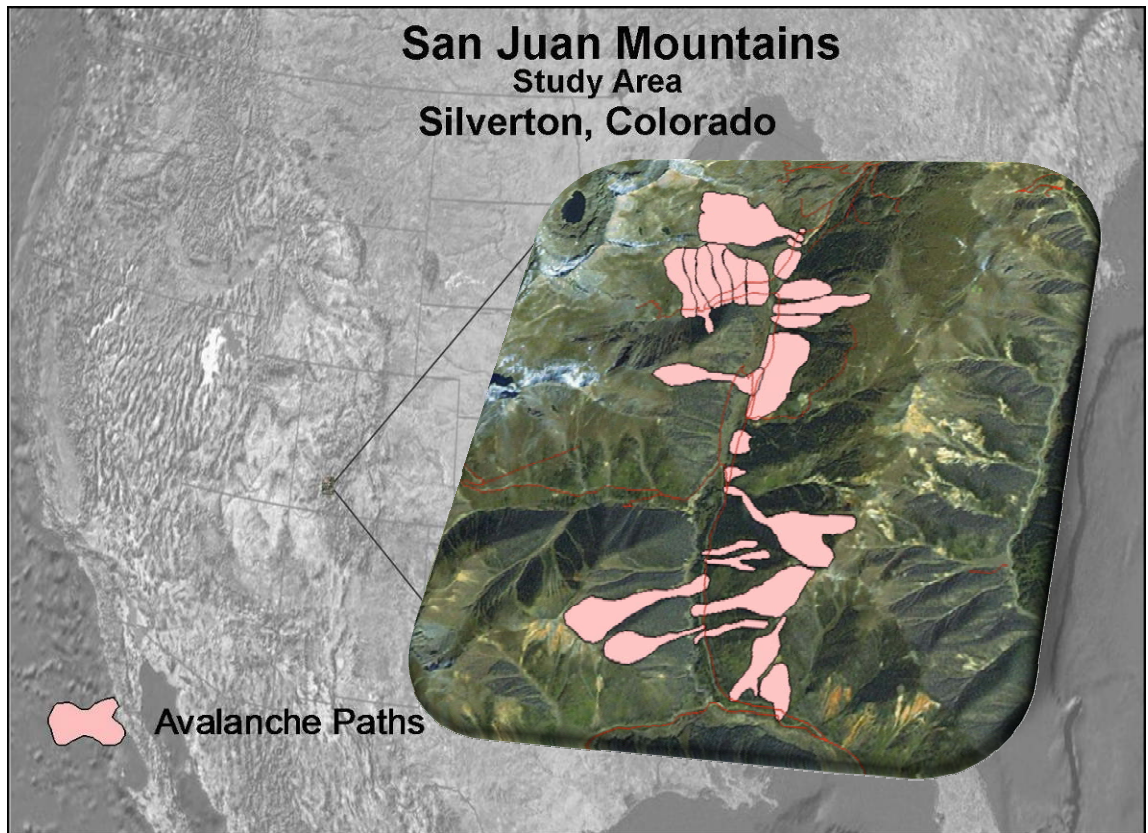
Figure 1.2 San Juan Mountains study area Silverton, Colorado (locator map)

The frequency of avalanches here has made this area a hotspot for avalanche research. Previous research completed in this area allowed the CAIC to provide the data needed to complete this study. The focus area within this study is comprised of five of the most active avalanche paths. These five paths are associated with the Red Mountain Pass weather station, which provided all the historical weather for this study. The previous avalanche research, weather station, and high avalanche activity made this an ideal study site.

1.3. Client

The primary client for this project is Ethan Greene, the Director of the Colorado Avalanche Information Center (CAIC). The CAIC is part of the Colorado Geological Survey Department, and is responsible for forecasting avalanches in the backcountry and

along highway transportation routes for the Colorado Department of Transportation (CODOT). Additionally, the CAIC educates the public about risks associated with avalanches in an effort to limit the negative effects avalanches have on the residents of Colorado (CAIC, 2007).

1.4. Client Expectations

The client expects this project to address four goals.

1. Create a map of known avalanche paths that affect Highway 550 near Silverton, Colorado.

2. Create a database of attributes for the avalanche paths. The database would include historical information on the frequency of avalanche activity for the given paths, as well as historical meteorological data.

3. Create a tool to analyze historical avalanche and metrological data.

4. Display results by using the same colors as the CAIC danger rose (Figure 1.3).
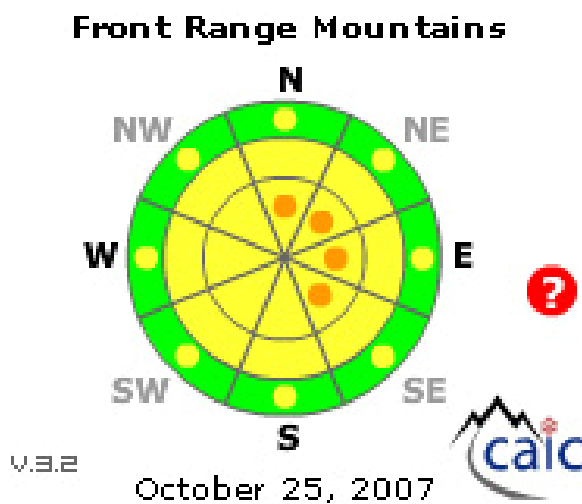
Figure 1.3 Avalanche Danger Rose displaying a moderate risk. JPEG Courtesy of CAIC

2. Background and Literature Review

Most of the literature involving the use of GIS for avalanche study discusses the high level of uncertainty and corresponding factors that cause uncertainty when mapping or modeling avalanche terrain. Scale and spatial data variability are the major causes of inaccuracy when using a GIS for avalanche studies (Campbell, Jamieson, and Hageli, 2004). Over the past two decades, the majority of the research associated with avalanches has been conducted to better understand scale issues and the nature of spatial variability of snow stability.

The largest limitation of the use of a GIS for avalanche work is scale. The discrepancies between the real world and the scale of the GIS representations of avalanche terrain can be immense (McCollister & Birkeland, 2006). These differences may be attributed to the restrictions of available data that can be used within a GIS. For example, to calculate the slope and aspect of an area, one would use a Digital Elevation Model (DEM). However, the most commonly available DEMs are 30 meter DEMs which are not accurate enough for avalanche forecasting (Campbell, Jamieson, and Hageli, 2004). "Subtle changes in slope angle can mean big changes in avalanche frequency, so knowing the difference between a 28 degree slope (which almost never slides), a 33 degree slope (which sometimes slides), and a 38 degree slope (which commonly slides) is critical, and these changes are much too subtle to be picked up with a 30 meter DEM" (McCollister & Birkeland, 2006) (See Figure 2.1).
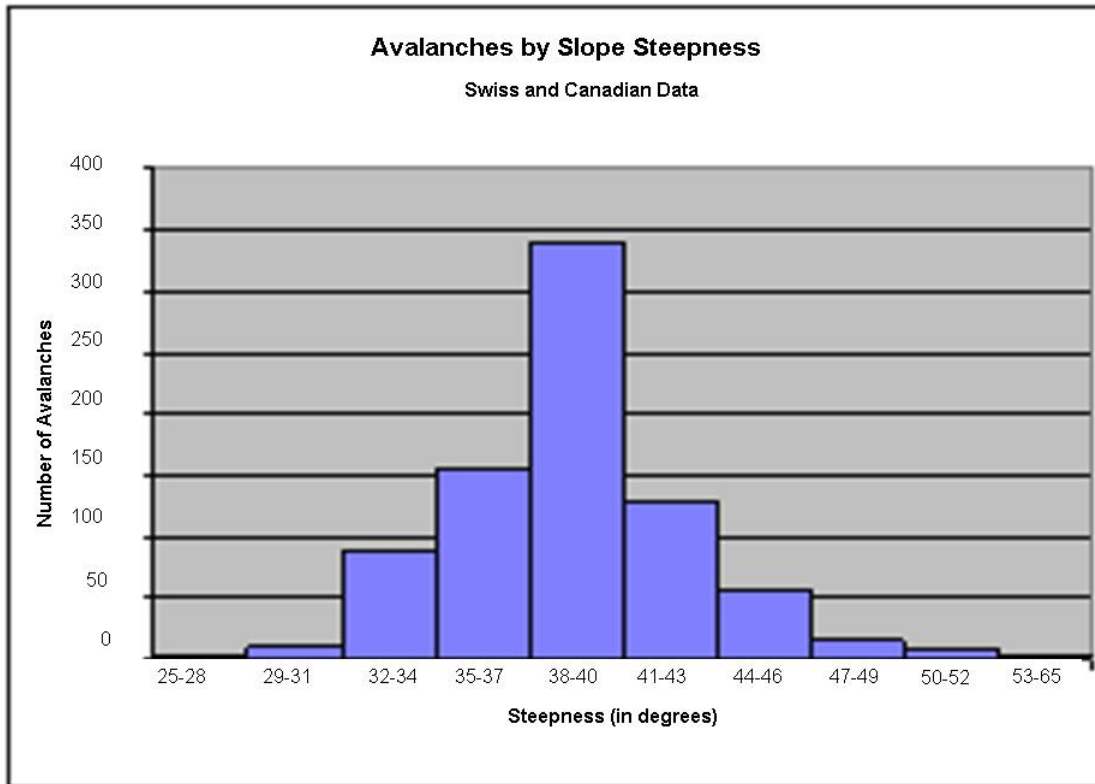
Figure 2.1 Number of avalanche on given slopes. Graph adapted from avalanche.org retrieved from http://www.avalanche.org/~uac/ed-faq.htm on February 18, 2007

While the accuracy of the DEM causes the most glaring miscalculations, the frequency at which other spatial and temporal data changes also limits the ability to use a GIS to accurately map or model avalanche terrain.

Spatial variations create large amounts of uncertainty for mapping or modeling avalanche terrain. Spatial and temporal variations in snow properties present significant challenges for the research of snow processes (Deems, 2002). These variations are most apparent when trying to determine snow stability. The challenge arises from the fact that snow stability, a key component in avalanche forecasting, is very difficult to measure. It is nearly impossible to have enough observation points to collect the data needed to accurately map snow stability (Campbell, Jamieson, and Hageli, 2004). To counter this problem, forecasters must interpolate stability test results to untested areas. To accurately interpolate snow stability, avalanche forecasters routinely perform their stability tests at

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carefully selected sites to reveal conditions presumed to be representative of nearby avalanche terrain (McClung and Schaerer, 1993). In snow studies, this process of interpolation is termed "scaling" (Campbell, Jamieson, and Hageli, 2004). While this may help the forecasters generate predictions about an area, the use of interpolated data brings uncertainty into the forecast and places limitations on the size of forecast areas. These size limitations are a direct result of Tobler's law: things that are near each other are more similar than things that are far apart (Maguire, 1991). Since the stability tests were performed to determine snow stability at a specific site, the further away from that site one tries to interpolate conditions, the greater the uncertainty (Logan, 2005).

As mentioned before, temporal variations can have a large impact on snow stability as well. As a snowpack ages, it is exposed to variables, including temperature, solar radiation, and wind exposure, that cause the layers to undergo a metamorphosis (Kozak, Elder, Birkeland, and Chapman, 2003). As the layers change, they may become more or less stable, depending on the variables they are exposed to. Consequently, forecasters must understand the effects of these variables (Kronholm, 2004). As a snowpack ages and its layers change, it becomes more difficult to interpolate snow stability because spatial variation increases (Birkeland and Landry, 2002).

Due to such spatial and temporal variations, determining snow stability for an entire area is one of the hardest things associated with avalanche forecasting. While the physical aspects of avalanche forecasting can be taught in a classroom, only through experience can one become an expert at interpolating snow stability (McCollister & Birkeland, 2006; McClung, 2002a).

The previously mentioned issues have limited the uses of a GIS for avalanche work. At this time, there is no accurate way to use a GIS to forecast avalanches over a large area (McCollister & Birkeland 2006). Despite these limitations, a GIS may be very useful for examining the massive amount of data associated with avalanche forecasting

(McCollister & Birkeland 2006). Because slide paths have a geographic location along with geographic attributes, such as aspect and elevation, they can be mapped, analyzed, and viewed with a GIS (Stoffel et al., 1998). Mapping these data and linking the digitized data with historical slide data could prove to be very useful for forecasters. Additionally, this would allow forecasters to analyze patterns of slides and slide data (McCollister, 2004). The resulting data gathering could help forecasters know where to direct their attention. For example, if chute "A" does not historically slide until late January, forecasters would know when it is more likely to slide. Additionally, this information could also be used with the conditions that were present when avalanches have occurred historically. For example, if chute "B" has historically slid when temperatures are between 28 and 34 degrees Fahrenheit and after four or more inches of new snow has fallen, forecasters would know when and where to focus their attention. While this project will not be able to make a large scale prediction possible, it will help forecasters in local areas. Having this data in a GIS will also make it easier to disseminate the data to other forecasters and agencies. Hopefully, closer examination and dissemination of data will lead to a more robust large scale GIS avalanche forecasting model. Until then, geographic information systems must be used to the best of their capabilities to gain as much insight into the phenomena of avalanches as possible (McCollister & Birkeland, 2006).

2.1.   Proposed Solution

The proposed solution is an ArcGIS Server application providing two separate functions. The first function will provide an overview of the area that the Silverton forecasters are responsible for. This portion will also serve as an educational tool for individuals not familiar with the area, allowing searches by path name or most active avalanche paths. The second function of this ArcGIS Server application will allow a forecaster to use historical weather data to determine avalanche focus areas. This prototype feature will permit individuals to enter forecasted weather data into a form, and then the application will query this information against historic data to see what effect similar weather conditions have had in the past.

3.   Geodatabase Design

In order to create this application, a personal geodatabase was created. This personal geodatabase was selected by the client because of their use of Microsoft Access. The database is comprised of four feature classes, two data tables, and a background raster (Figure 3.1)
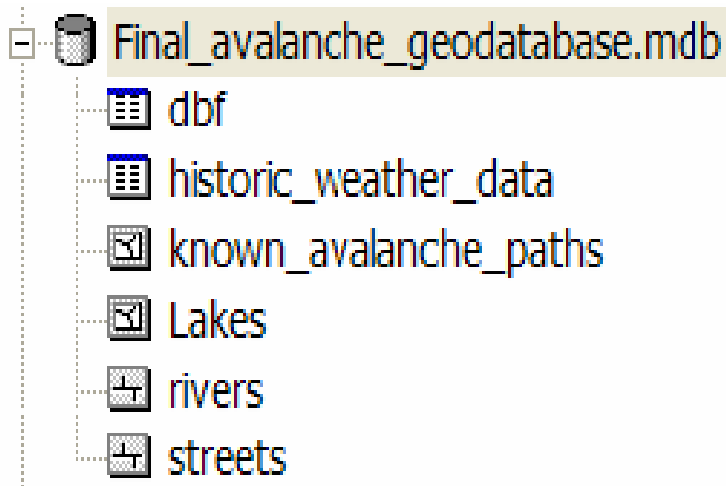
Figure 3.1 Avalanche Personal Geodatabase

All of the feature classes within this personal geodatabase have been projected into North American Datum (NAD) 1983 Universal Transverse Mercator (UTM) zone 13N. This projection was selected because the avalanche paths provided were in this projection.

3.1.   Known Avalanche Paths Feature Class

The Known Avalanche Paths feature class is comprised of polygon shapes that represent the known avalanche areas within the San Juan Mountains that affect Colorado Highway 550. This feature class has attribute fields such as name, aspect, elevation, activity per year, and activity per year that affects specifically Colorado Highway 550. The attributes of this feature class are utilized as the queries in the ArcGIS Server application.

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3.2. Lakes Feature Class

The Lakes feature class consists of polygons representing the lakes and reservoirs in the study area which have attributes such as name, shape, and area. This feature class was included for area familiarization and to show where water naturally accumulates.

3.3. Rivers Feature Class

The Rivers feature class is illustrated with vector lines representing the rivers and streams in the study area. This feature class has attributes such as name and length, and was included for familiarization and to show natural low tracts.

3.4. Streets Feature Class

The Streets feature class is represented by a vector line representing Colorado Highway 550. This feature class is included to show areas in which the avalanche paths intersect the highway. This is particularly important class because keeping the highway open is one of the top priorities of the Silverton forecasters.

3.5. Focus Area Feature Class

The Focus Area feature class is comprised of polygons that represent the avalanche paths associated with the Red Mountain Pass weather station. This feature class is used to complete the prototype portion of this application, which uses historical data to determine possible avalanche risk. This feature class is used for symbology. Importing symbology from this feature class allows the layer on the map output to follow the color symbology parameters of the Avalanche Danger Rose.

3.6. Historical Weather and Avalanche Activity Data Table

The Historical Weather and Avalanche Activity table was created by combining two separate databases, both provided by CAIC. The first database presented historical avalanche activity for five of the paths in the study area that intersect Colorado Highway 550. The second database provided weather information that was recorded by the Red Mountain Pass weather station. This database consists of average, maximum, and

minimum daily temperatures, as well as daily and cumulative precipitation. The combined database will provide the data which will be queried as part of the prototype application provided by the ArcGIS Server application. When combined, the database consisted of one row for each of the 1825 days in the study period, with temperature and precipitation data for each day, as well as information on avalanche activity. A subset of that database containing only the rows for the active avalanche days appears in Figure 3.2.

DATE	PILL	PREC	TMAX	TMIN	TAVG	PRCP	Overall_avalanche_activity	Eagle	Muleshoe	Porcupine	Silver Ledge	Telescope
111294	4.3	5.8	4.1	-6.9	-2.1	1.5	1					1
111594	6	7.6	-3.1	-22.6	-15.7	0	1					1
121594	10.8	12.1	-2.1	-18.5	-13.3	0.2	1					1
10695	11.8	13.6	-5.2	-9.6	-8.3	0.4	2	1			1	
10795	12.3	14	-7.8	-12.7	-11.1	0.7	4	1		1		2
10895	13	14.7	-4	-12.9	-8.3	0.1	2	1				1
12695	15.3	16.7	-0.6	-11.2	-5.7	0.2	1					1
12795	15.6	16.9	-1.5	-9.3	-6.7	0.5	1			1		
12895	16.3	17.4	-3.4	-11.3	-8.9	0.2	1	1				
12995	16.4	17.6	-0.6	-14.6	-10.6	0	2	1		1		
20395	16.6	17.7	5.2	-10	-3.1	0	5					
21495	19	19.9	-4.1	-9.4	-6.7	1.2	1	1				
21595	20.4	21.1	-2.2	-10.6	-5.4	0	4	2	1			1
22795	20.7	21.4	3.1	-11.4	-5.9	0	1					
30295	22.3	22.8	3.1	-6.5	-4.6	0.4	1	1				
30695	24.6	24.9	-0.8	-9.6	-4.9	0.7	2	1	1			
120696	11	15	-2.4	-10	-5.8	0.9	5	1	1	1	1	1
120796	11.7	15.9	-4.8	-10.8	-8.2	0	1		1			
11297	17.8	22.2	-5.9	-12.5	-10	0.7	1	1				
11397	18.6	22.9	-7.9	-12.4	-10.2	1.4	1		1			
11597	19.9	24.3	-18.7	-20.1	-19.4	0.6	2	1				1
22497	25.5	29	-4.4	-17.7	-11.9	0	1					1
12700	8.7	9.3	0.8	-7.7	-4.9	0.1	8	3		2		3
21100	9.7	10.3	-0.9	-8.1	-5	0.4	3	2				1
30800	16.8	17.2	0.9	-10.4	-5.6	0.3	5	3	1			1

Figure 3.2 Subset of historical weather and avalanche activity data

4. Application Design

This section gives an overall description of the design of the "GIS Server Application for Avalanche Studies" intranet mapping project. Subsequent chapters will go into greater detail regarding how each portion of the project was created, functions, and satisfied the client's requirements for the project.

4.1. Interface

"GIS Server Application for Avalanche Studies" is a prototype web mapping application and associated ArcGIS tool designed for the CAIC. The purpose of this application is to design a prototype application that can display known avalanche areas, and provide detailed information on an individual avalanche path. Forecasters and researchers will be able search for avalanche paths by path name or by avalanche activity. The purpose of this site is to allow users to explore and to learn more about the study area without physically entering the avalanche territory.

This application is designed for avalanche professionals who may not be familiar with GIS. With this in mind, this application was kept as simple as possible. The map was created by using natural colors, with the avalanche paths represented in pink. Furthermore, the query menus are designed as either drop-down menus or with the most common inputs as defaults.

4.1.1. Avalanche Forecasting Tool

The Avalanche forecasting tool is slightly more complex than the rest of the tools within this application, and may be used outside of the "GIS Server Application for Avalanche Studies." In order to use this tool, data layers and data fields for the tool must be added to process. The user must then enter target information, such as temperature and precipitation. To successfully utilize this application, the user would need some familiarity with GIS software. The uses of this tool and the outputs will be discussed further in the following chapters.

4.2. System Architecture

This application is powered by ArcGIS Server, and was built using ArcGIS Server Manager and Microsoft Visual Studio 2005. The base map was created using ArcMap and ArcCatalog. Once created, the base map was published to the internet using ArcGIS Server Manager. Once published, it is accessible on the World Wide Web via a wide area network (WAN).
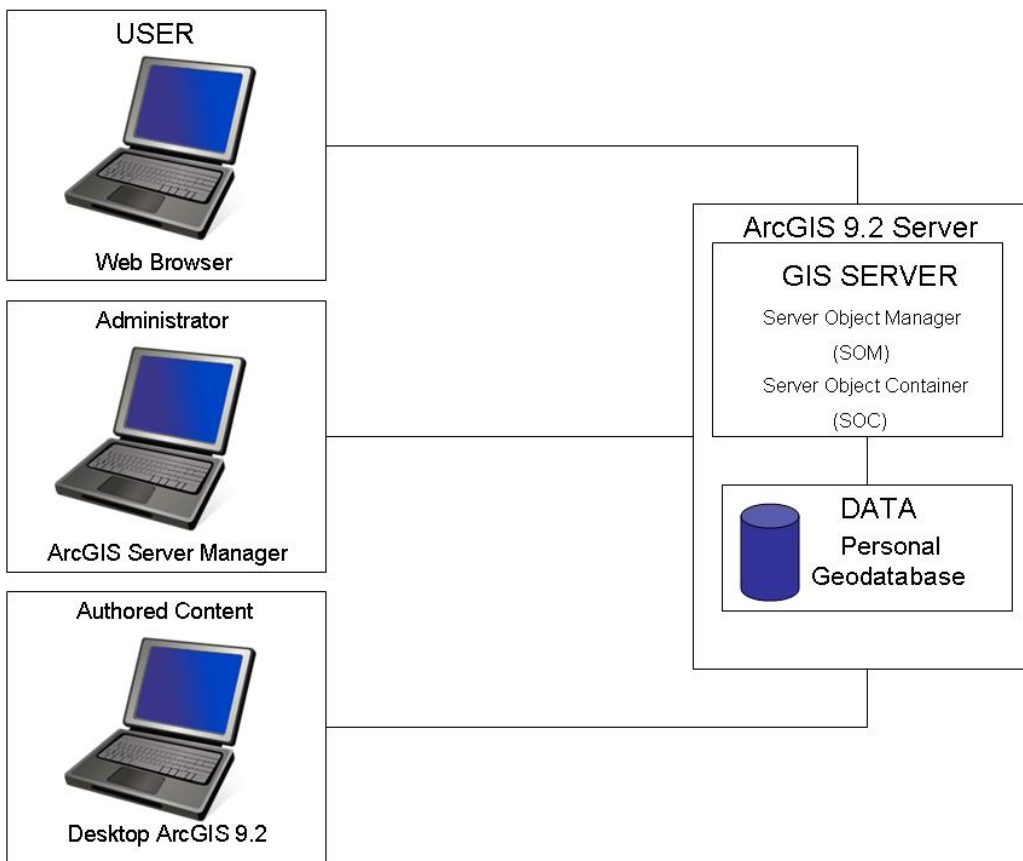
Figure 4.1 GIS Server Application for Avalanche Studies

4.2.1. Inputs

There are three main inputs for this system:

1. Historical Weather and Avalanche Activity table.

2. Vector data of the avalanche paths within the study area.

3. Imagery for Red Mountain Pass.

4.2.2. Data storage

The data storage device for this project is a personal geodatabase. This will provide all the capabilities needed for the geospatial analysis portion of this project.

4.2.3. Data dissemination

The data dissemination will be left to the client's discretion. The client has proposed making data and forecast examples available on their ftp site. However, due to liability risks the client will not be able to share the actual forecast with the general public.

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4.2.4. Data analysis

The geospatial analysis was accomplished within the ArcGIS 9.2 commercial, off-the-shelf software. The nearest neighbor data analysis, which will be discussed in Chapter Six, was completed by using a created ArcGIS tool. This tool executes a series of queries and then displays the results via a table and a new shapefile layer.

4.2.5. Data and product output

At this time, there are two output products this project will provide. The main output
product will be a new shapefile of the focus area, establishing the likelihood for the focus
area to produce an avalanche. This will be demonstrated much like the Danger Roses that
avalanche forecasters currently use to communicate forecasts. The areas will be
symbolized with different colors: green, yellow, and red, with red indicating the highest
probability for avalanches. The second output will be a data table of the most similar
days.
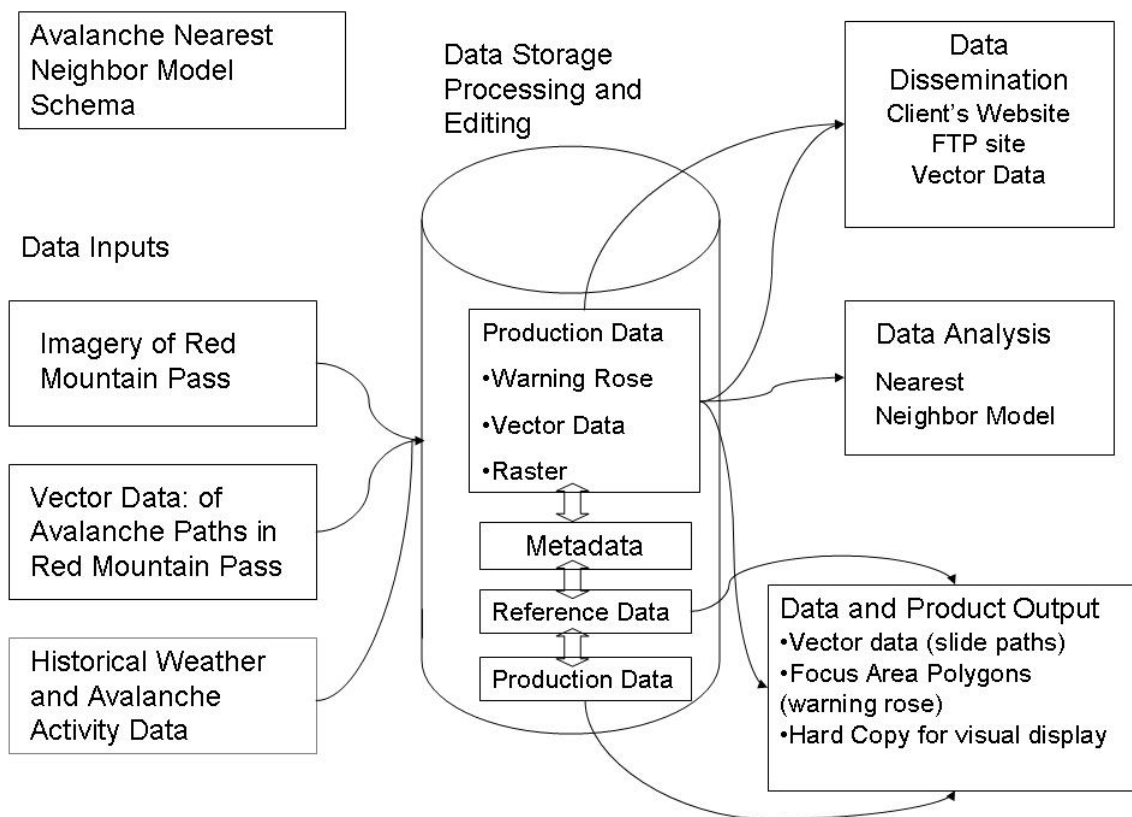
Figure 4.2 Avalanche nearest neighbor model architecture

5. GIS Server Application for Avalanche Studies Development

The creation of the "GIS Server Application for Avalanche Studies" consisted of three separate stages. The first stage was the creation of the map document (MXD) titled Avalanche Base Map. The avalanche base map was created using ArcGIS desktop products ArcMap and ArcCatalog. The second step was designing the web-based application in ArcGIS Server Manager. The third and final step was customizing the application using Microsoft Visual Studio 2005.

5.1. Avalanche Base Map

The avalanche base map was created using the ArcGIS desktop products ArcMap and ArcCatalog. Before creating the map, it was necessary to gather geographic data. The streets and water data was obtained from ESRI's US base map data (Figure 5.1), which is provided with the software. In order to find this data, one would navigate to the file where the software was installed, then navigate through the data folder to the maps and data folder and select USA (Data\Arc9\Maps_and_Data\usa).

Figure 5.1 ArcCatalog navigating to USAbasemap.lyr

The Avalanche Paths shapefile was provided by Douglas Scott of Avalanche Mapping Corporation.

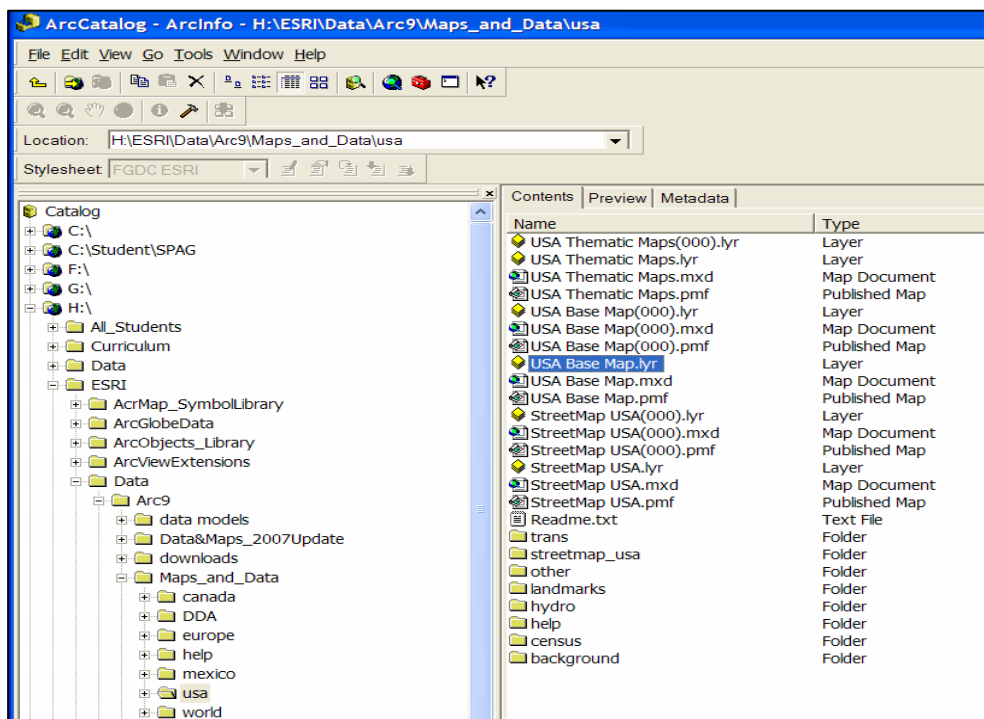The final layer for this map document was a high resolution image of the study area, acquired from ESRI's ArcWebServices, which served as a base image for the MXD. In order to include this image, an ArcWeb Services account had to be established. A trial ArcWeb Services account may be acquired at http://www.esri.com.

Once all of the data layers were collected, they had to be re-projected into an appropriate projection using the project tool. This projection selected was NAD_1983_UTM_Zone_13N, placing all the layers into the same projection as the avalanche paths layer.

5.2. Designing the application with ArcGIS Server Manager

The "GIS Server Application for Avalanche Studies" was designed using ArcGIS Server Manager, a web application that complements the ArcGIS Server application. This web-based application allows administrators to create, publish, and manage web mapping applications and services. The ArcGIS Server Manager is also used to manage the GIS server on which the applications are stored.

5.2.1. Publishing Avalanche Base Map document

When creating a web mapping application with ArcGIS Server Manager, the first step is to publish the associated MXD. In order to accomplish this, permission was granted to allow the Server Object Container (SOC) to access the MXD, then the SOC account was added to the folder containing the all the data used in the "GIS Server Application for Avalanche Studies" (Figure 5.1).
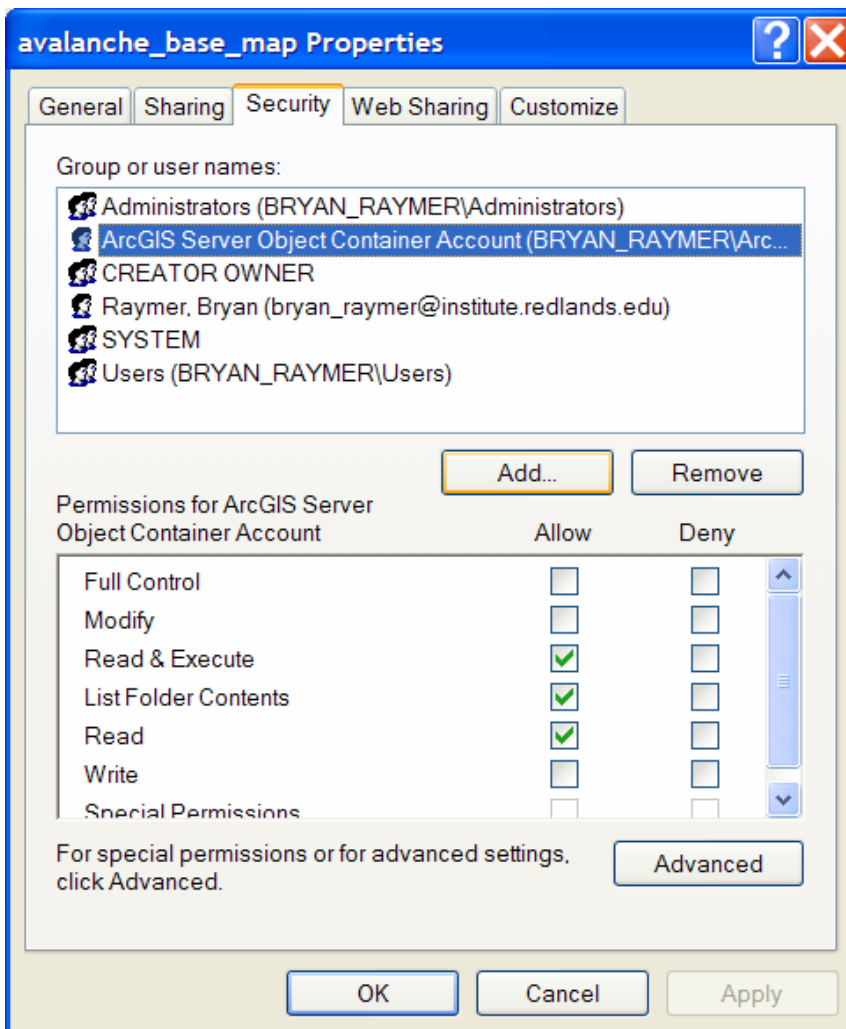
Figure 5.1 Giving the SOC permissions to access avalanche geodatabase

Once this was done, ArcGIS Server Manager was used to publish the MXD. This tool provided a wizard menu, which walks users through the process for publishing a MXD. The first step within the wizard is to specify the MXD, by navigating to where the MXD was stored. Then a folder was created on the server to publish the resource to (Figure 5.2).
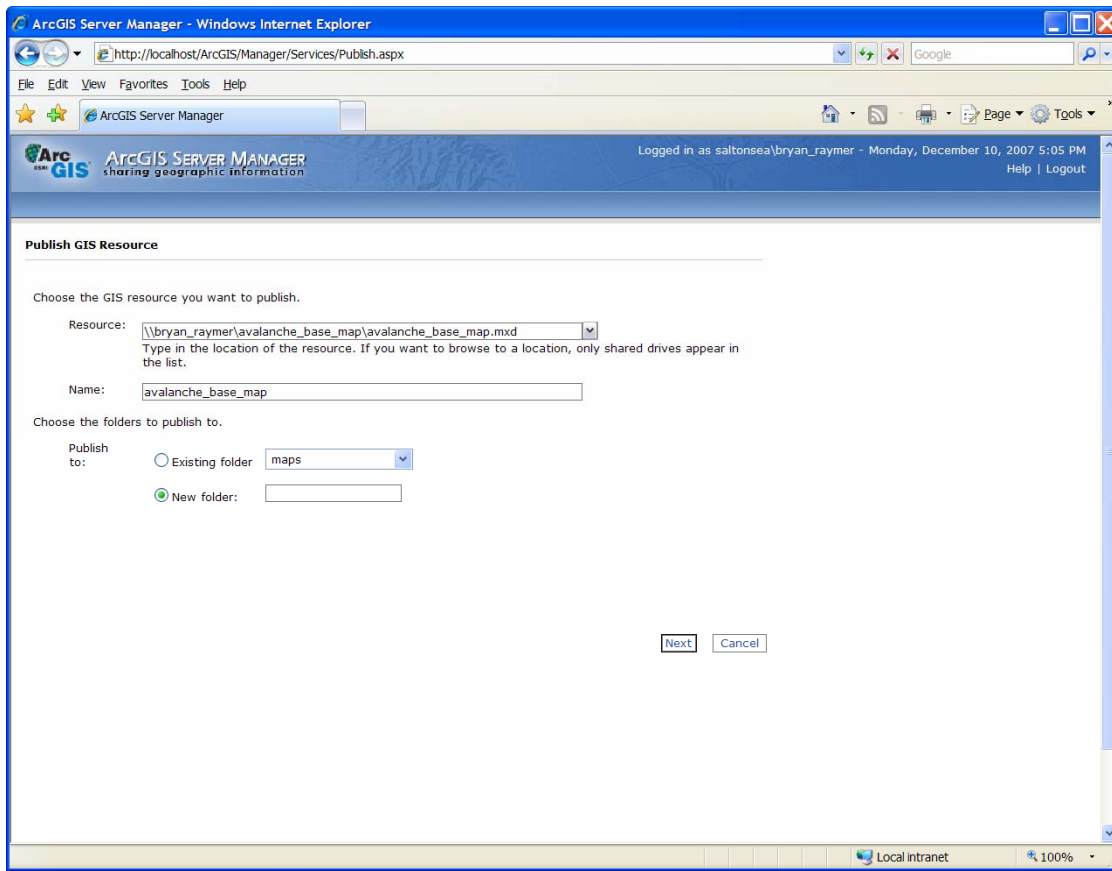
Figure 5.2 Publishing wizard used to publish the avalanche base map

The final task needed to complete this initial publication was to choose what capabilities this application would need. For this application, the only one needed was web mapping (Figure 5.3).
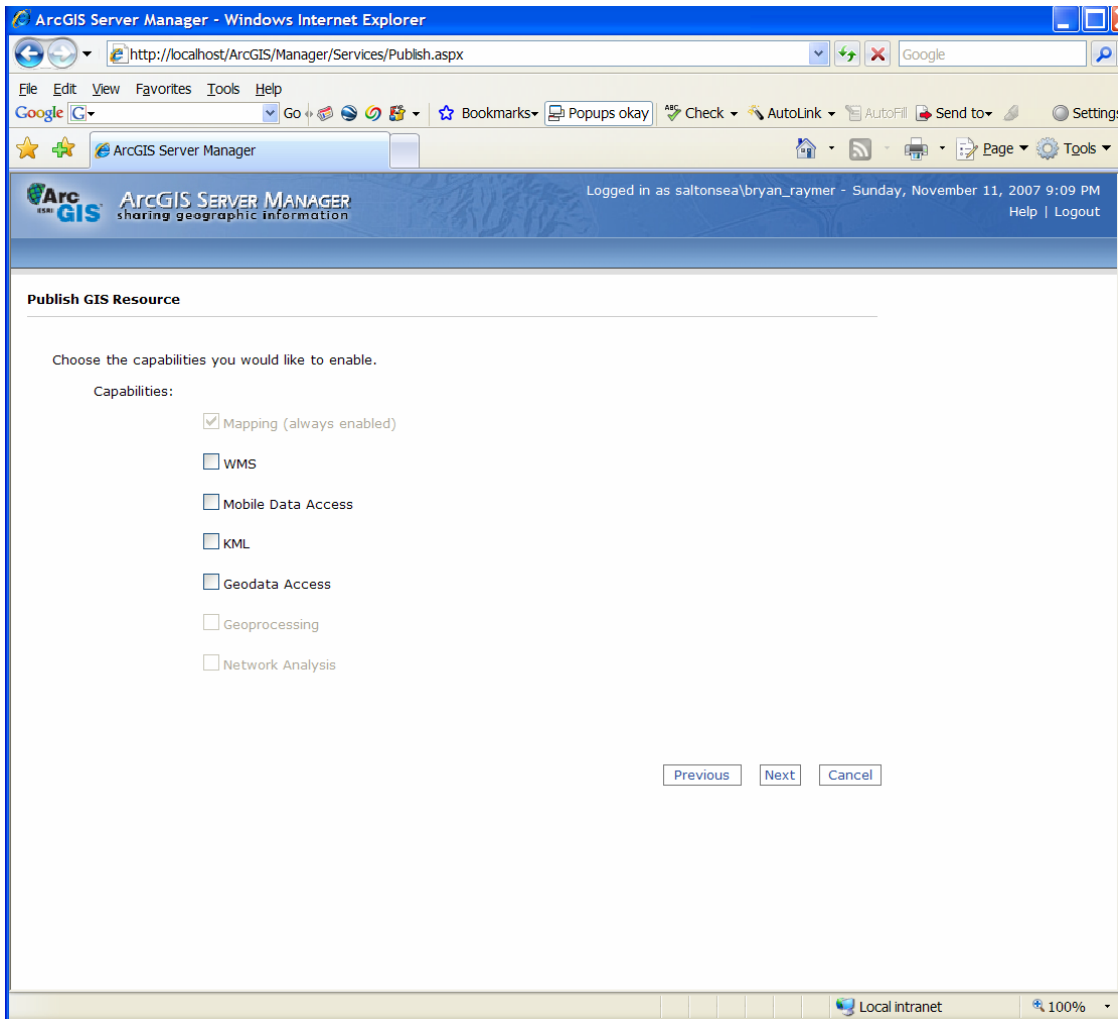
Figure 5.3 Wizard used to add the mapping resource

5.2.2. Creating the Web application and adding Tasks to the "GIS Server Application

for Avalanche Studies"

With the publishing of the MXD completed, the next step was to create the web
application with ArcGIS Server Manager and add tasks to the application. Tasks serve as
tools that allow the user to analyze or gain more information from the map. There are six
standard tasks included with ArcGIS Server. The six tasks are editing, find address, find
place, geoprocessing, query attributes, and search attributes (Figure 5.4).
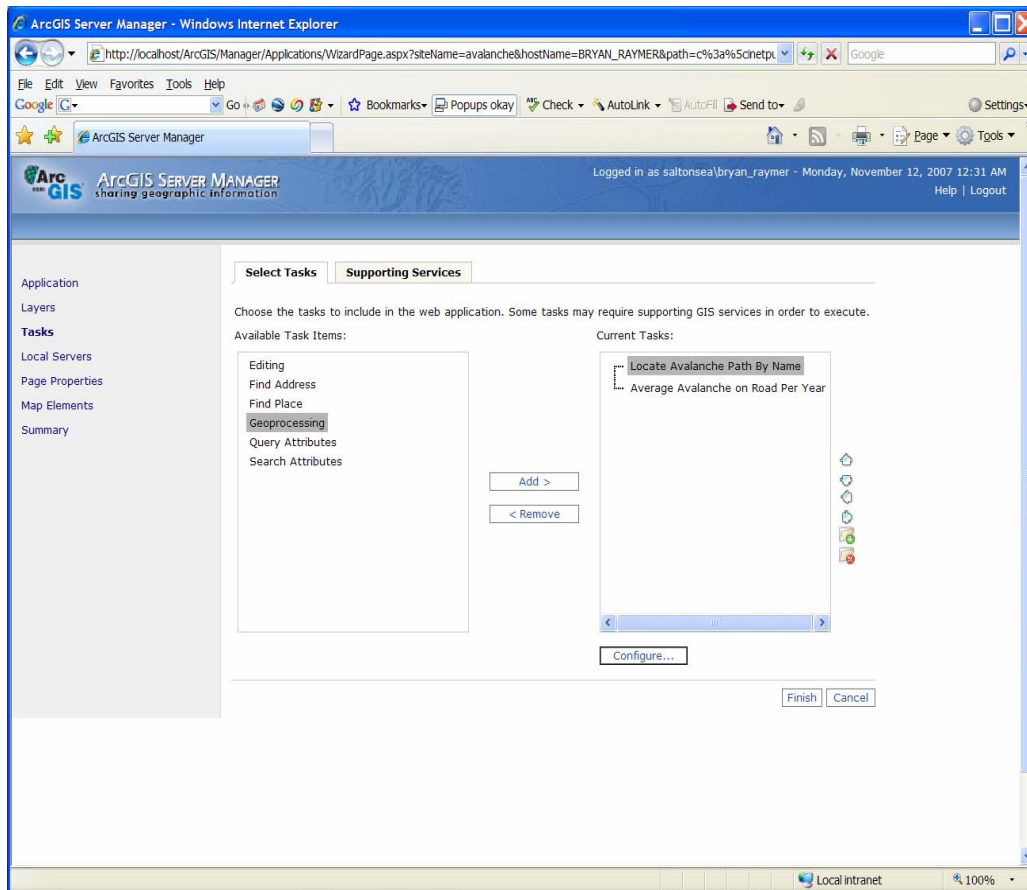
Figure 5.4 Wizard used to set up task

The "GIS Server Application for Avalanche Studies" uses a total of four tasks. Two of the tasks are Query Attribute tasks titled "Locate Avalanche Path by Name" and "Calculate Average Road Crossings per Year Tool". The third task is a Geoprocessing task titled "Nearest Neighbor Avalanche Forecasting Tool," which will be discussed in Chapter Six. The fourth and final task is a print task titled "Print Map." The print function, not an out-of-the-box function, was created by Bryan Baker at ESRI (Baker, 2007). The print task is available as a sample task for the Web ADF/ArcGIS Server and is scheduled to be included in the ArcGIS Server 9.3 release. Once the required tasks were added, they were configured using the Task Configuration tool within ArcGIS Server Manager. The Task Configuration tool allows for the creation of titles for each of the tools, customization of the button text, and customization of task-specific settings such as default values for the queries. This tool also allows one to choose how the

selected items would be displayed within the Web application. The "Locate Avalanche by Path Name" tool configuration window is depicted in Figure 5.5.
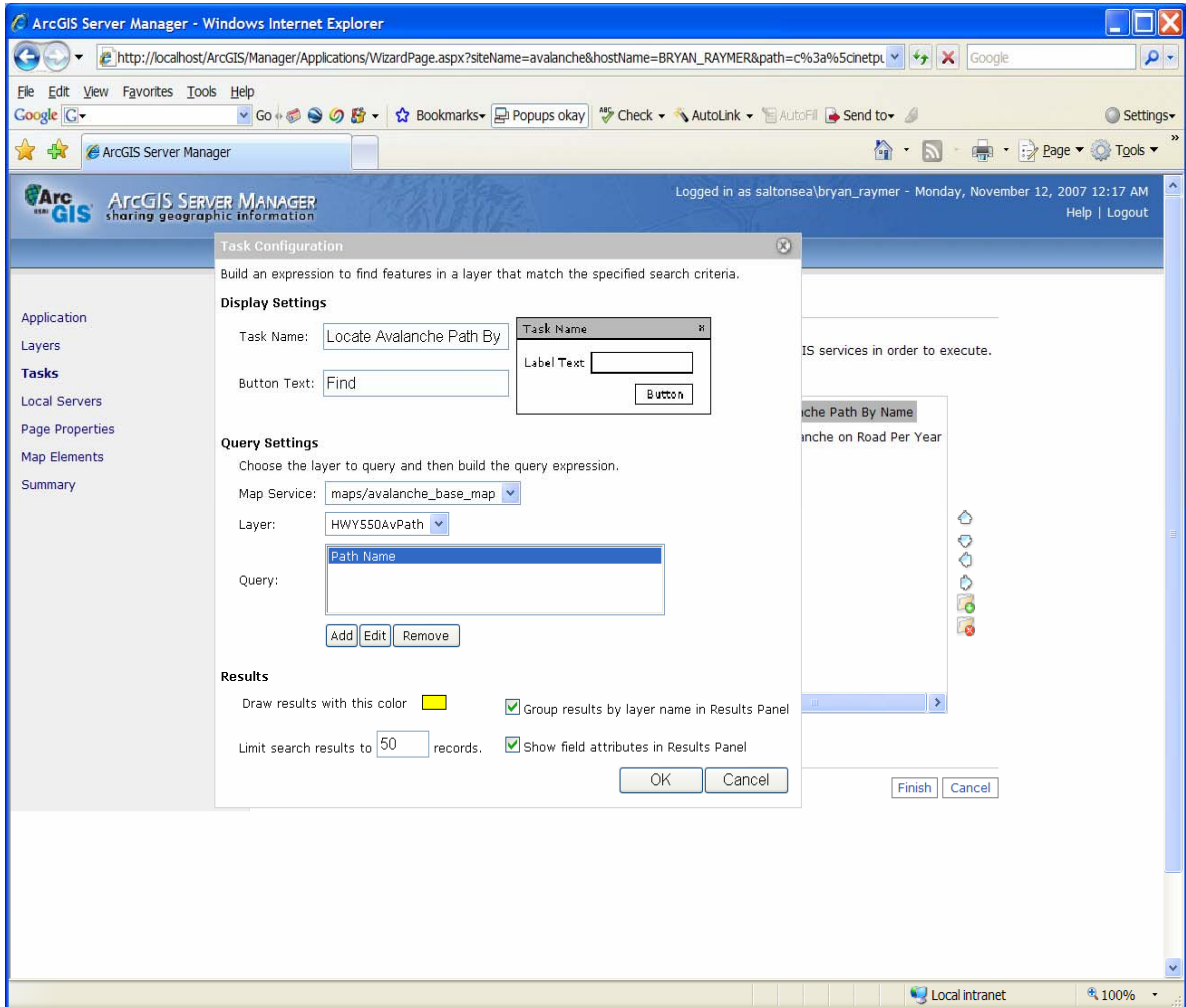
Figure 5.5 Locate Avalanche by Path Name task configuration window

In order to add or edit tasks using these wizards, the user must first select the map service for the task to be added. In this instance it was the Avalanche Base Map. Next, the MXD layer that the attribute query task queries must be selected. In this instance, it is the Colorado Highway 550 avalanche paths layer. The button text and the title of the tool were set in the dialog. The task was then configured such that users could select paths by

name from a drop down list, given that many users would not be able to remember each path by name. The final step in designing this task was to choose the display color of the selected path. Yellow was selected for this application because it is bright and easily seen against the background map.

The task titled Calculate Average Road Crossings per Year Tool was designed following these same methods.

5.3.   Customizing the application in Microsoft Visual Studio 2005

The final customization of the "GIS Server Application for Avalanche Studies" web application was completed using Microsoft Visual Studio 2005. The final customizations that were completed were determined by consulting the client, the advisor, and committee member Bryan Baker. The first customization was to modify the title bar. The University of Redlands logo, and links to the CAIC's and the Avalanche Mapping Organization's website, were added to the title bar of the application. Then the color of the application theme was changed. The client determined that the default blue application theme color was not visually appealing with the corresponding map. Based on this the client choose the green application theme color. The next step was deciding which typical GIS tools, such as zoom, zoom to full extent, pan, identify, measure, and magnify, to include.

Figure 5.6 GIS tools offered before customization

After consulting with the client, it was decided to include the zoom tools, the pan tool, and the identify tool. While some of these tools could have all been removed to simplify the application, the client wanted them included in the event that the prototype would be expanded.
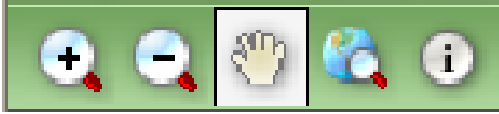
Figure 5.7 GIS offered after customization

The final customization that occurred was to cause results to be expanded immediately upon being added to the task results panel. This change required a change in the application code for a property of the task results panel called expansion depth. The original expansion depth in the code was set at "1". At this level users would need to be familiar enough with GIS applications to intuitively know how to expand the results. To make this section of the application more intuitive for non-GIS users, the results expansion depth was reset to "3". The results of this change are illustrated in Figure 5.8.
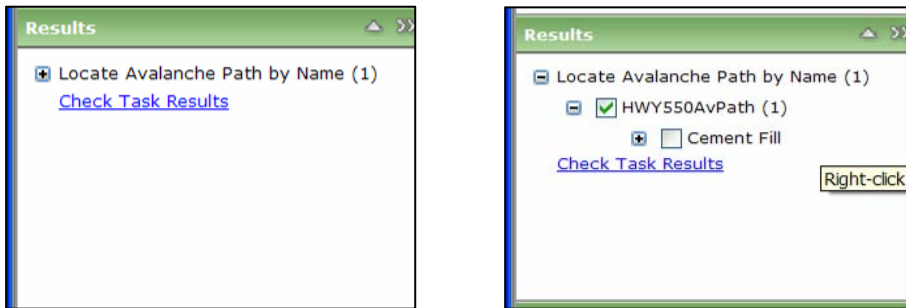
Figure 5.8 Results of expansion depth change

6. Development of the Nearest Neighbor Avalanche Forecasting Tool

There are two data mining techniques that are commonly used in avalanche forecasting. The first technique involves the use of regression trees to analyze the days before an avalanche event, to determine what conditions cause avalanches (McCollister, 2004). The second technique, and the one used for this research, is called the "Nearest Neighbor" technique (McCollister, 2004). This technique examines only the actual day that an avalanche occurred to determine the conditions that cause avalanches. This latter technique was used in this project, at the client's request.

The prototype "Nearest Neighbor Avalanche Forecasting" tool is based on the nearest neighbor data mining technique used by avalanche researchers. This technique treats days with avalanche activity as target days. Target day values are then used as indicators to determine what conditions have historically produced avalanches. These indicators are then used to determine whether incoming conditions might produce an avalanche. For example, if forecasted weather conditions are similar to the conditions that have historically produced avalanches, forecasters know that avalanches are possible.

The Nearest Neighbor Avalanche Forecasting tool is an ArcGIS model that utilizes a Python script to query a Microsoft Access database. This model sorts variables and distinguishes possible areas of interest to avalanche forecasters. However, the model is not intended to make avalanche predictions for large areas, but will focus on relatively small, well-known areas. The "Nearest Neighbor Avalanche Forecasting" tool allows the user to employ historical weather and avalanche activity to identify areas where avalanches have taken place in the past under similar weather conditions. To use this product, forecasters will input the needed data. The forecasters will begin by selecting the path or paths to be forecasted. They will then input the predicted incoming weather data

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precipitation and temperature. The model will complete a number of queries and use this data to create a new shapefile to demonstrate the probability of an avalanche to occur in the given focus areas based on the predicted weather conditions.

6.1. Avalanche Forecasting Python Script

The Python script embedded within the "Nearest Neighbor Avalanche Forecasting" tool is the core of this model. The first task that this script completes is to calculate the difference between the user defined inputs and all of the corresponding historical data. Differences are calculated for both maximum temperature and precipitation for every day within the database. Once these differences have been calculated, a second script adds each historical day's differences together. Since all avalanche areas are different, forecasters can elect to weight these parameters to make the model more effective for their forecast area. Then another query examines the different values and identifies the days with the least total difference in values.

After determining the five nearest neighbor days, another query is initiated. This query searches the avalanche activity field in the five nearest neighbor days and calculates a sum of avalanche activity, which is the basis for the final output shapefile, to be symbolized on. If the sum of the avalanche activity is less than one, the avalanche paths will be symbolized in green, signifying that no avalanches had occurred under similar weather conditions. If the sum of the avalanche activity is equal to one, the avalanche paths will be symbolized in yellow, signifying that moderate avalanche activity had occurred under similar weather conditions. If the sum of the avalanche activity is greater than one, the avalanche paths will be symbolized in red, signifying that a high level of avalanche activity occurred under similar weather conditions. Figure 6.1 represents the finished script as an ArcGIS Tool.
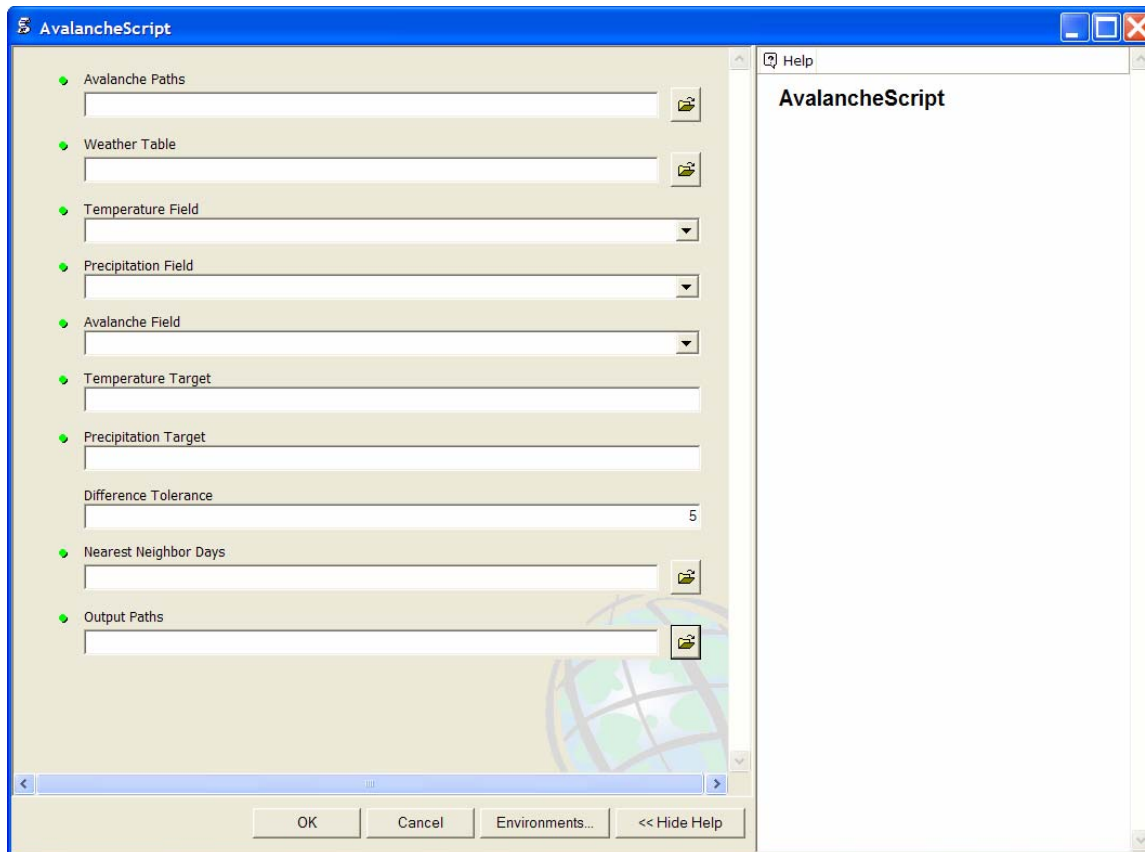
Figure 6.1 Avalanche Forecasting tool GUI in Python script state

6.2.   Developing the Avalanche Forecasting Model

The nearest neighbor Arc model was designed to make this tool user-friendly. Without this model, users would have to know what specific data types and data fields would be needed to run the analysis. The model simplifies this process by allowing the data and the data fields to be set using the Python script. The data inputs for this model are avalanche paths and historical weather data. Additionally, the model also allows the parameters of the model to be set. The parameters for this model are maximum temperature (max temp) and precipitation (prec). However these parameters can be changed in order to use minimum or average temperature. The two parameters are entered by the user and represent forecasted weather data.

The final step of the model is to designate the location where the model's output will be stored. Since this tool will be utilized via the World Wide Web, the outputs are stored in memory.

6.3. Publishing the Nearest Neighbor Avalanche Forecasting Tool

Once the "Nearest Neighbor Avalanche Forecasting" tool was completed, it was published to the "GIS Server Application for Avalanche Studies". In order to accomplish this, the Server Object Container (SOC) needed permission to access the tool (Figure 6.2).
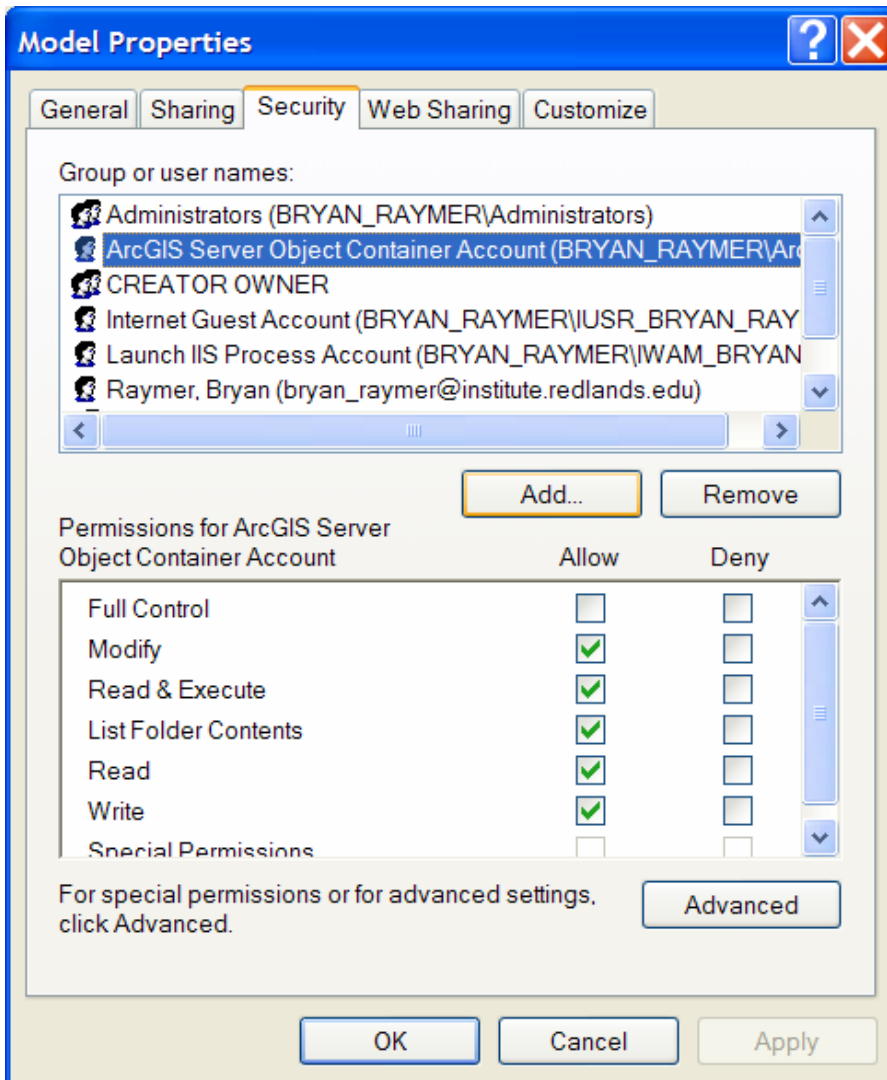
Figure 6.2 Granting the SOC permission to access the model

Once permission was granted, ArcGIS Server Manager was utilized to finish publishing the tool. Within ArcGIS Server Manager, the publish service wizard was used. The first step was to navigate to where the tool was stored and to name it (Figure 6.3)

Figure 6.3 Directing Server Manager to the avalanche forecasting tool

Once the tool was added to the server it had to be added to the applications itself. To do this, the application was edited using the edit application tool (Figure 6.4).
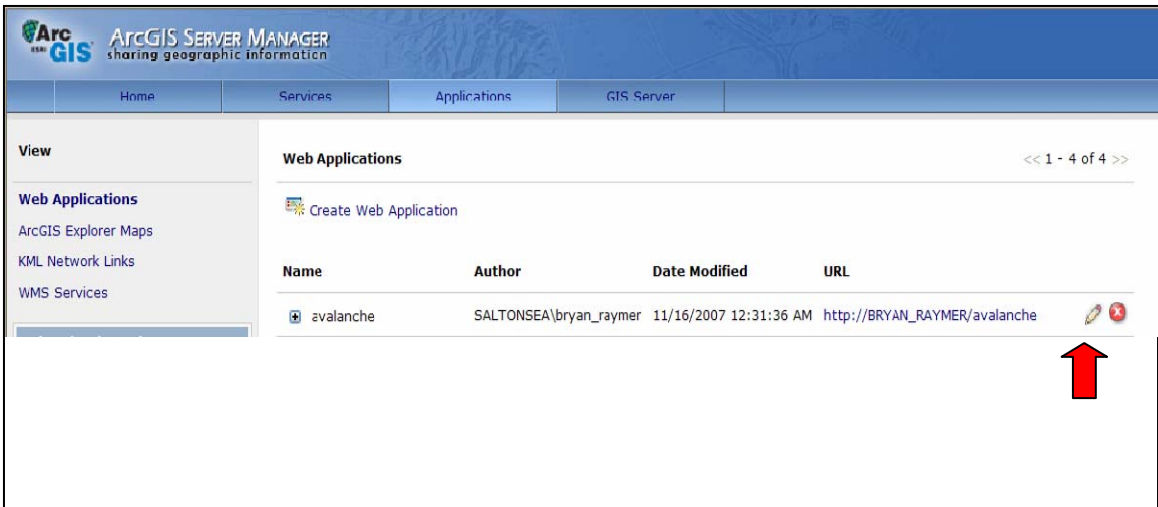
Figure 6.4 Edit application tool

Once inside the editing session, the add task link was clicked, launching a GUI that allowed the geoprocessing service to be added to the application (Figure 6.5).
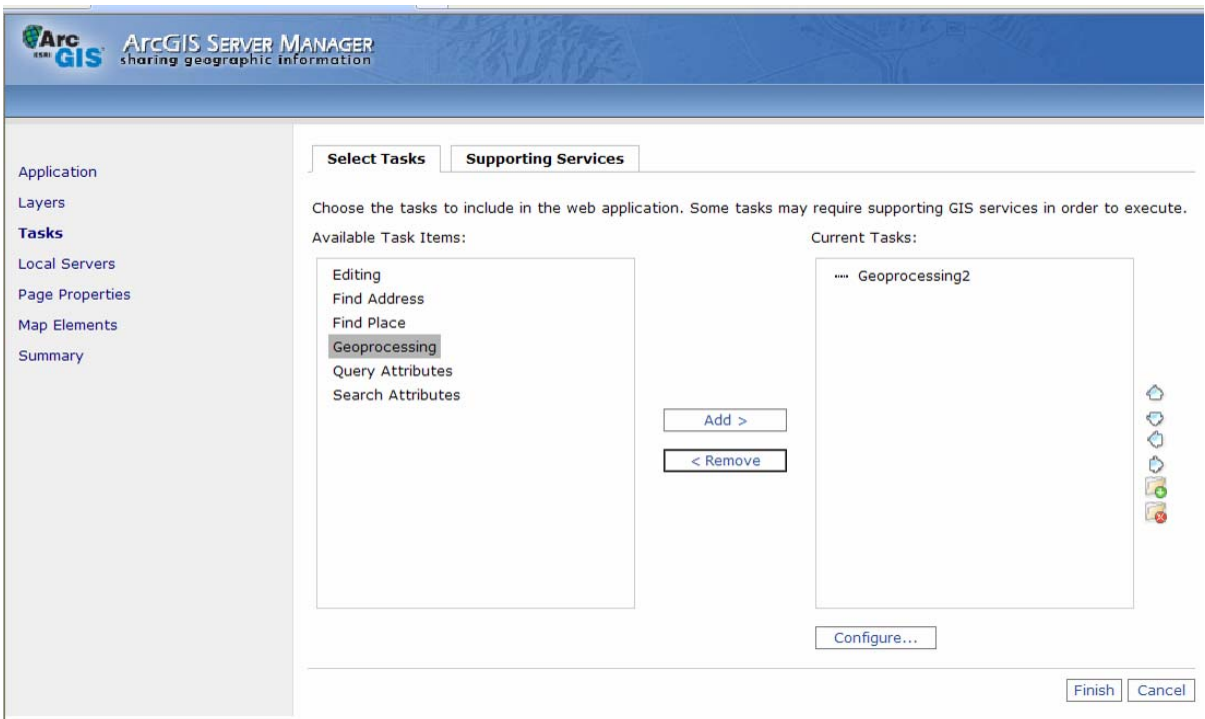
Figure 6.5 Adding a geoprocessing services to the GIS Server Application

After adding the services, the associated supporting services were established (Figure 6.6).
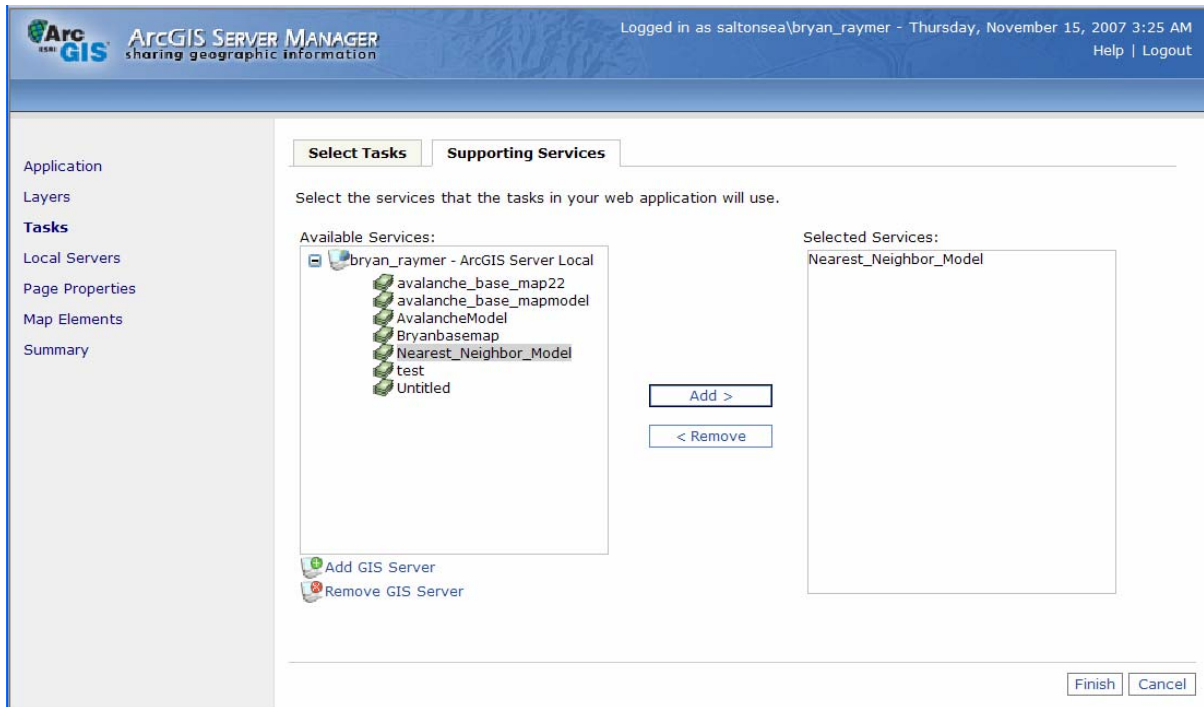
Figure 6.6 Adding a supporting service to run the geoprocessing services

Once the associated service and the geoprocessing tool were configured, the defaults on the remaining wizard windows were accepted until the tool was successfully added to the application.

7. Using the "GIS Server Application for Avalanche Studies" Tools

The "GIS Server Application for Avalanche Studies" application was designed to allow users to learn more about the study area without actually having to go out into the field. This application supplies four tasks for users to gather and share information about the study area. The four tasks provided are: "Select Avalanche Path by Name," "Calculate Average Road Crossings per Year," "Forecasting Tool," and "Print Map."

7.1. Locate Avalanche Path by Name

The "Locate Avalanche Path by Name" tool allows users to quickly and correctly find the locations of a given avalanche path. The tool was designed particularly for users who might not be familiar with the study area. To make this tool user-friendly it was designed with a drop down menu. To use this tool the user must select "Path Name" and then choose an avalanche path from the drop down menu (Figure 7-1).
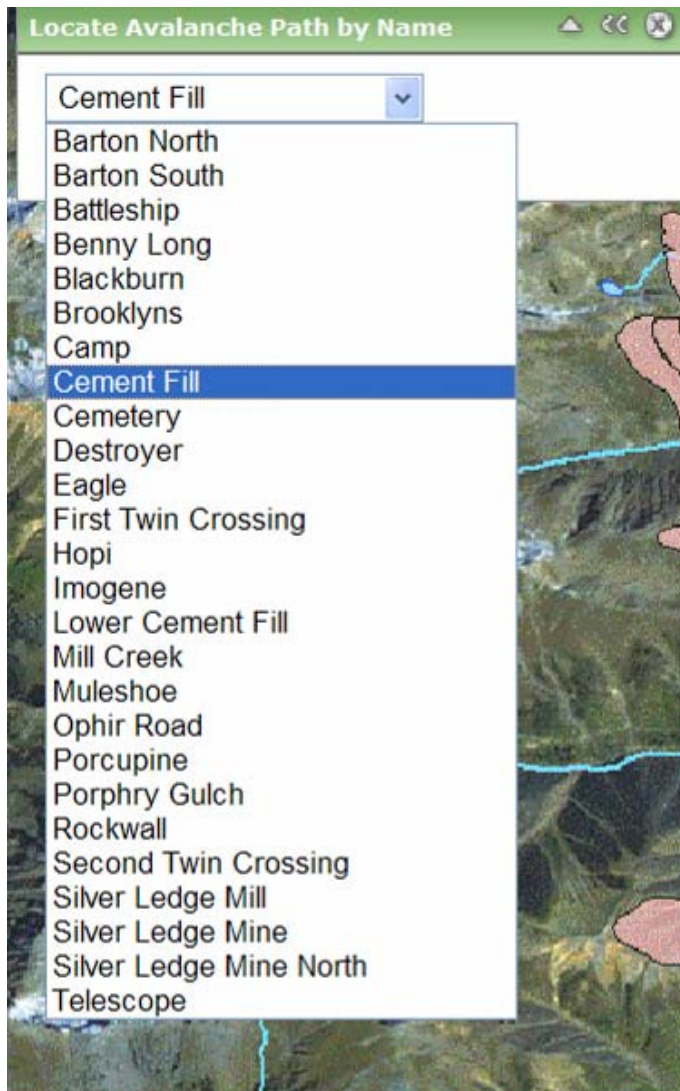
Figure 7.1 Locate Avalanche Path by Name tool and associated drop down menu

Once the user selects one of the path names the results will be displayed in the results window In order to display this result on the associated map, the user must check the box next to the associated path. Checking this box will display the corresponding path on the map in yellow (Figure 7.2).
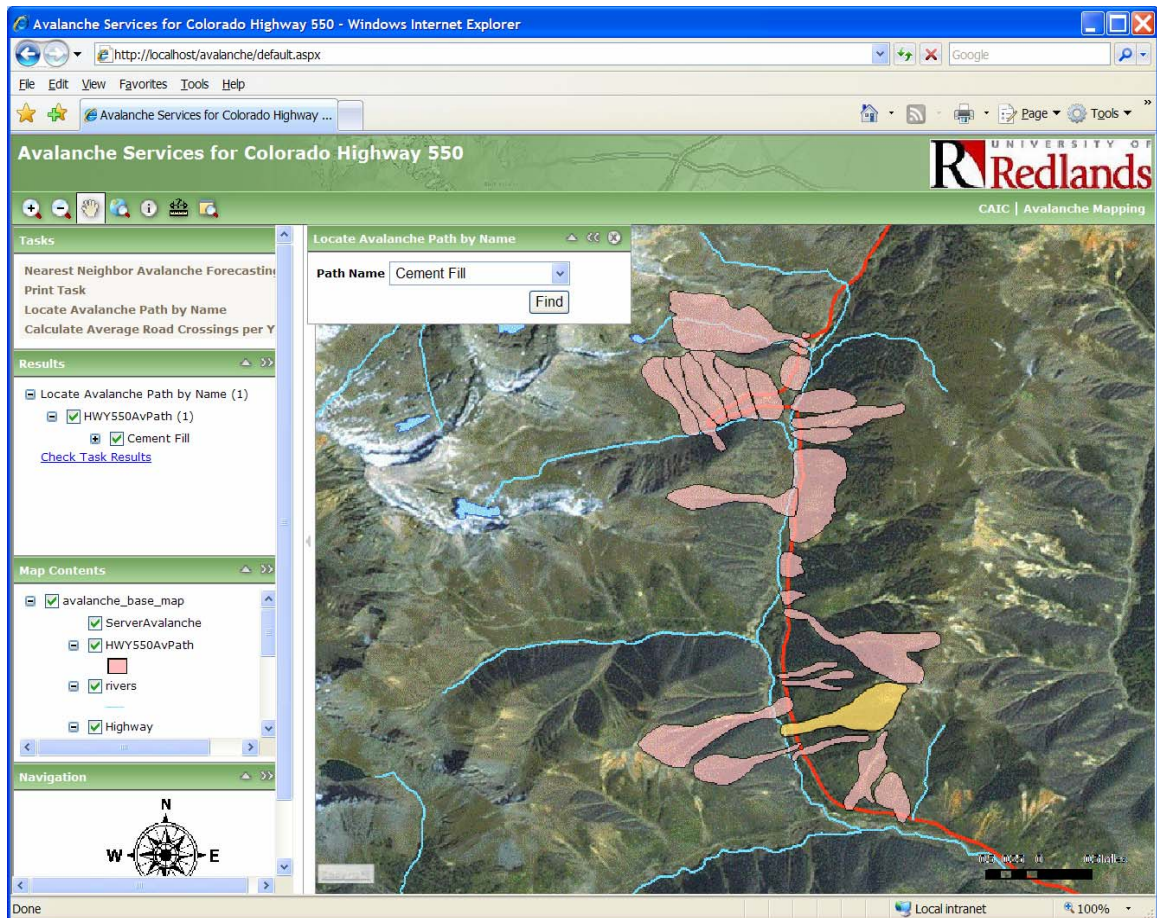
Figure 7.2 Map displays of results from the Locate Avalanche Path by Name

7.2. Calculate Average Road Crossings per Year Tool

The "Calculate Average Road Crossings per Year Tool" tool allows the users to sort and identify avalanche paths by number of avalanches they produce that affect Colorado Highway 550. Avalanche forecasters in this area concentrate their efforts on the paths that have the most potential to affect Colorado Highway 550. This tool allows forecasters to query the Historical Avalanche Activity database to determine which avalanche paths have had the largest effect on Highway 550. To use this tool, users first need to select the task. A simple fill-in-the-blank menu is then displayed (Figure 7.3).

Figure 7.3 Average Avalanches on Road per Year GUI

This fill-in-the-blank Graphical User Interface (GUI) is designed with a default value of "1". However, the user may choose any numerical value to input into the GUI and select evaluate. The tool will then query all the paths and only select those that produce this number or greater number of avalanches which have affected Colorado Highway 550. The results of this query will be displayed in the results window (Figure 7.4).
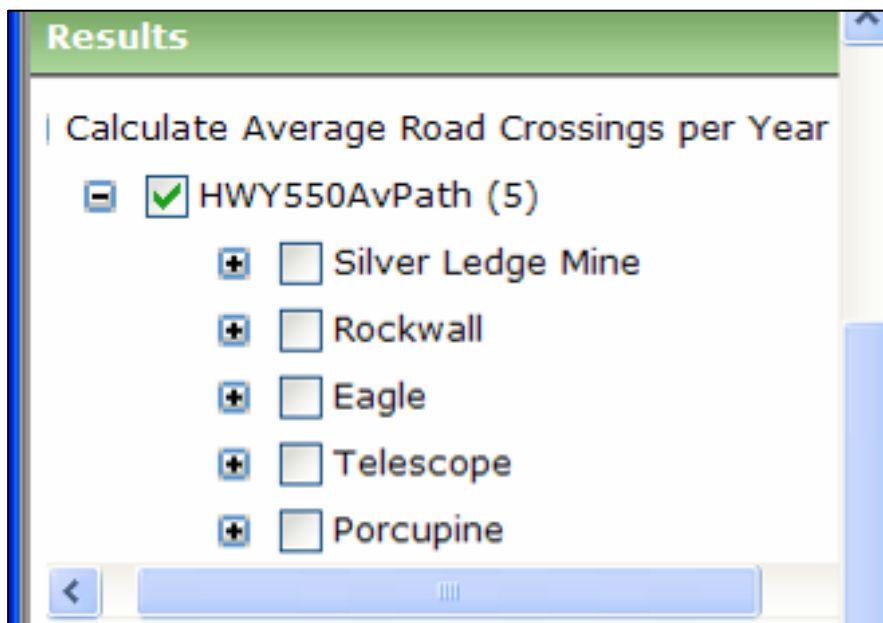
Figure 7.4 Results from Calculate Average Road Crossings per Year Tool

To display these results on the associated map, the user must select which paths they want to display. This function takes slightly more effort and GIS familiarity, but gives users the ability to display the paths one at a time (Figure 7.5) or all at once (Figure 7.6).
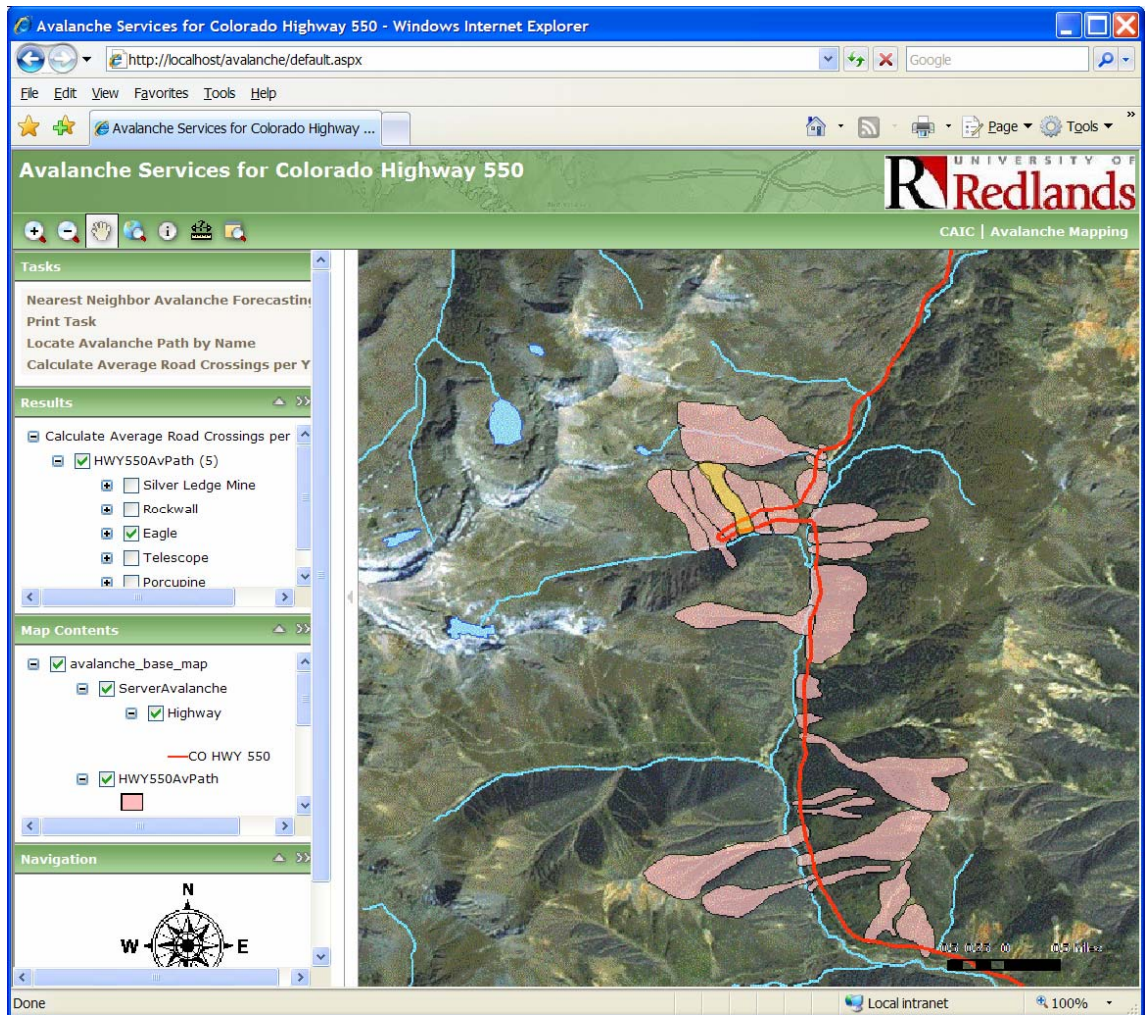
Figure 7.5 Results of Calculate Average Road Crossings per Year Tool with only one of the selected avalanche paths highlighted on associated map.
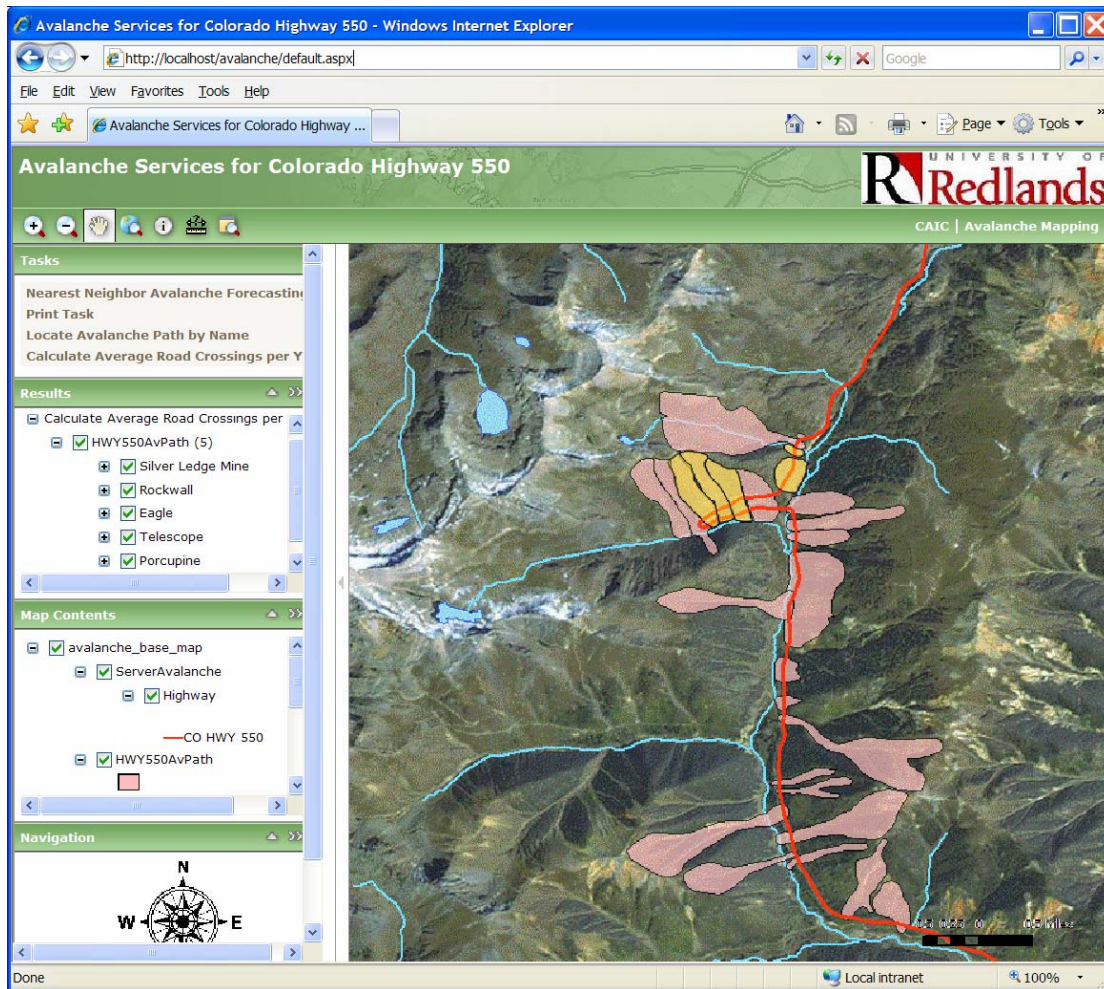
Figure 7.6 Results of Calculate Average Road Crossings per Year Tool with all of the selected avalanche paths highlighted on associated map.

7.3. Using the Nearest Neighbor Avalanche Forecasting Tool

The Nearest Neighbor Avalanche Forecasting tool allows users to quickly query the associated database to search for historical avalanche activity that has occurred on historically similar weather days. This tool was designed to be user friendly and for individuals who are not familiar with GIS. To launch this tool, the user simply selects the tool in the task menu. Once the tool is launched, a simple fill-in-the-blank GUI appears (Figure 7.7).

Figure 7.7 Nearest Neighbor Avalanche Forecasting Tool GUI

The GUI is designed so that users may input forecasted maximum temperature and precipitation, and the tool will search the database for historically similar days.

Once the user enters the values and selects submit, the tool runs. The values, a tool status message, and the results of this tool will display in the results window. To view the results, the box next to the output must be selected. Figure 7.8 illustrates the resulting output from this tool. (Note: This figure was created using ArcGIS desktop product ArcMap. On December 1, 2007 ArcGIS Server would not display the geoproccessing tools output.)
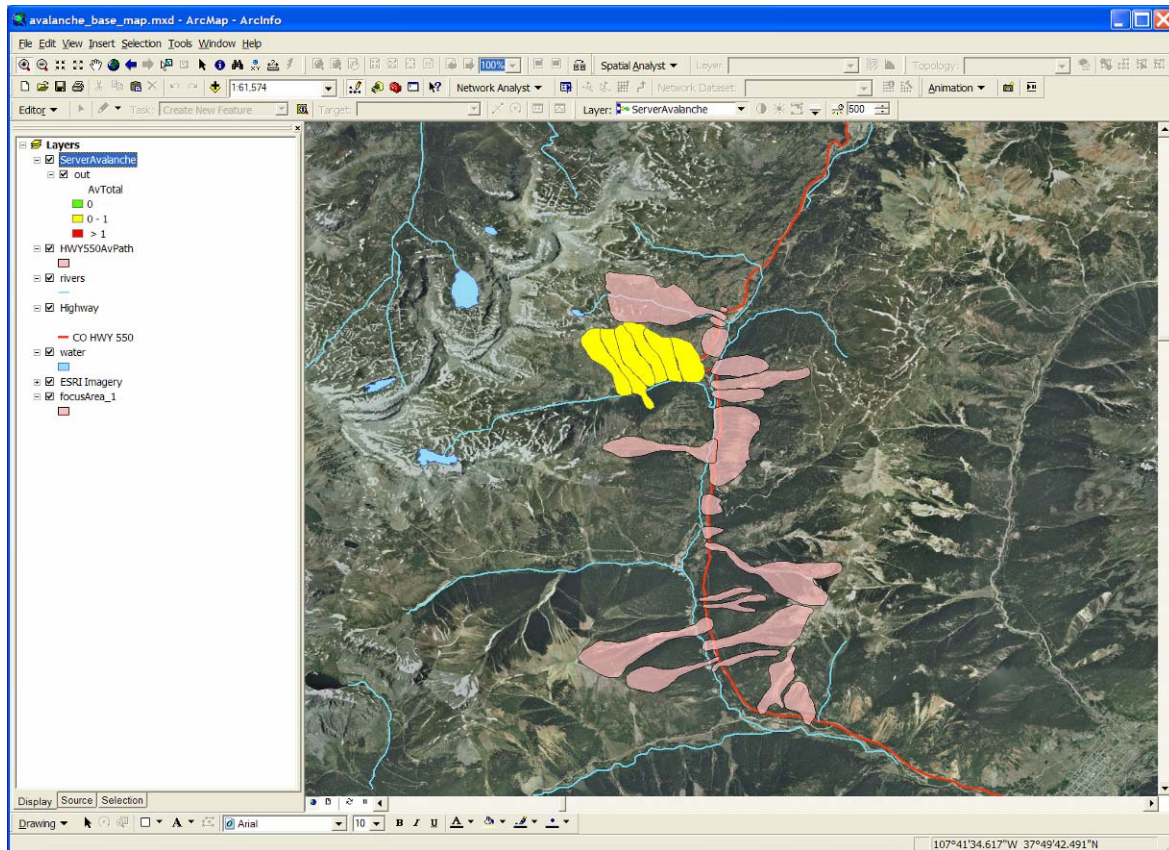
Figure 7.8 Display of results of avalanche forecasting tool illustrating a moderate risk on associated map.

7.4. Using the Print Function

The Print Map function allows users to print the map being viewed within the web browser. To use this function, users need to zoom in or pan to the area of interest. Once this area is clearly in view, the user can simply select the print map task and a print map dialog box is launched. This dialog box allows users to change certain settings such as title, size, resolution, and scale (Figure 7.9).

Figure 7.9 The print task GUI

Once this GUI is completed, the user selects the "create print page" to execute the print function.

8.   Conclusion

The "GIS Server Application for Avalanche Studies" is a prototype tool that allows avalanche forecasters and avalanche researchers to retrieve information about this avalanche study area without venturing into avalanche territory. The user friendly application provides the following tools for forecasters and avalanche researchers.
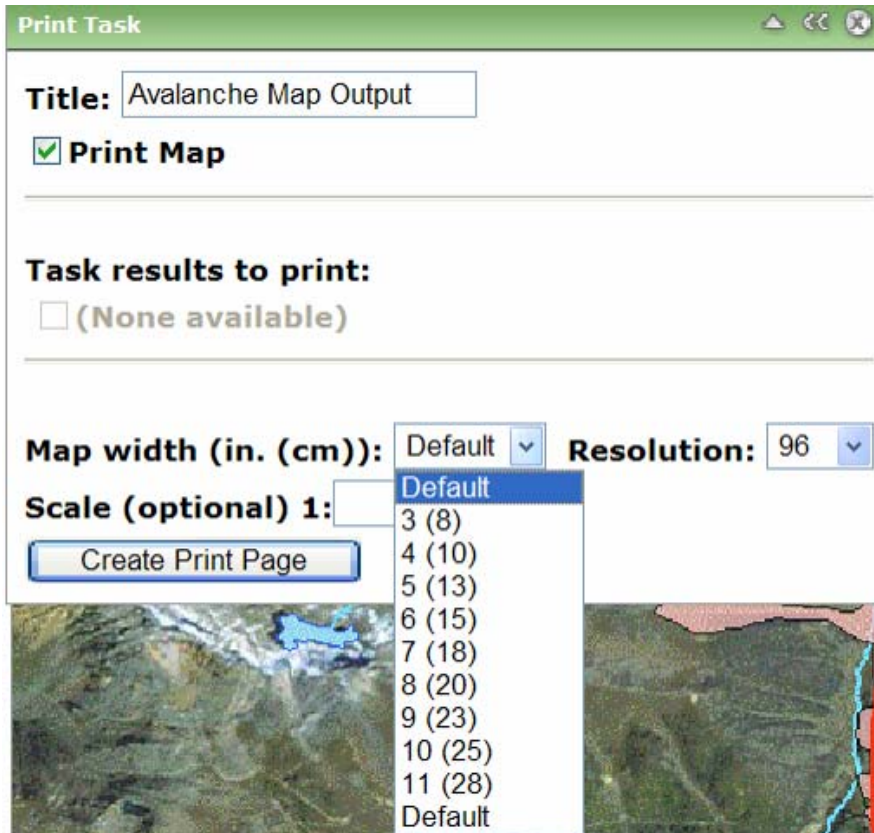
Tools included in "GIS Server Application for Avalanche Studies":

1. Quickly and correctly identifies avalanche path by name.

2. Quickly and correctly identifies avalanche paths that have historically affected Colorado Highway 550.

3. Provides a prototype avalanche forecasting tool.

4. Allows forecasters to utilize the wealth of historical data that have been compiled.

5. Provides a Print function

8.1.   Future Work

The "GIS Server Application for Avalanche Studies" provides several opportunities for future research endeavors. These endeavors include but are not limited to testing and expanding the study area.

8.2.   Initial Testing

The next logical step for this application is further testing of the prototype "Nearest Neighbor Avalanche Forecasting Model." The first test that should be completed would be a test to see if the avalanches actually occurred when the model said that avalanches would be most probable. One option for further testing could be completed by obtaining more data. For example, the historical weather data from known paths that have generated avalanches could be input to the model to determine if the program recognizes these paths as likely candidates to produce slides. This testing could provide evidence for

or against the continuing use of the maximum temperature and precipitation parameters for avalanche forecasting.

8.3. Parameter Testing

A parameter test could also be done by using the same data that was used in creating the prototype tool. For example, the parameters currently used for the tool are maximum temperate and precipitation. The temperature parameter could be changed to minimum temperature or average temperature, while the precipitation parameter could be changed to year-to-date precipitation. The model could be executed with any or all combinations of these parameters. The output results when using these different parameters could then be compared. If each of these parameters produced different results, the results could be tested in a similar way as the first test discussed. Testing such as this could help improve the overall accuracy of the model.

8.4. Expanding the Study Area

Expanding this study area to include surrounding avalanche areas is another possibility for future work. There are two possible ways that this application could be expanded. The first technique would be to create separate applications for each separate avalanche area for which the CAIC is responsible. For example, an organization such as the CAIC could build a separate application for each of their focus regions, allowing individuals to gather and spread information about each avalanche area.

8.5. Compare Results from Different Study Areas

In some avalanche areas it is believed that parameters such as wind have a higher correlation to avalanche activity than temperature and precipitation. Both wind speed and direction are important to the probability of an avalanche occurring, due to the transferring of snow from one area to another adding new weight to the snowpack , a process known as wind loading (LaChapelle, 1980). One way to illustrate this is to compare model results from different study areas. For example, if a model proves accurate in one study area and highly inaccurate for another study area, it could illustrate the need to use different or more parameters, such as wind, in future models.

8.6. Future Works Conclusion

Due to the complex nature of avalanches, it is currently impossible for one model to predict avalanches for all areas. Tests such as these are, however, very important in furthering avalanche research. Only through research and tests such as these can researchers begin to build accurate and useful avalanche models. Hopefully, future research will lead to a robust large scale GIS avalanche forecasting model. But until then, GIS may be used to gain insight into the phenomena of avalanches as possible (McCollister & Birkeland, 2006). Only by gaining information can researchers and policy makers counter the negative effects that avalanches produce.

9. References

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Apendix A – Nearest Neighbor Avalanche Forecasting Tool's Python Script

```
# Import modules and create the geoprocessor

import sys, string, os, arcgisscripting

gp = arcgisscripting.create()

gp.overwriteoutput = 1

PathsFC = sys.argv[1]

WeatherTable = sys.argv[2]

TempField = sys.argv[3]

PrecipField = sys.argv[4]

AvalancheField = sys.argv[5]

TempTarget = sys.argv[6]

PrecipTarget = sys.argv[7]

DifferenceBreak = sys.argv[8]

OutputTable = sys.argv[9]

OutputFC = sys.argv[10]

try:

    #gp.addMessage("Initialized")

    PrecipDifField = "PrecipDif"

    TempDifField = "TempDif"

    TotalDifField = "TotalDif"

    Scratch = gp.scratchWorkspace

    TableWorkspace = os.path.dirname(OutputTable)

    TableName = os.path.basename(OutputTable)

    inWorkspace = os.path.dirname(WeatherTable)
```

```python
gp.addMessage("Adding required fields...")

gp.tabletotable_conversion(WeatherTable,"in_memory",TableName + "_temp")

tempTable = "in_memory" + "\\" + TableName + "_temp"

gp.addfield_management(tempTable,PrecipDifField,"DOUBLE")

gp.addfield_management(tempTable,TempDifField,"DOUBLE")

gp.addfield_management(tempTable,TotalDifField,"DOUBLE")

gp.addMessage("Calculating difference...")

#gp.addmessage('Abs("' + PrecipField +'" - ' + PrecipTarget + ")")

gp.calculateField_management(tempTable,PrecipDifField,'Abs([' + PrecipField +'] - ' +
PrecipTarget + ")")

#gp.addmessage('Abs("' + TempField +'" - ' + TempTarget + ")")

gp.calculateField_management(tempTable,TempDifField,'Abs([' + TempField + '] - ' +
TempTarget + ")")

#gp.addmessage('Abs("' + PrecipDifField +'" - "' + TempDifField + '")')

gp.calculateField_management(tempTable,TotalDifField,'Abs([' + PrecipDifField +'] -
[' + TempDifField + '])')

gp.addmessage("Getting the top " + str(DifferenceBreak) +  " values...")

TotalValueArray = []

rows = gp.SearchCursor(tempTable)

row = rows.next()

while row:

    TotalValueArray.append(row.GetValue(TotalDifField))

    #gp.addmessage("Added " +  str(row.getValue(TotalDifField)) + " to array")

    row = rows.next()

TotalValueArray.sort()
```

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```
    index = int(DifferenceBreak) - 1

    BreakValue = TotalValueArray[index]

    gp.addMessage(str(index) + ":" + str(BreakValue))

    gp.addMessage("Calculating Sum...")

##    for i in range(1,index):

##        #gp.addMessage(str(TotalValueArray[i]))

##        topValues = topValues + str((TotalValueArray[i])) + ","

##        gp.addmessage(str(topValues))

##    topValues = topValues[:-1]

    #gp.MakeTableView(tempTable, "TopValues", '"TotalDifField" <= ' +

str(BreakValue))

    AvalancheSum = 0

    gp.addmessage("1")

    topRows = gp.SearchCursor(tempTable, 'NOT "' + AvalancheField +'" IS NULL AND

"' + TotalDifField + '" <= ' + str(BreakValue))

    gp.addmessage("2")

    toprow = topRows.next()

    gp.addmessage("3")

    while toprow:

        gp.addmessage(str(toprow.GetValue(AvalancheField)))

        AvalancheSum = AvalancheSum + int(toprow.GetValue(AvalancheField))

        gp.addmessage("here")

        toprow = topRows.next()
```

```
    gp.addmessage("Number of Avalanches of Nearest Neighbors = " +
str(AvalancheSum))
    gp.addmessage("Cleaning Up...")
    gp.TableToTable_conversion(tempTable,TableWorkspace,TableName,'"' +
TotalDifField + '" <= ' + str(BreakValue))
gp.FeatureClassToFeatureClass(PathsFC,os.path.dirname(OutputFC),os.path.basename(
OutputFC))
    gp.addField_management(OutputFC,"AvTotal","SHORT")
    gp.calculateField_management(OutputFC,"AvTotal",AvalancheSum)
    gp.delete(tempTable)
except:
    gp.adderror(gp.GetMessages())
```