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GIS Applications for Coal Mine Subsidence in the State of Colorado

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GIS APPLICATIONS FOR COAL MINE SUBSIDENCE IN THE STATE OF COLORADO

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by

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1. ABSTRACT

The state of Colorado has an extensive history of subsurface coal mining. Due to the widespread extraction of coal, numerous subsidence events have occurred, causing both costly and potentially dangerous conditions. The two most common types of underground coal mines in Colorado are slope and shaft mines, which are prone to roof collapse that can propagate to the surface in the form of sinkholes and troughs. Sinkholes and troughs can occur over prolonged periods of time or as instantaneous events, which may leave landowners little reaction time and expensive repairs. As of January 2010, no spatial database existed that covered all subsidence events for the state of Colorado, which caused difficulties for developers, government agencies, and the general public when attempting to identify subsidence hazards.

The Colorado Geologic Survey recognized the necessity of locating past subsidence events and has funded a project that utilizes a Geographic Information System (GIS), on an ESRI geodatabase platform, to identify and visualize such events. Subsidence events were collected from several primary sources including the Mine Subsidence Information Center (MSIC) at the Colorado Geological Survey (CGS), the Office of Surface Mining (OSM), the Division of Reclamation Mining and Safety (DRMS), and various historic article and newspaper clippings. Several hundred subsidence events were then organized and catalogued into a file geodatabase using automated and manual entry from spreadsheets, reports, and maps. This file geodatabase

uses domains, both coded and range, to simplify and standardize common data input, which will allow an efficient flow of information into the geodatabase for future subsidence events. Hyperlinks were attached to subsidence events within the file geodatabase so that users can dynamically link to scanned documents and images about a specific subsidence event.

Several GIS mapping interfaces were constructed, for data input, query, and analysis by the CGS, and for outside users to navigate the map and export reports and images of subsidence events in a user friendly format. The purpose of this project was to use proper documentation of past subsidence events to identify future subsidence hazards. The subsidence events GIS will allow users the ability to rapidly query and analyze historic subsidence data, view images of subsidence events, and export documents and reports of subsidence events, thereby optimizing the safe, efficient and economic planning of building developments.

2. Acknowledgements

I would like to express my gratitude to Heather B. Hicks for her guidance, suggestions, and support, throughout my Masters of GIS. Heather through all of this was my boss, my advisor, and most importantly my friend, and through it all we managed to not only stay friends, but build a lasting relationship.

A very special thanks is extended to TC Wait of the Colorado Geological Survey for her help in the management and creation of this project. Without the patience, respect, and confidence TC showed in me during the course of this project I would have certainly floundered under the pressure of holding down a demanding full time job, acquiring a Masters of GIS, and working on this project as a consultant for TC. I owe TC many things she would never expect or accept, thank you.

Also, thanks are given to my entire family, of which the love, inspiration and work ethic, were achieved to accomplish this Masters of GIS. Thanks to my wonderful wife, who loved me unconditionally as I worked nights and weekends, and only smiled and asked, "do you have time for that," as I headed out for another mountain bike ride, thank you my love for all of your help through this Masters.

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5. Introduction

Coal mine subsidence is the movement of the ground surface that takes place due to underground coal extraction (Bell et. al., 2000), which results in two primary features: trough subsidence, which is a gentle broad depression of the surface, and chimney or sinkhole subsidence, which is a deeper conical depression (Karfakis and Topuz, 1991) (Figure 1). Understanding and locating where coal mine subsidence occurs is a critical project for the development of infrastructure and safety of the people living in and around undermined areas.

Due to a rich coal-mining history, beginning in the middle of the 19th century, the state of Colorado has experienced multitudes of subsidence events. As a result of the potential hazards and economic detriment caused by coal mine subsidence, the Colorado Geologic Survey (CGS) recognized the necessity of locating subsidence events and funded a project that utilizes a Geographic Information System (GIS). The GIS, built and managed using ESRI software, was created to store, identify, analyze, and view coal mine subsidence events. The goal of the project was to: 1) use a file geodatabase to document historic subsidence events, 2) make the geodatabase accessible to the general public and CGS staff, and 3) use the geodatabase for prediction of future subsidence hazards.

Ultimately, users of the subsidence events GIS will have the ability to rapidly query and analyze historic subsidence data, view images of subsidence events, and export documents and reports of subsidence events. The Subsidence Events file geodatabase will help maximize the efficiency at which the CGS can make decisions regarding coal mine subsidence and optimize urban planning.

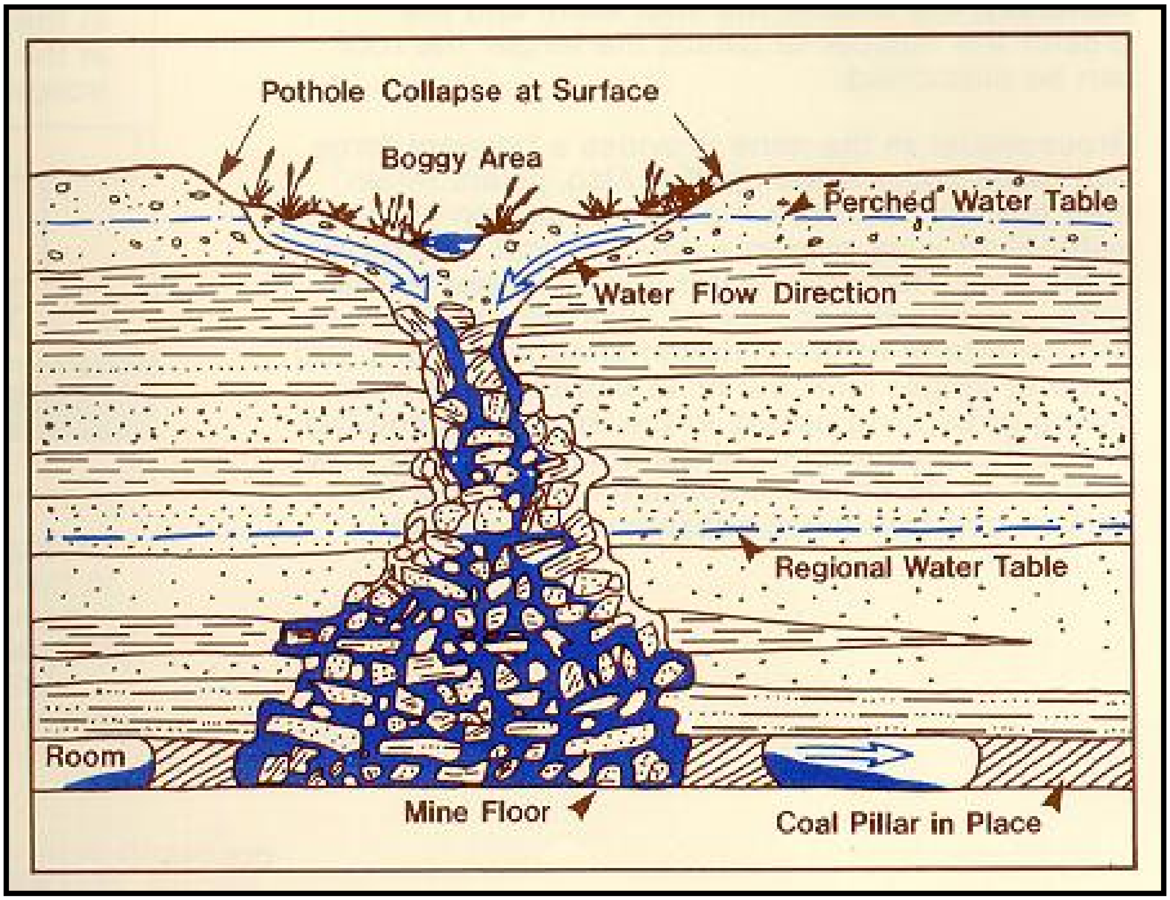

Figure 1: Image of coal mine subsidence from room and pillar coal extraction. Source: Illinois Department of Natural resources. http://dnr.state.il.us/mines/lrd/images/subpit.jpg. Date Accessed 04.16.2010.

6. Literature Review

6.1 Geology

Coal has been a primary energy source for the state of Colorado for nearly 150 years (Scamehorn, 2002). From 1864 to 2004, over "1.24 billion tons of coal have been mined in Colorado" (Carroll, 2005), and Colorado is commonly ranked among the top ten coal producing states (EIA, 2008; Carroll, 2005). Coal mining began in Colorado along the Eastern Slope of the Rocky Mountains in the 1860's (Scamehorn, 2002) and continues today in Delta, Gunnison, La Plata, Garfield, Moffat, Montrose, Rio Blanco, and Routt counties (Carroll, 2005). Routt county's Foidel Creek mine was ranked as the largest underground coal mine in the United States in 2004 (Carroll, 2005). Figure 2 indicates the locations of Colorado's eight coal producing regions.

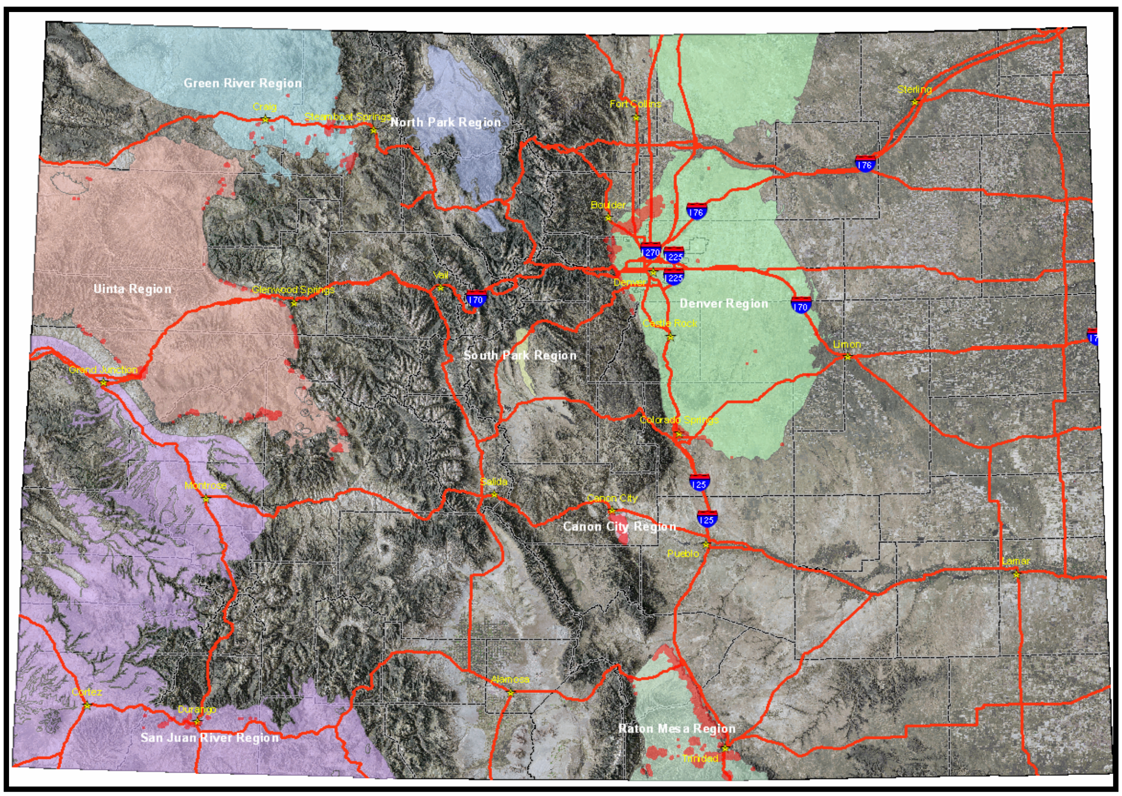

Figure 2: Eight Coal Regions in Colorado. Strickler, 2010.

Colorado has multiple types and qualities of coal, which are all primarily sourced from Cretaceous-aged formations (Carroll, 2005). The quality of coal is directly related to the maturation of organic matter within the coal; anthracite is the most mature form of coal and therefore has the highest energy capacity, whereas lignite is the least mature form of coal and therefore generates the lowest energy capacity. As a whole, coal from the state of Colorado has an average heat value of 11,131 Btu/lb, and is considered 'clean', meaning that the coal contains little sulfur, mercury, or ash content (Carroll, 2005), which has allowed Colorado to remain competitive in the coal mining markets.

Depending upon the depth of the coal deposit and topography of the surface, various styles of mining were used to extract coal. One of the most widely used extraction methods in Colorado, the room-and-pillar method (Figure 3), involved extracting the majority of coal in a room, but leaving pillars to support the overlying roof.

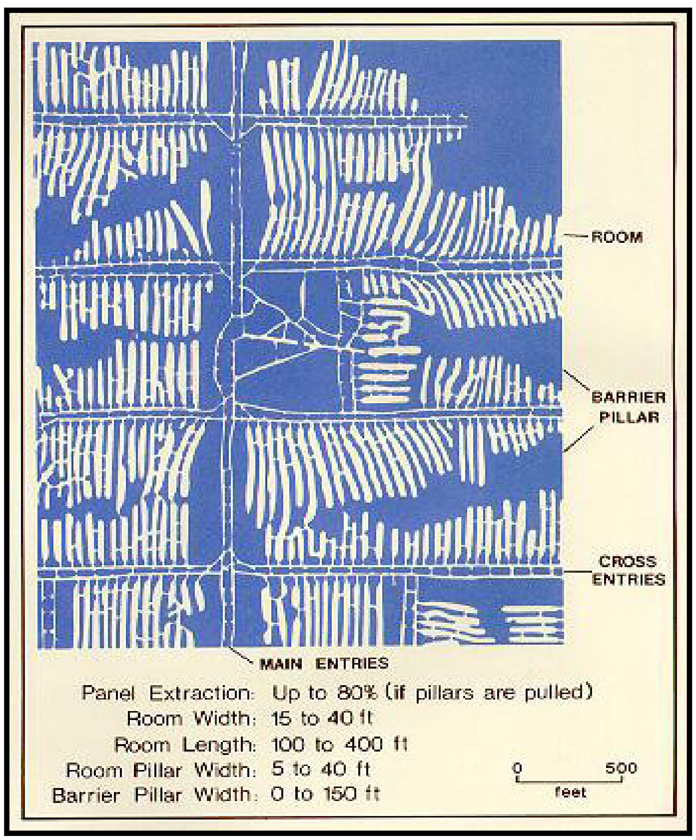

Figure 3: Layout of the room-and-pillar method (DuMontelle, 1981).

Once all of the rooms in a coal seam were cleared, the pillars were often removed, which increases the risk of surface subsidence (Scamehorn, 2002).

Unfortunately, overburden from the remaining overlying column of rock commonly results in subsidence, or the sinking of the sediment column. Subsidence can occur rapidly or gradually, but always poses hazards for developers and homeowners. Due to poor identification of subsidence hazards, nearly 5,000 homes along Colorado's front range urban corridor are potentially vulnerable to risks from coal mine subsidence (Turney, 1985) (Figure 4). As a result of a State law passed in 1977, potential surface subsidence must be considered prior to new mining (Turney, 1985); however, subsidence danger still exits from historic coal mines. In order to mitigate future subsidence hazards, previous subsidence events must be gathered into a user-friendly database.

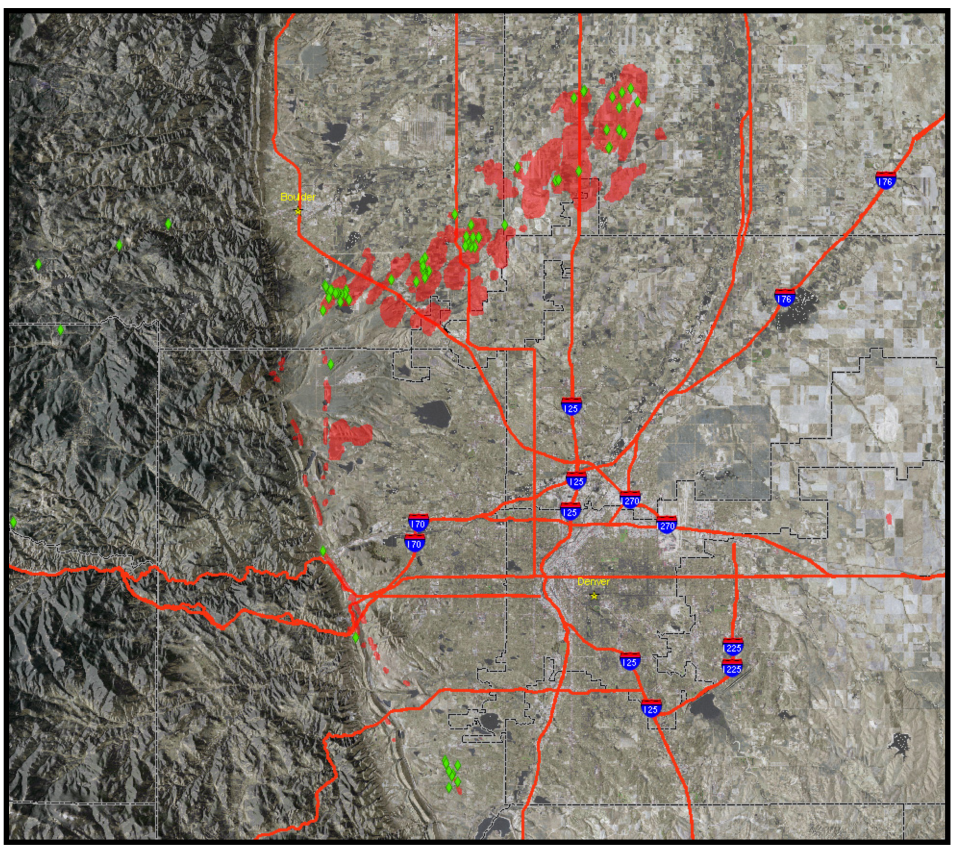

Figure 4: Coal undermined areas. Strickler, 2010.

6.2 GIS

Previously unrecognized patterns, correlations, and relationships can be discovered by managing spatial data in a GIS for organization, analyzing, and mapping (Lang, 1998). In order to make critical environmental and resource business decisions, GIS has been used as a tool by a wide range of scientific disciplines including: biology, geology, urban planners, petroleum engineers, mining, water resources, gas and electric utilities, and forestry.

In reference to subsidence, GIS has had a variety of valuable applications in previous studies. For example, in 2007, Ge et. al. used a synthetic aperture radar, a remote sensing application, to measure surface subsidence at a large scale. The study by Ge et. al. (2007), indicated that surface subsidence features can be efficiently stored, analyzed, and mapped in a GIS using a remote sensing application.

In another coal subsidence study, Gorokhovich, et. al. (2003), used GIS analysis to develop a priority list for coal mine reclamation in the contiguous United States. Gorokhovich, et. al. (2003) found that GIS was a helpful tool when creating cost effective methods of reclaiming mined areas.

Finally, Treworgy and Hindman (1991), demonstrated the benefits of GIS in urban planning by using a GIS to analyze the proximity of coal mines to urban developments in the state of Illinois. In the study by Treworgy and Hindman (1991), hazard zones and coal undermined areas were mapped in relation to urban areas. The state of Colorado has utilized various aspects of GIS with regard to coal mine subsidence; however, this project will be the first comprehensive geodatabase of all subsidence events within the state of Colorado.

7. Study Area

This project was funded by the Colorado Geological Survey, which determined the study area as the political boundary of the state of Colorado. Encompassing over 100,000 square miles of land, and elevations ranging from 14,440 feet at the top of Mt. Elbert, to 3,315 feet where the Arkansas River exits Colorado, the state of Colorado spans a diverse geographic region. Colorado can be split into three primary geographic areas; the west slope, the Rocky Mountains, which run north to south through the middle of the state, and the high plains, which are part of the great plains of the mid-west (Figure 5). Colorado is divided into 8 coal regions including: the Denver, Raton Mesa, North Park, South Park, Canon City, Green River, Uinta, and the San Juan region (Scamehorn, 2002).

Figure 5: Colorado State. Date Accessed: 04.16.2010, Modified from Google Maps.

8. Methodology

In order to create the Subsidence Events file geodatabase, the following primary steps were taken: 1) a schema for a file geodatabase was developed, 2) historic subsidence event data was collected, 3) historic subsidence data sources were entered into a single Subsidence Events file geodatabase, 4) associated mapping interfaces were constructed, and 5) workflow tutorials were created for editing, updating, exporting, and overall maintenance on the geodatabase (Figure 6).

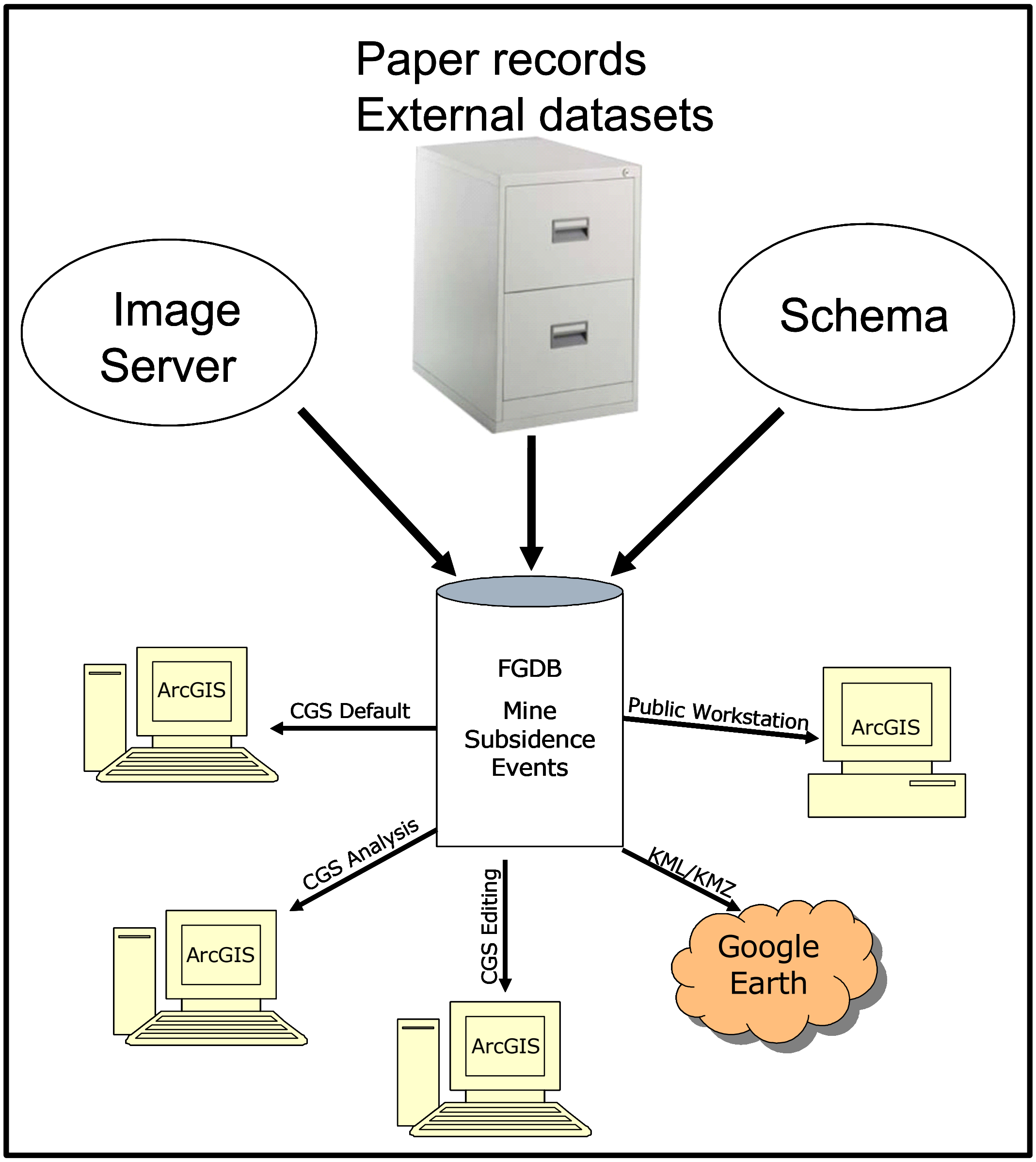

Figure 6: Project Workflow. Strickler, 2010.

8.1 Creation of a Subsidence Events file geodatabase

Choosing a type of geodatabase is not often considered amongst GIS professionals; however, the CGS requested the creation of a personal geodatabase, as opposed to a file geodatabase, because personal geodatabases use Microsoft Access as the database, which allows access for non-GIS users. However, the decision to use a file geodatabase remedied issues of size limitations caused by the inclusion of rasters in the feature class, prevented editing lockouts, and increased overall geodatabase performance by optimizing indexing and storage parameters. The CGS recognized the benefits of using a file geodatabase and determined that an editing workflow tutorial would supplement the file geodatabase.

The first step in creating the file geodatabase of coal mine subsidence events was to determine what attribute fields would efficiently store the most information without degrading the integrity of the dataset. The attribute fields created for the Subsidence Events file geodatabase were supported by researching the attributes contained within the three primary data sources. The file geodatabase ended up with 40 fields; 18 fields used domains, of which 15 were coded and 3 were range, a raster field for subsidence photos, and a hyperlink field to access the scanned MSIC documents was also created (Appendix A). The schema for the Subsidence Events file geodatabase was designed so that a non GIS professional could operate and edit with limited familiarity of spatial and database concepts. A simple file geodatabase was created through an extensive use of domains, both coded and range, which allows the user to choose attributes from pre-coded drop down menus, as opposed to typing-in values.

8.2 Data collection

Data in this project originated from three primary sources: the Office of Surface Mining (OSM), the Division of Reclamation Mining and Safety (DRMS), and the internal CGS Mine Subsidence Information Center (MSIC). The field calculator tool, from ESRI ArcGIS software, was used after data was loaded to fill in attributes, for example Data Source, and Rank Accuracy could be auto populated after loading the source data. The most challenging data source was the MSIC, a collection of hard copy documents and maps located in several file cabinets at the CGS office, which were searched meticulously for subsidence features. The OSM dataset consisted of an Excel database, which made collection of the subsidence events less time consuming; however, acquiring the correct attribute information proved to be much more challenging than obtaining the data from the MSIC. The DRMS dataset consisted of a shapefile with a large collection of attributes in the associated .dbf table. Loading the data was the most time consuming step in the project, since each datasets attributes needed to be modified before being loaded into the Subsidence Events file geodatabase.

8.3 Loading data

The MSIC files were input manually by researching the reports and maps associated with coal mine subsidence events, which were often full of relevant information, but time consuming to extract the pertinent information. The majority of reports in the MSIC were coal mine subsidence investigation reports for housing and building developments, which often had field studies to see if any subsidence had occurred in the study area. The location information for the subsidence events were most often gathered from a combination of written descriptions, township and section lines on a reference map, and physical addresses. The subsidence events were then plotted onto

Google Earth, or the internal CGS ArcGIS 9.3.1 mapping document, to acquire an actual latitude and longitude value for input into the Subsidence Events file geodatabase. The reports and maps were then used to obtain attribute information for manual entry into the geodatabase.

The OSM dataset came in the form of an Excel spreadsheet and consisted of 193 subsidence events. The first step was to delete all unnecessary and unpopulated fields out of the Excel document, which trimmed the attribute fields down to a manageable number. The Excel document was then converted into a .dbf 4, or dbase IV, database document for input into ArcGIS. The .dbf 4 was imported into an ArcGIS mapping document and the Display XY tool, from ESRI ArcGIS software, was run to create a shapefile of the database. The existing attributes of the shapefile were then edited to fit the geodatabase schema of the Subsidence Events file geodatabase, which included adding, deleting, and merging several fields to match the data type, field length, and purpose of the attribute. Slight differences in the purpose of the attributes were often found in the OSM dataset and the Subsidence Events file geodatabase, but the general purpose for both attributes were the same.

The last dataset to load was the DRMS, which consisted of a shapefile with numerous attribute columns and 250 subsidence events. The first step was to delete all unnecessary and unpopulated fields out of the Excel document, which trimmed the attribute fields down to manageable number. The Excel document was then converted into a .dbf 4 database document, similar to the OSM data, for input into ArcGIS. The .dbf 4 was imported into an ArcGIS mapping document and the Display XY tool was run to create a shapefile of the database. The attributes of the DRMS shapefile were then edited to fit the geodatabase schema of the Subsidence Events file geodatabase, which included adding, deleting, and merging several fields to match data type, field length, and purpose of the attribute. Slight differences were found in the purpose of the attributes of the DRMS dataset and the Subsidence Events file geodatabase, but the general purpose for both attributes were the same.

8.4 Mapping interfaces

The final step in this project was to create several mapping interfaces for both internal CGS use and external usage for the public. Due to the lack of experienced GIS users at the CGS, static, process driven, mapping interfaces were created. Overall two mapping interfaces were created for public use and three mapping interfaces for internal use by the CGS. Several map document templates were created to preserve the structure of the mapping interfaces in case of corruption by the CGS staff. Only one CGS staff member was given editing privileges to the Mine Subsidence feature class, which was done by creating an editing mapping interface and storing that on their local drive. The display bar in the ArcGIS mapping interface was grouped into several categories, for all mapping interfaces, which allowed the users to quickly identify the layers they wish to turn on or off, export data, and change symbology if needed.

The two public mapping interfaces consisted of one built in ArcGIS 9.3.1 and the other built using Google Earth as the platform. The first map built in ArcGIS 9.3.1 has a very simple map layout with limited functionality and tools. ESRI's Image Server was used on the public mapping documents for NAIP 2009 1-meter aerial imagery, a statewide mosaiced topo dataset, a 10-meter DEM, and a 10-meter hillshade as a basemap for viewers, which greatly increased the refresh rate and overall performance of the mapping interfaces.

The second map created used the Google Earth platform and Subsidence Events, Undermined Areas, and MSIC data was overlaid onto that platform using kml/kmz files exported from ArcGIS 9.3.1. This was built for the very basic user who has no GIS experience, in the hopes that the Google Earth platform would be a simple web mapping platform for the user. Google Earth also has several built in tools and views that make navigation and viewing easy for the basic user. The kml/kmz files are available both in the CGS public workstation as a Google Earth mapping interface, and can be emailed upon request to the public.

The purpose behind building public-use specific mapping interfaces was to distribute the most accurate and reliable GIS data available from the CGS. The CGS wanted to set up scale dependencies so that users could not zoom into full resolution due to the ramifications of users misinterpreting the Subsidence Events and Undermined Areas datasets thereby controlling scale error issues and appropriate use. The Subsidence Events feature class was collected from various sources, which often were unreliable with geometry and attributes. The Undermined Areas feature class was digitized using a smaller scale then what the public users could zoom into, which meant that the accuracy would be less than the built mapping interface. The free basemaps offered today, for example National Agriculture Imagery Program (NAIP) 2009, allow users to see their house, yards and sheds with amazing clarity. Due to the legal ramifications the CGS must be very careful in displaying natural hazard datasets to the public.

There were three internal mapping interfaces created for the CGS using ArcGIS 9.3.1. The three mapping interfaces consisted of an editing interface, a viewing interface, and an analyzing interface. Each of these mapping documents were saved out as a map document template in case of accidental corruption of the original mapping document.

The internal mapping documents did not need the scale dependencies at large scales, since none of the mapping interfaces would be used by the public. Image Server was used on the internal mapping documents for NAIP 2009 1-meter aerial imagery, a statewide mosaiced topo dataset, a 10-meter DEM, and a 10-meter hillshade, which greatly increased the refresh rate and overall performance of the mapping interfaces.

The editing interface was set up with the Editor toolbar, for updating the Subsidence Events feature class, the Standard toolbar, for some administrative tools, and the Draw and Tools toolbar, for basic map functions. The editing interface was constructed in conjunction with a workflow tutorial for adding new subsidence events, as well as updating and editing existing feature geometries and attributes. The editing interface was stored on a local drive in the effort that other users would not attempt to edit the data, therefore allowing the geodatabase to have a single database owner.

The viewing interface is the simplest of the mapping interfaces, designed for general viewing, identifying features, querying, measurements and very basic analysis, screen shots for PowerPoint, field maps, and printing to several scales. ArcToolbox is not activated by default so that no significant analysis can be done using this mapping interface. The toolbars displayed for this mapping interface will include only the Tools toolbar, which will allow basic map functions like zooming and identifying features, and the Layout toolbar, which will be used in the layout view for printing.

The analysis mapping interface is the most robust and dynamic mapping interface utilizing all the functionality and tools of ArcGIS. This interface is used to analyze the Subsidence Events and the Undermined Areas, which are the primary datasets in these mapping interfaces. ArcToolbox is activated for analysis as well as these toolbars; Standard, Layout, Tools, and the Draw toolbar.

8.5 Workflow tutorials

This project required several workflow tutorials to be built, for both internal CGS employees and external public users, due to the complexity of the ArcGIS 9.3.1 software. A total of three workflow tutorials were created for this project: 1) editing, updating, and maintenance of the Subsidence Events file geodatabase, 2) basic workflow and tools for ArcGIS map document, and 3) viewing, exporting, and printing MSIC documents from the hyperlinked and raster attribute fields. The first workflow tutorial is built for the internal CGS mapping interface and is limited to the owner of the Subsidence Events file geodatabase. The second workflow tutorial is available for both internal CGS staff as well as public use for the external ArcGIS mapping interface. The third workflow tutorial is available both internally and externally; however, the workflow will be written for the public users, since they do not have direct access to the MSIC.

9. Results and Deliverables

The goal of the project was to: 1) use a file geodatabase to document historic subsidence events, 2) make the geodatabase accessible to the general public and CGS staff, and 3) use the geodatabase for prediction of future subsidence hazards. The subsidence events GIS allows users the ability to rapidly query and analyze historic subsidence data, view images of subsidence events, and export documents and reports of subsidence events, thereby optimizing the safe, efficient and economic planning of building developments. Currently, this legacy Subsidence Events file geodatabase is available for public use at the CGS. The results of this project will serve as a tool to aid in urban planning, create a digital storage for all subsidence events in the state of Colorado, and analyze coal mine subsidence events.

9.1 Subsidence Events file geodatabase

The decision to use a file geodatabase remedied issues of size limitations caused by the inclusion of a raster field in the feature class (Figure 7), prevented editing lockouts by viewers during an edit session, and increased overall geodatabase performance by optimizing indexing and storage parameters. The Subsidence Events file geodatabase was created with 40 fields; 18 fields used domains, of which 15 were coded and 3 were range, a raster field for subsidence photos, and a hyperlink field to access the scanned MSIC documents was also created. The schema for the Subsidence Events file geodatabase was designed so that a non GIS professional could operate and edit with limited familiarity of spatial and database concepts.

The Subsidence Events file geodatabase was built using no coordinate system or projection, and was in the NAD83 datum. Using a non-projected format was done to simply data transfer between the CGS and its clients. All mapping interfaces were

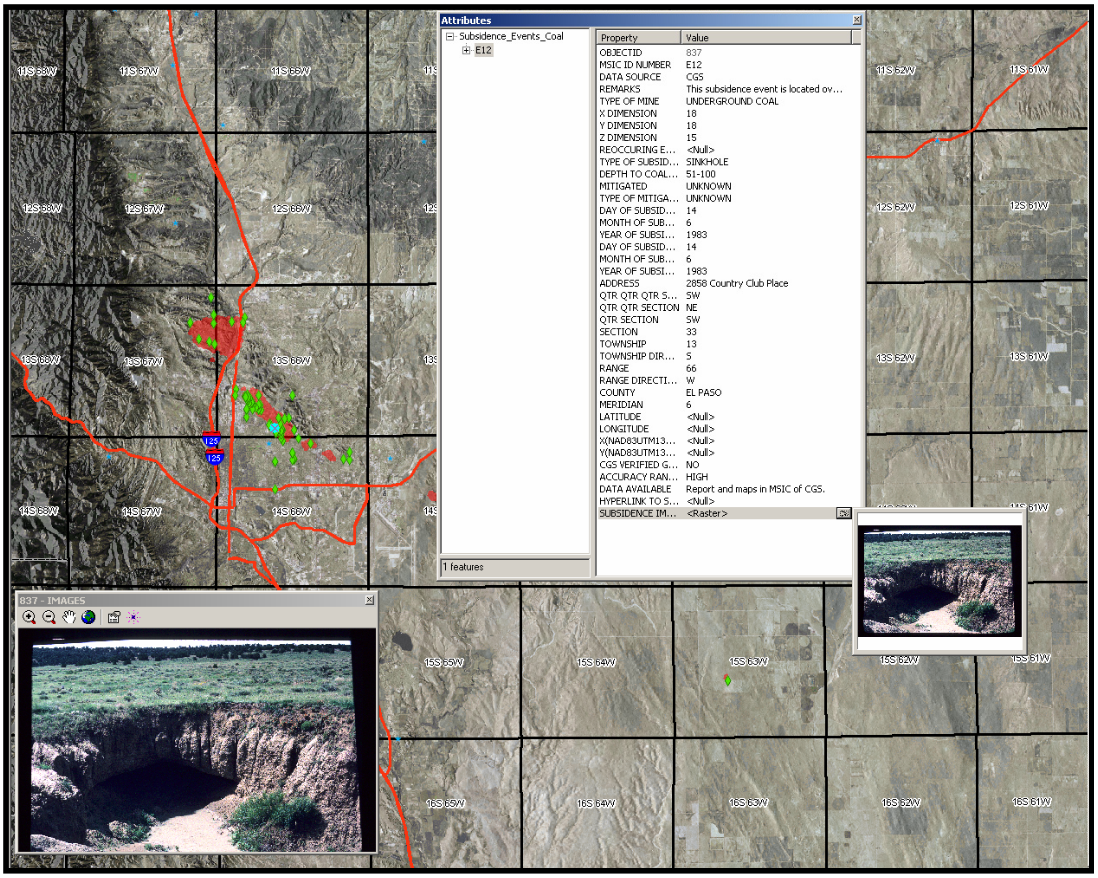

Figure 7: Raster field in feature class. Strickler, 2010.

projected, which meant that ArcGIS did an on the fly projection of the file geodatabase; however, the integrity of the data's geometry is not lost during a simple on the fly projection. The Subsidence Events file geodatabase stored the following data for viewing and analysis: 1) Subsidence Events, both coal and other, 2) MSIC, which is any mine subsidence related information, whether subsidence occurred or not, and 3) Undermined Areas, which are large polygons drawn around old mine workings maps (Figure 8). A simple file geodatabase was created through an extensive use of domains, both coded and range, which allows the user to choose attributes from pre-coded drop down menus, as opposed to typing-in values.

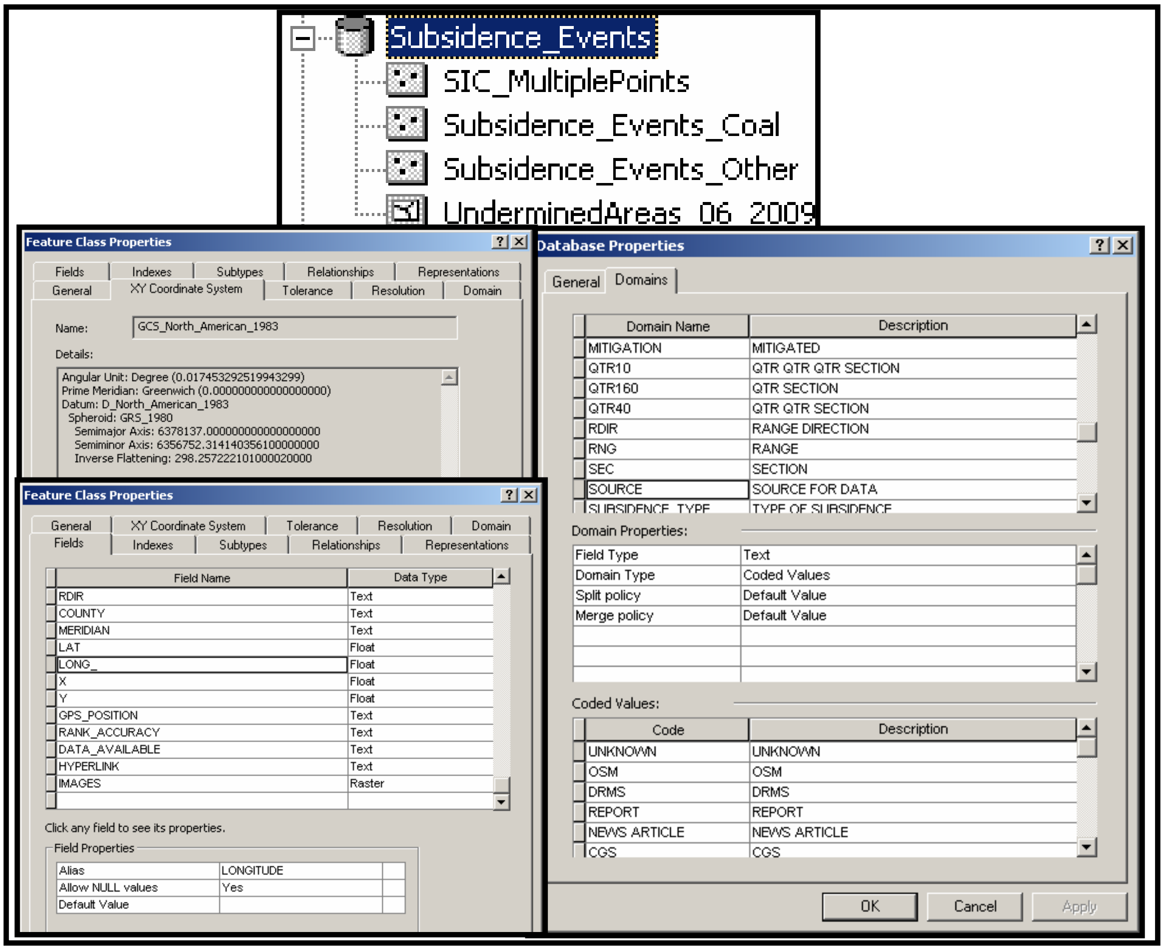

Figure 8: Subsidence Events file geodatabase, Strickler, 2010.

ArcGIS 9.3.1 and Google Earth mapping interfaces were created for both internal CGS use and external usage for the public; two mapping interfaces were created for public use, and three mapping interfaces for internal use by the CGS. The first public mapping interfaces was built in ArcGIS 9.3.1, with a simple map layout and limited functionality and tools (Figure 9). The second public mapping interface used Google Earth as the platform and only brought in kml/kmz files of the Subsidence Events file geodatabase (Figure 10).

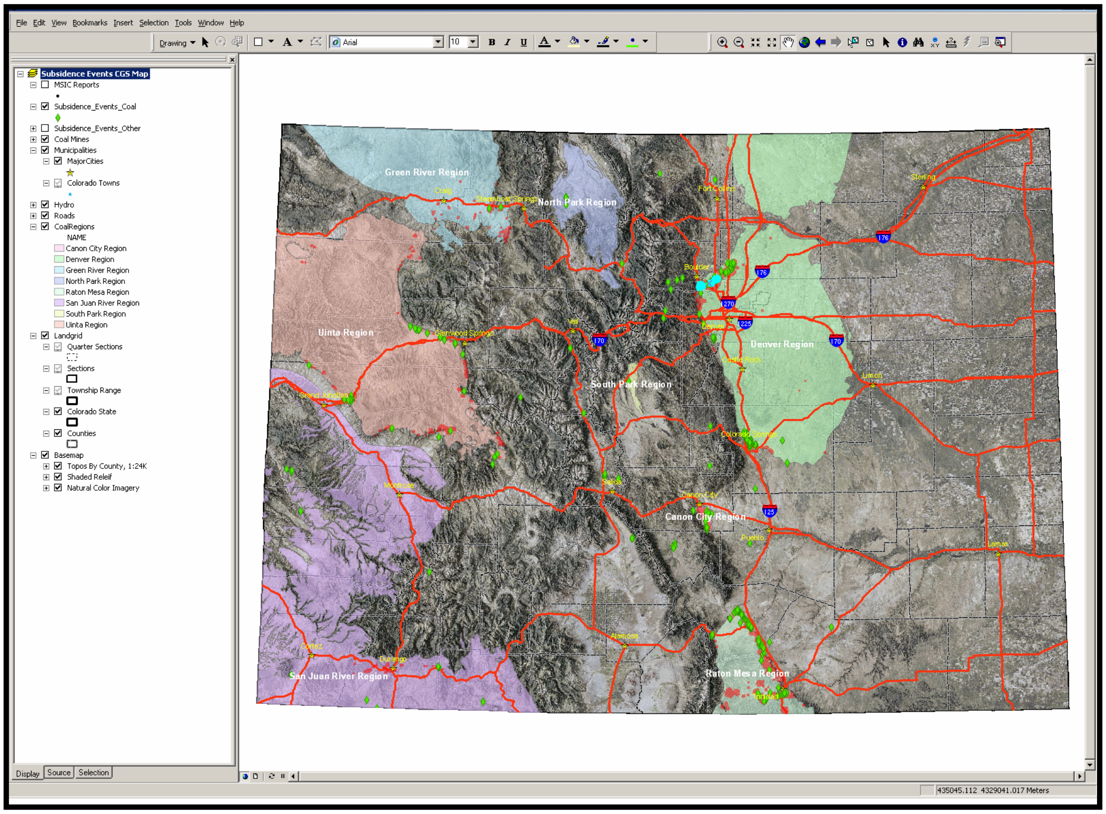

Figure 9: Public mapping interface using ArcGIS 9.3.1. Strickler, 2010.

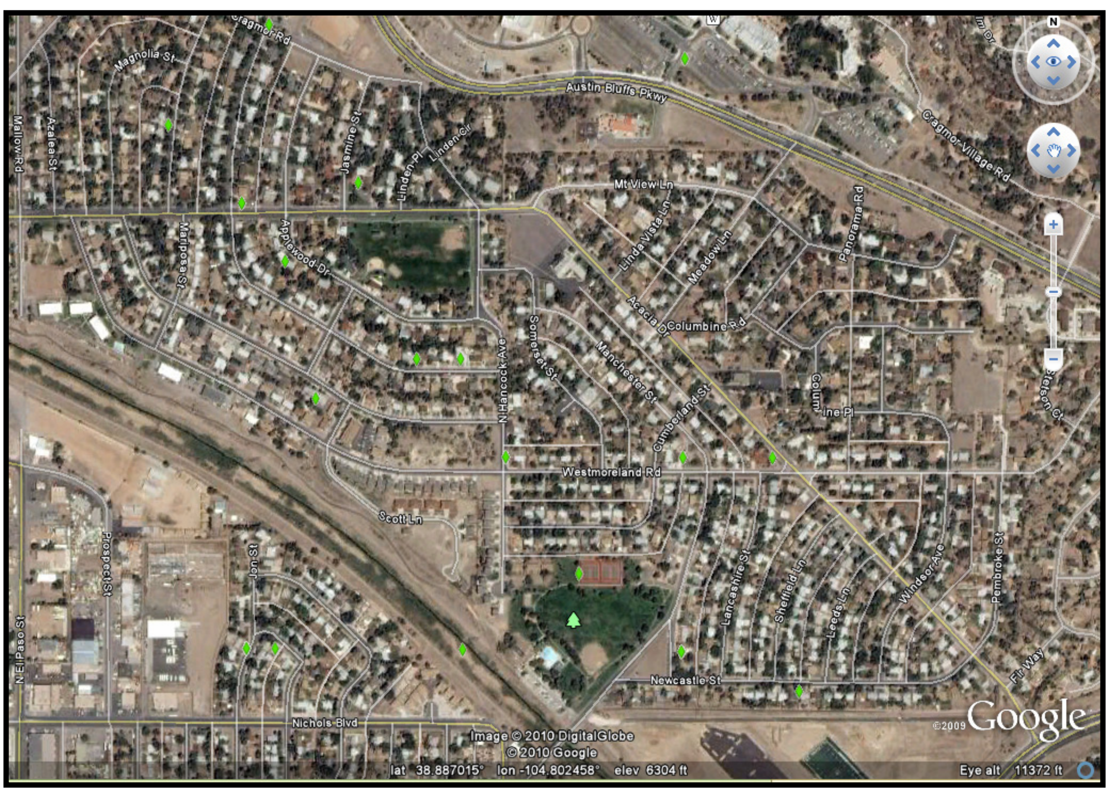

Figure 10: Public mapping interface using Google Earth. Strickler, 2010.

Three internal mapping interfaces were created for the Colorado Geological Survey using ArcGIS 9.3.1: 1) the editing interface (Figure 11), for updating the Subsidence Events feature class, 2) the analysis mapping interface (Figure 12), built with all the functionality and tools of ArcGIS and used to analyze the Subsidence Events and the Undermined Areas feature classes, and 3) the viewing interface, the simplest of the mapping interfaces, designed for general viewing, identifying features, querying, measurements, basic analysis, field maps, and printing (Figure 13).

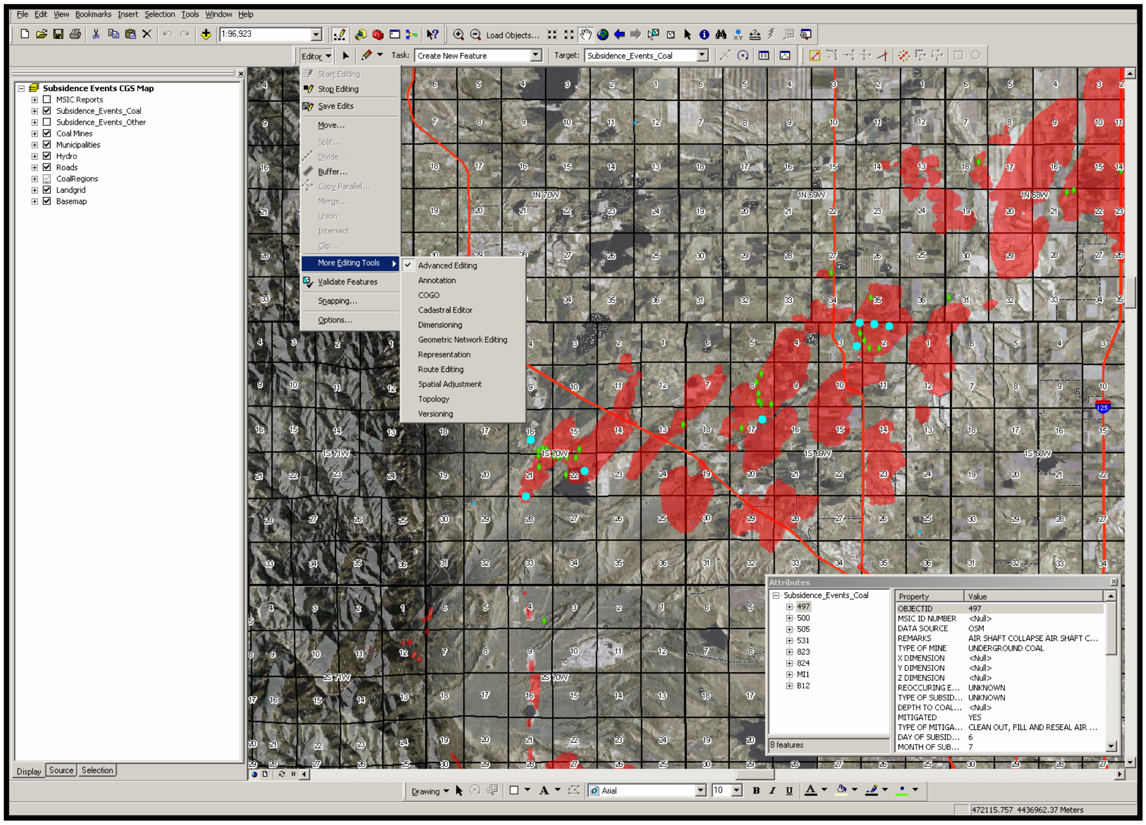

Figure 11: Internal CGS editing mapping interface. Strickler, 2010.

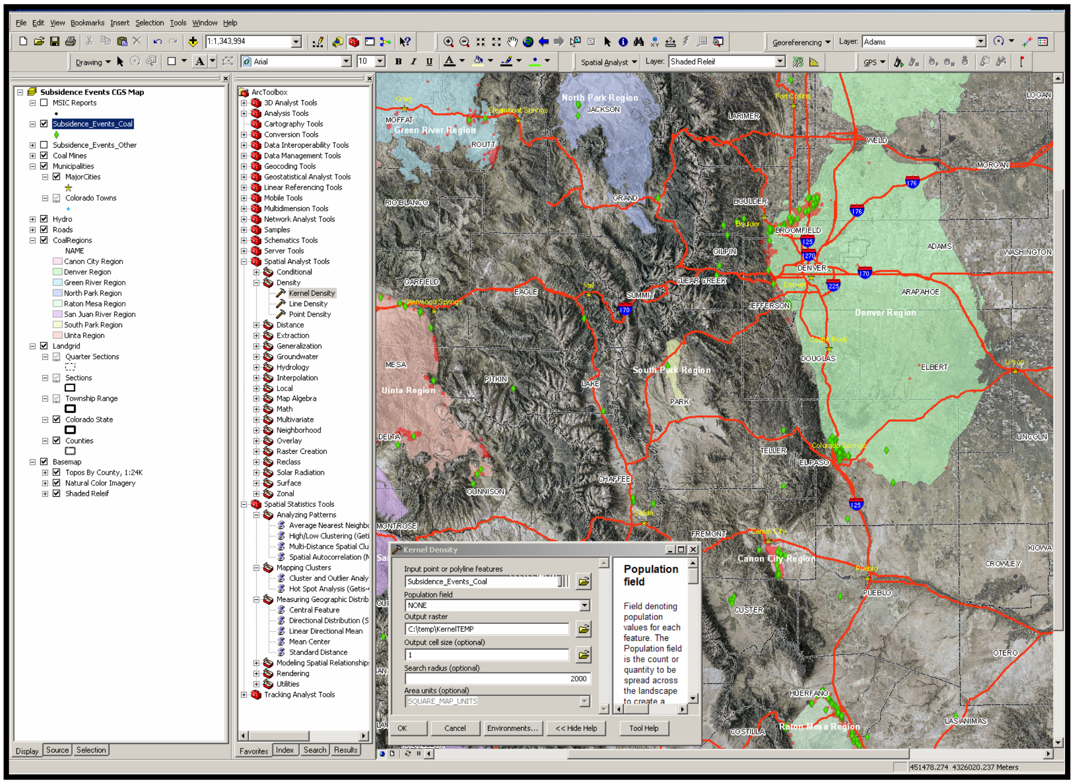

Figure 12: Internal CGS analysis mapping interface. Strickler, 2010.

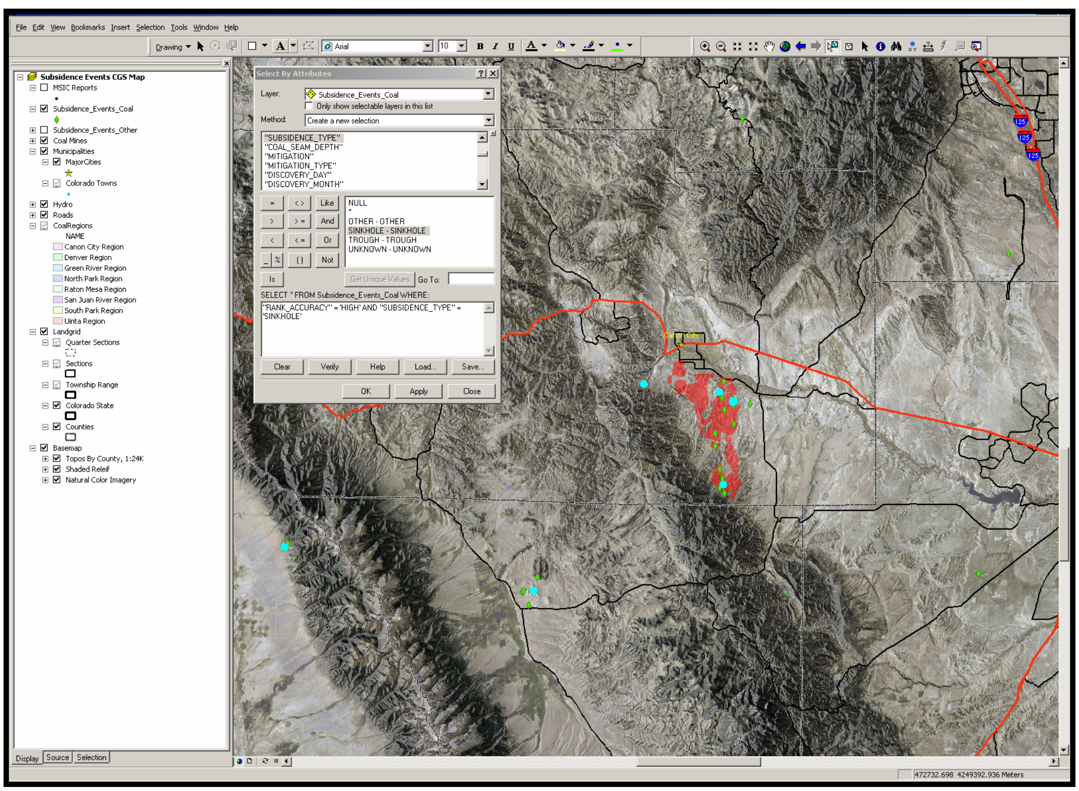

Figure 13: Internal CGS viewing mapping interface. Strickler, 2010.

9.2 Prediction of future subsidence hazards

The primary result for this project was to create a Subsidence Events file geodatabase and a mapping interface to store and analyze coal mine subsidence in the state of Colorado for prediction of future subsidence hazards. The Subsidence Events file geodatabase allows users to rapidly obtain comprehensive coal mine subsidence information, by location or attribute, using a simple GIS. Utilizing the tools of GIS, CGS staff can now use the Subsidence Events file geodatabase to aid city, county, and state developers in urban planning.

An example of one such analysis is shown in Figure 14, where coal mine subsidence events were identified in areas not located above a coal mine. This analysis shows that 209 subsidence events fall within an undermined area; however, it also shows that 266 subsidence events do not fall over an undermined area. Subsidence events that do not fall within a boundary of an underground coal mine are one or more of these possible factor: 1) subsidence event is not in the correct location, 2) subsidence event is not related to an underground coal mine, 3) the mechanics of subsidence can allow for surface subsidence outside mined limits, and 4) further work must be done to delineate coal mine boundaries.

Further updating and editing of the Subsidence Event file geodatabase must be done to ensure that all undermined areas are mapped within the Undermined Areas feature class. Future work for this project will be to use this GIS to view and analyze subsidence events and undermined areas during proposals of urban and rural developments.

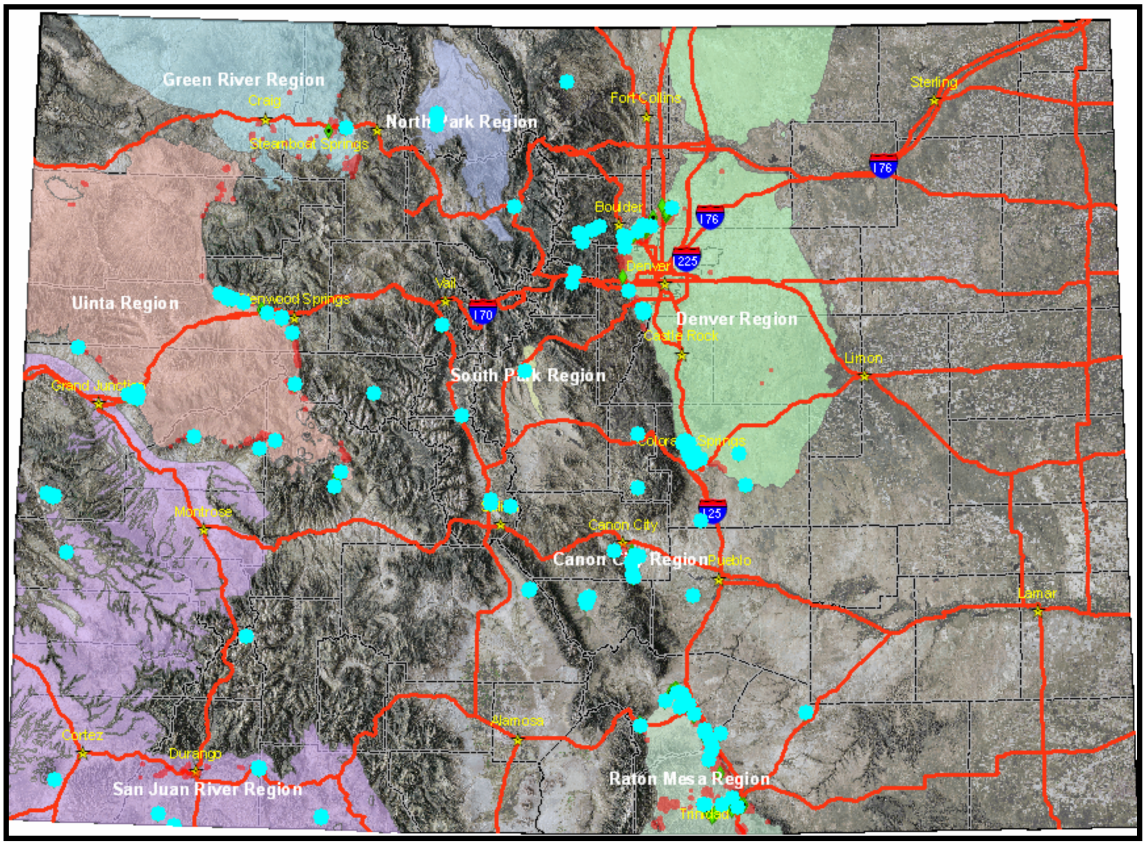

Figure 14: Subsidence events not located over a documented underground coal mine. Strickler, 2010.

10. Summary

A file geodatabase was created in order to catalog the state of Colorado's historic subsidence events for the CGS. After compiling subsidence data from the MSIC, the OSM, and the DRMS, a Subsidence Events file geodatabase was populated with attribute data from spreadsheets, reports, and maps.

Once populated with data, the Subsidence Events file geodatabase was displayed in a user-friendly format so that non-GIS users could easily query subsidence events by location or attribute and subsequently view and export information associated with the particular location. Advanced GIS users at the CGS can use the Subsidence Events file geodatabase for prediction of subsidence hazards and ultimately make recommendations regarding urban planning.

Subsidence events caused by underground coal mines have proved to be both hazardous and expensive for the state of Colorado. The use of the Subsidence Events file geodatabase will not only empower the public to make educated decisions when purchasing a new parcel of property, but it will also enable the state of Colorado to potentially save lives and funds by developing infrastructure in areas without subsidence hazards. Overall, applying GIS tools to the state of Colorado's historic subsidence events will ultimately prove to be a cost-effective and convenient method of solving the complex problem of predicting subsidence hazards.

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12.1 APPENDIX A: Geodatabase schema

Fields	Type	Alias	Allow Null Values	Default Value	Length	Geometry Type	Domain	Domain Type	Domains
OBJECTID	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Shape	Geometry	SHAPE	N/A	N/A	N/A	Point	N/A	N/A	N/A
GLOBALID	Guid	GLOBALID	N/A	N/A	N/A	N/A	N/A	N/A	N/A
MSIC_ID_Number	Text	MSIC ID NUMBER	Yes	No	10	N/A	No	N/A	N/A
SOURCE	Text	DATA SOURCE	Yes	Unknown	20	N/A	Yes	Coded	Unknown, OSM, DRMS, Report, News Article, CGS, Other, Local Government
REMARKS	Text	REMARKS	Yes	No	255	N/A	No	N/A	N/A
MINE_TYPE	Text	TYPE OF MINE	Yes	Underground Coal	10	N/A	Yes	Coded	Underground Coal, Underground Clay, Strip, Unknown, Other, Metal
X_DIMENSION	Short Integer	X DIMENSION	Yes	No	N/A	N/A	No	N/A	N/A
Y_DIMENSION	Short Integer	Y DIMENSION	Yes	No	N/A	N/A	No	N/A	N/A
Z_DIMENSION	Short Integer	Z DIMENSION	Yes	No	N/A	N/A	No	N/A	N/A
REOCURRENCE	Text	REOCURRING EVENT	Yes	No	100	N/A	No	N/A	N/A
SUBSIDENCE_TYPE	Text	TYPE OF SUBSIDENCE	Yes	Unknown	20	N/A	Yes	Coded	Sinkhole, Trough, Other, Chimney, Combination, Entry, Unknown
COAL_SEAM_DEPTH	Short Integer	DEPTH TO COAL SEAM	Yes	Unknown	N/A	N/A	Yes	Coded	0-50, 51-100, 101-150, 151-200, 201-250, 251-300, 301-350, 351-400, 401-500, >500
MITIGATION	Text	MITIGATED	Yes	Unknown	10	N/A	Yes	Coded	Yes, No, Unknown
MITIGATION_TYPE	Text	TYPE OF MITIGATION	Yes	Unknown	60	N/A	No	N/A	N/A
SUBSIDENCE_DATE	Date	DATE OF SUBSIDENCE	Yes	No	N/A	N/A	No	N/A	N/A
DISCOVERY_DATE	Date	DATE OF DISCOVERY	Yes	No	N/A	N/A	No	N/A	N/A
ADDRESS	Text	ADDRESS	Yes	No	40	N/A	No	N/A	N/A
MERIDIAN	Text	MERIDIAN	Yes	Unknown	15	N/A	Yes	Coded	6, Ute, New Mexico, Costilla, Unknown
COUNTY	Text	COUNTY	Yes	Unknown	25	N/A	Yes	Coded	64 Counties, each a coded value
TWN	Short Integer	TOWNSHIP	Yes	No	N/A	N/A	Yes	Range	1-51
TDIR	Text	TOWNSHIP DIRECTION	Yes	No	1	N/A	Yes	Coded	N, S
RNG	Short Integer	RANGE	Yes	No	N/A	N/A	Yes	Range	0-105
RDIR	Text	RANGE DIRECTION	Yes	No	1	N/A	Yes	Coded	W, E
SEC	Short Integer	SECTION	Yes	No	3	N/A	Yes	Range	1-36
QTR10	Text	QTR QTR QTR SECTION	Yes	No	2	N/A	Yes	Coded	NE, NW, SE, SW
QTR40	Text	QTR QTR SECTION	Yes	No	3	N/A	Yes	Coded	NE, NW, SE, SW
QTR160	Text	QTR SECTION	Yes	No	4	N/A	Yes	Coded	NE, NW, SE, SW
LAT	Float	LATITUDE	Yes	No	10	N/A	No	N/A	N/A
LONG	Float	LONGITUDE	Yes	No	10	N/A	No	N/A	N/A
X	Float	X(NAD83UTM13Nmtrs)	Yes	No	10	N/A	No	N/A	N/A
Y	Float	Y(NAD83UTM13Nmtrs)	Yes	No	10	N/A	No	N/A	N/A
GPS_POSITION	Text	CGS VERFIED GPS LOCATION	Yes	No	3	N/A	Yes	Coded	Yes, No, Unknown
RANK_ACCURACY	Text	ACCURACY RANKING FOR LOCATIONS	Yes	Unknown	15	N/A	Yes	Coded	High, Medium, Low
DATA_AVAILABLE	Text	DATA AVAILABLE	Yes	No	50	N/A	No	N/A	N/A
HYPERLINK	Text	HYPERLINK TO SCANNED MSIC	Yes	No	40	N/A	No	N/A	N/A
IMAGES	Raster	SUBSIDENCE IMAGES	Yes	No	N/A	N/A	No	N/A	N/A

12.2 APPENDIX B: Statement of qualifications

Charles Jacob Strickler
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stricklerc@plateaugeospatial.com

Education:

- Masters of Science in GIS. University of Denver, Denver, CO. 2010
- GIS Certificate of Advanced Study. University of Denver, Denver, CO. 2008
- Bachelor of Science Geology. Southern Oregon University, Ashland, OR 2006

Professional:
Colorado Geological Survey
GIS Consultant

- Work Period: 2009-Present
- Build and populate a File Geodatabase for coal mine subsidence
- Write comprehensive metadata
- Construct a GIS mapping interface for internal and external use
- Build workflow tutorials for editing and use of the GIS
- Analytical projects
    - Mapping
    - Hyperlinks
    - Hydrology watershed mapping and analysis
    - Compilation of various geologic maps into a single detailed geologic map with ArcGIS mapping interface

EnCana Oil & Gas (USA) Inc.
GIS Technologist

- Work Period: 2009-Present
- Assist in building of Enterprise GIS
- Basic to detailed knowledge about how SQL Server, ArcSDE, ArcGIS Server, and Flex Builder interact and work with one another.
- Analytical projects
    - Mapping
    - Digitizing
    - Spatial Analyst
    - 3D Analyst
- Field mapping using ArcMobile Technology
- Database Management
- Raster Catalog construction

GeoScience Technician

- Work Period: 2007- 2009
- Geological Field Evaluation (For Sale or Development)
- Small scale GIS construction, management, mapping, analysis, and numerous other spatially related projects.
- Map Making

        - ArcGIS 9.3.1
        - PETRA
        - ER Mapper
        - Global Mapper
    - Data Management
        - Logs
            - Quality Control
            - Uploading & Downloading
            - Normalizing
        - File Room
        - Maps
        - LiDAR Processing & Analysis
    - Created a new PETRA project with a full datum shift.

Oregon Water Resources Department

Assistant Watermaster of Josephine County:

- Work Period: 2005-2006
- This position was broken down into five priorities:
    1) respond to the general public in the office and over the telephone
    2) respond to and handle complaints
    3) Regulate junior water rights users
    4) research water rights
    5) assist co-workers in any field work
- Measuring irrigation ditches and streams for appropriation
- Investigate water rights violations
- Correspondence letters with customers
- Compiled and filed nearly 700 well logs in an updating project
- I assisted in running the stream walker program for several months, repairing broken Aquacalcs (used to measure stream discharge) and meters (AA, Pygmy), assisted with measurement locations, and planned measurement routes
- Helped in the training of the Southwest Regional Hydrographics Technician

Stream walker:

- Work Period: June 2002-October 2002, June 2003-October 2003, June 2004-October 2004, May 2006- September 2006 (~ 5 months/year)
- Organizing and running the stream walker program
- Stream gauging(discharge measurements in cfs) of 62 separate stations
- Self Taught Repair of all measuring equipment including Aquacalc 5000 & Pro

Geologic Field Camp and Field Methods, SOU Ashland, OR:

- Geologic Mapping of Structurally Diverse Areas
    - Faults
    - Geologic units
    - Mélanges
    - Lava flows
    - Sedimentary beds

    - Landslide areas
- Hydrographic analysis of stream discharge loss/gain with relation to geologic units
- Hydrologic budget
- Completed a stratigraphic section
- Mapping of multiple landslides
- Acquired professional note taking skills

Technical Skills:

- ArcGIS, Versions 9.2 and 9.3x
- AutoCAD 2006
- PETRA
- Global Mapper
- ER Mapper
- TNTmips
- ENVI
- PI Dwights
- Adobe Acrobat
- Quattro Pro
- GPS/ both data gathering and manipulation in GIS, Trimble
- Fluent in Microsoft Office suite of software