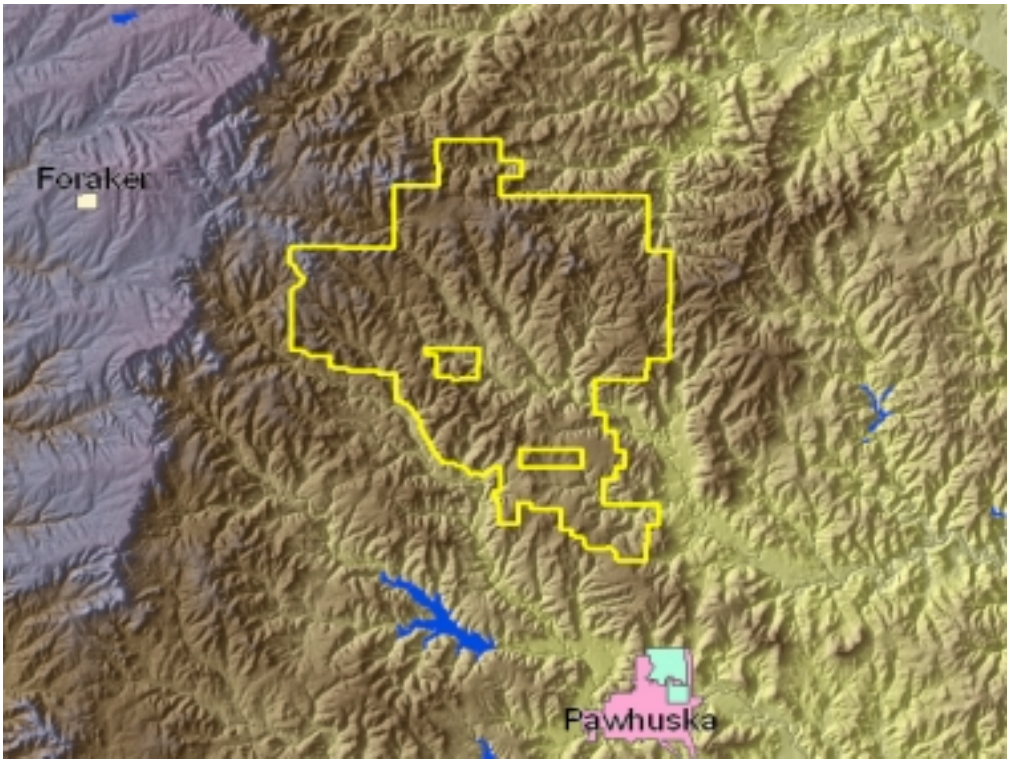
National Petroleum Technology Office

UCRL-ID-142371

Data Collection Protocol for Developing Geographical Information Systems to Investigate and Manage Ecological Impacts at Petroleum Exploration and Production Sites



January 2001

Funding Provided by
The U.S. Department of Energy
National Energy Technology Laboratory
National Petroleum Technology Office

Lawrence Livermore National Laboratory
Oak Ridge National Laboratory

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Data Collection Protocol for Developing Geographical Information Systems to Investigate and Manage Ecological Impacts at Petroleum Exploration and Production Sites

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Funding Provided by
The U.S. Department of Energy
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DISCLAIMER

This work was partially performed under the auspices of the U. S. Department of Energy by the University of California, Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48, and by Oak Ridge National Laboratory under contract DE-AC05-00OR222725 with Batelle, LLC.

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1. Introduction

In the past decade, concern over the impacts of contaminants in the environment to ecological receptors has increased. State and federal agencies are increasingly requiring ecological risk assessments (ERAs) to estimate such impacts. These ERAs can be complex, relying on overly conservative assumptions to extrapolate laboratory toxicity data to field sites and often consider areas that are too small to be ecologically relevant. Through the operation of upland exploration and production (E&P) sites, the petroleum industry has thousands of sites which may be impacted by the release of petroleum-related products (primarily petroleum compounds and brine fields) to various degrees. Many of these sites will also be undergoing closure in the near future. Due to their remote location, it is possible that ecological receptors, not human health, will drive the risk at these sites. Conducting traditional ERAs and any subsequent cleanup/site restoration could be quite costly industry-wide. These costs would be particularly burdensome to small, independent operators who do not typically have substantial resources. And such efforts may actually be unnecessary, as many areas impacted by petroleum-related products within E&P sites are small and localized within the context of a larger site. Conducting ecotoxicologically-based ERAs at each of these isolated, impacted areas may provide a misleading estimate of the true impact on populations and communities at larger, more ecologically meaningful scales.

Therefore, Lawrence Livermore National Laboratory (LLNL) and Oak Ridge National Laboratory (ORNL), are engaged in a project to create tools and techniques for evaluating ecological impacts at E&P sites from a larger landscape or ecosystem perspective. We have identified the creation of a geographical information system (GIS) for E&P sites as one of the first steps necessary in evaluating a site from a landscape perspective. In this document, we outline the steps and data necessary to create such a GIS. This is done through considering an example site, the Tallgrass Prairie Preserve (TPP) in northeastern Oklahoma. We discuss the necessary coverages and layers required in a GIS, and identify sources for these data, including publicly available sources as well as site specific sources.

2. Web Site and Geographic Information System

2.1. Purpose

To support the development of an ecological framework for E&P sites, a web-based GIS that will serve to organize and integrate numerous data sets from E&P sites is desirable. In this document we describe our work to date in developing protocols to: 1) acquire data, 2) assess its scope, quality, accuracy, precision, and applicability, 3) establish spatial data in a common projection system, 4) associate tabular data with spatial locations where useful, 5) preprocess or correct data as needed, and 6) maintain the data for the research consortium for use in models, analyses, presentations, and publications, as needed. This document will be revised as protocols are developed in greater detail.

We are using the Tall Grass Prairie Preserve (TGPP) in northeastern Oklahoma as the example site for the GIS development. The approach and data types used to build the GIS will

be applicable to any site in which it is desired to investigate impacts at higher levels of ecological organization.

2.2. Architecture

The GIS should be accessible using browsers available for most of the existing platforms to facilitate multiple users. Currently this includes Netscape 4.7 or higher or Internet Explorer 4.0 or higher. Depending on the E&P site, the web site may restrict access to authorized users. For our ecological framework development, general users access the web site with links to a general description of the framework project, the project sponsors, partners, collaborating research institutions, descriptions the study site(s) used to develop the framework, and supporting text references and reports. Authorized users have access to the population and community models and the GIS internet map server (ArcIMS™) that presents general maps and other graphic output, model results, and ad hoc maps to web clients for displaying data or results, and other data pertaining to the specific site. The GIS data layers are designed to meet a variety of scales required for detailed assessment of the site. Figure 1 shows details of the architecture being developed for the ecological framework project and the Tallgrass Prairie site.

For the ecological framework project, we are using ArcIMS™, ESRI's newest Internet Map Service software. ArcIMS™ has a number of features that make it especially suitable for use in a GIS for an E&P site that may require access by multiple users. It offers browser-based access to data served over the Internet and available on the client's local machine for query, analysis, and display. It allows initiation of custom applications such as the ecological models many E&P sites may use. The map services published by ArcIMS can be used outside the browser environment by local users of ArcView and ArcINFO 8.1 and ArcExplorer (free **JAVA viewer**).

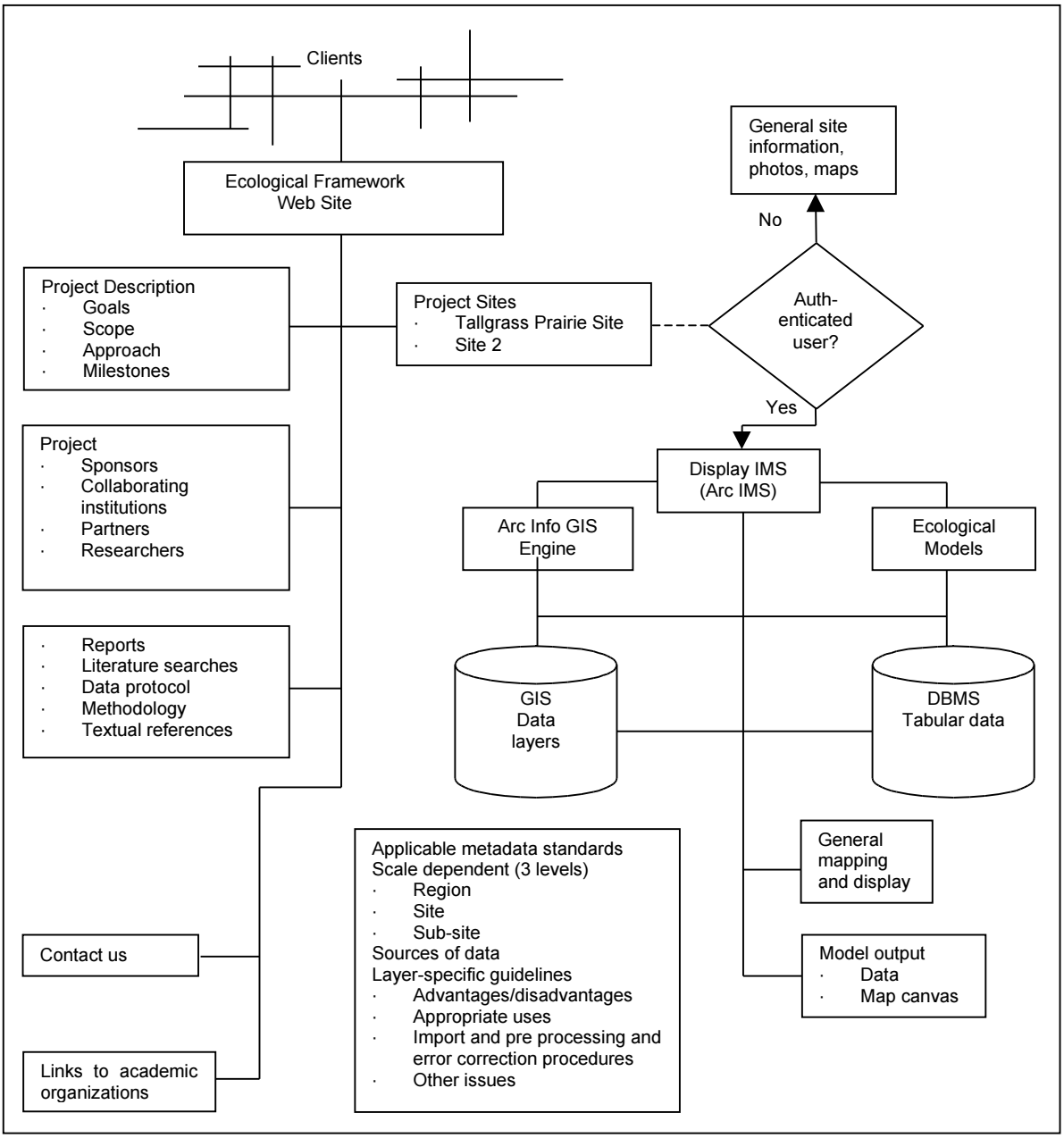

Fig 1. Ecological Framework Web site and GIS Architecture

2.3. Software, Hardware, and Server Architecture

The ecological framework web site will be hosted at LLNL and will be accessible to all authenticated project sponsors, partners, and collaborating researchers through any standard browser from either a Mac or PC platform. This web site will be established in the second quarter of FY 2001. In addition to the usual NT/WN2000 operating system, it will have the latest release of Arc IMS™ and the primary GIS analytical "engine," Arc INFO™ and associated modules. This software is recommended for use in developing GIS for large E&P sites. As development proceeds, we will make decisions such as the actual IMS, what platform and operating system environment to use, firewall provisions, password access, and other configuration issues, such as the choice of ASP, Java or html web server. Some of these requirements are unique to the LLNL environment, but similar considerations will be required for most web-accessible GIS of E&P sites. This document will be revised once these decisions are finalized.

3. Data Required for an E&P Site GIS

For the ecological framework project, ORNL and LLNL GIS teams are collaborating on the web-based GIS development and deployment as well as the data acquisition, quality assurance, and preprocessing of the data. Data are critical to the evaluation of E&P sites at the landscape or ecosystem scale, and a considerable proportion of our project resources are devoted to its acquisition, evaluation, processing, storage and delivery, analysis, and presentation in graph, tabular, and map form. It will also be the case for any E&P site wishing to construct a GIS that the greatest expenditure of resources (i.e., time) will be spent acquiring and processing the data with which to populate the GIS.

3.1. Data Layers

We are in the process of acquiring the data sets shown in Table 1 for the Tallgrass Prairie site in Northern Oklahoma to support the development of the ecological framework. The table is organized by data layers recommended for any E&P site in which landscape level analysis is desired, as well as by additional layers that may be useful depending on the specific site. The data layers we are developing for the TGPP are good examples of the data types required for any E&P site.

Table 1. Required data layers and sources.

Required data layers	**Sources**
Site boundary	Site-specific: For TGPP from U. of Tulsa
E&P features (wells, pipelines, drilling platforms, buildings, fences, spill sites (oil and brine)	Site-specific: For TGPP from U. of Tulsa
Cultural features (roads [paved, dirt, gravel], populated places, power lines, public facilities and buildings, etc.)	ArcData online, National Atlas of the United States
Animal dens, populations, and migration routes	Site-specific: Point data samples from surveys and field observations
Satellite or aerial imagery	Landsat MSS, NDVI, AVIRIS
Soils	STATSGO
Land use	USGS Land Use Land Cover
Vegetation	USGS DLGs
Topography	USGS 30-m DEM; 10- DEM available
Hypsography	USGS 100K DLG Contours; Digital Atlas of Oklahoma, USGS Open-File Rpt 97-23
Hydrology	ArcData online, National Atlas of the United States
Meteorological data	NOAA
Slope	
Aspect	
State, federal, and school district administrative boundaries, 100k and 250k topo, shaded-relief image; USGS stream gage locations; watershed boundaries; weather station locations; census block group boundaries and selected data; elevation contours (corrected); elevation points; geographic names; roads, streets, address ranges; streams, rivers, lakes; public land survey system	HUCS; Digital Atlas of Oklahoma, USGS Open-File Rpt 97-23; ArcData online, National Atlas of the United States
Digital Ortho Quads	Site-specific: For TGPP from U. of Tulsa
Other useful site dependent data layers	*Sources*
Census block group data	ArcData online, National Atlas of the United States
Fire history	Site-specific, site manager
Flood history	Site-specific
Other data	*Sources*
Drilling results: Oil, Gas or Dry; Number of wells and producers; Stratigraphic Intervals Tested; Decade of Oldest Drilling; Decade of Oldest Production	USGS 1995 National Oil and Gas Assessment by 40-acre cell
Chemical point data samples	Site-specific surveys and field observations
Other terrain data	Digital Terrain Elevation Data (DTED) 70 meter data

3.2. Data format

For the ecological framework, a combination of raster and vector data will be used in the GIS to support ecological modeling. These data types, and their utility, is described below. Most E&P sites will likely require a combination of these two data types.

Raster

- Raster models divide the entire study area into a regular grid of cells in a specific sequence. The strength of a grid cell-based model is its analytical capability using grid algebra or map algebra. Each cell contains a value describing a specific location on earth. The cells are organized into rows and columns, the grid, which can represent either continuous data, such as population density, elevation value, or scanned images, or the grid can contain categorical data such as soil type or land use.

Vector

- Vector data uses discrete line segments or points to identify locations such as boundaries, roads, or streams and represents shapes accurately. A boundary, stream, or road can only be generalized and are less accurate in a grid. Vector data models are preferable for analyzing topological relationships (adjacency and connectedness).

3.3. Data Projection

A projection is a mathematical model that transforms the locations of features on the Earth's surface to locations on a two-dimensional surface. Because the Earth is three-dimensional, some method must be used to depict a map in two dimensions. Some projections preserve shape, others preserve accuracy of area, distance, or direction. However, any representation is a tradeoff that preserves one and distorts the other three parameters of the Earth's surface. Some projects are more suited to regional areas, some to areas oriented East-West, others to smaller areas. For the ecological framework project, the data are currently in Albers Equal-Area Projection. However, we are considering either UTM or state plane projection as the best suited for the size of area and type of modeling planned.

3.4. Data Precision

Precision refers to the number of significant digits used to store numbers, and in particular, coordinate values. Double precision should be used when available and single precision otherwise. The data precision should be identified in the metadata.

3.5. Data Resolution

Resolution is the accuracy at which a given map scale can depict the location and shape of geographic features. The larger the map scale, the higher the possible resolution. Resolution also refers to the distance between sample points in a lattice or the number of points in x and y in a grid or lattice. For most E&P sites, there will be the need to use data that varies in resolution. For regional information smaller scale maps can be used, where as for site or sub-site area higher resolution and more accurate representation of features is required.

Digital Elevation Models (DEMs) are distributed in two common scales. Thirty-meter DEMs (also known as 7.5 minute or 1:24,000 DEMs) cover the extent of a standard 7.5 minute, 1:24,000 USGS quad sheet. The nominal grid cell sampling resolution is 30 meters. Two hundred-fifty K DEMs (also known as "three second" or "three arc second" DEMs) cover the extent of a standard 1^{o}, 1:250,000 USGS quad sheet. The nominal grid cell sampling resolution is three arc seconds, a distance of about 90 meters. The use of one versus the other depends on the application. One-to-twenty-four thousand DEMs cover a smaller area of the earth's surface and have a correspondingly higher degree of accuracy and resolution than the 250K DEMs. They are generally preferred for modeling and analytical applications on a local or semi-regional scale such as the PERF-99 modeling. Many E&P sites, like the Tallgrass Prairie, will be larger than a single quad sheet, consequently it will be necessary to mosaic adjoining DEMs together into a single, larger DEM. For the Tallgrass Prairie, thirty-two adjoining DEMs were combined. At some point, the output DEM becomes too large to be practical, and the use of the 250K DEM may be necessary. The 250K DEM, although it has lower accuracy and resolution than the 24K DEM, is useful for regional modeling applications, and they are excellent cartographic tools for producing
three-dimensional vicinity maps to show local study areas within their broader, regional context. They can also be useful as an overlay tool for producing perspective photographic drapes.

One-to-twenty-four thousand DEMs are available in three different levels of accuracy and resolution: 30 meter, level 1; 30 meter, level 2; and 10 meter, level 2. Level 2 data are collected with different methods than level 1 and are generally both more accurate and of higher visual resolution than level 1. Thirty-meter coverage is available for the coterminous US. Ten-meter 24K DEM coverage is relatively rare.

USGS Digital Orthophoto Quarter Quads (DOQQs) are georeferenced, fully orthorectified, digital aerial photography. Each dataset represents one-quarter of a 24K quad sheet. Because the effects of rotation, tilt and terrain relief have been removed they can be used directly for feature digitization and GIS data layer updating. They are extremely useful as an overlay for verifying, revising, and supplementing the information content of DLGs, DRGs, and DEMs. They are also an invaluable tool in the field as an aid to environmental mapping. The imagery has a native resolution of 1 meter.

The STATSGO (State Soil Geographic) DataBase provides coverage of the coterminous U.S. at a scale of 1:250,000. The minimum area of delineation is approximately 625 hectares (1,544 acres), which is represented on a 1:250,000-scale map by an area approximately 1 cm by 1 cm (0.4 inch by 0.4 inch). Typically, there are 100 to 200 delineations per 1:250,000-scale quadrangle, but these numbers may increase up to 400 delineations per quadrangle. Delineations depict the dominant soils that make up the landscape. STATSGO data are relatively coarse. Some sites may be able to acquire a county-level soils database, SSURGO, which provides much finer-grained detail. There may be even higher resolution soils data available in certain areas.

For most E&P sites, 30-meter DEM data are useful for site characterization, general topography, large watershed basins, slope, and aspect analyses. They are less useful for accurately describing sub-water shed basins. They are difficult to edit. Some locales contain significant single-cell errors and an effect referred to as "handing." Banding is also introduced during production and is difficult to remove without severely smoothing the relief.

Another source of hypsographic data is either the 10-meter DEM or custom 10- to 20-meter DEMs calculated from either 100K or 24K scale hypsography.

3.6. Data Preprocessing

Lee (1996) and Wechsler (1999) address some issues relating to the accuracy and applicability of DEMs for hydrologic calculations and modeling. We have elected to use DLGs as the source of information on which to base calculations of sub-watershed basins and runoff estimates. The raw USGS DLG data contain errors in contour values. If corrected hypsography data are not available, a procedure we developed to correct contour data is given in Appendix 1 should this or similar processing be necessary for other data sets

3.7. Metadata

For the ecological framework project, the datasets will be stored in a fixed-directory structure and entered into ArcCatalog™, an ArcInfo™ module designed to organize geospatial information. ArcCatalog™ has a metadata menu that contains a special editor stylesheet to assist users in creating data documentation that conforms to Federal Geographic Data Committee (FGDC) document *Content Standard for Digital Geospatial Metadata*, available at http://www.fgdc.gov/metadata/contstan.html. The FGDC metadata standard is mandated by Executive Order 12906, "Coordinating Geographic Data Acquisition and Access: The National Spatial Data Infrastructure," signed in April 1994 by President Clinton, to be used by all federal, state, and local government agencies that receive federal funds to create GIS metadata. Use of the FGDC metadata standards will gradually create data consistency and facilitate data searches and data sharing. Thus, we recommend its use in any E&P site GIS. FGDC metadata documentation is organized into seven primary sections: Identification, Data Quality, Spatial data organization, Spatial reference, Entity and attribute, Distribution, and Metadata Reference. In addition, three supplemental sections are defined: Citation information, Time period information, and Contact information. The Arc Catalog™ FGDC metadata stylesheet corresponds to these sections. Additional documentation of the ESRI metadata stylesheets can be found at www.esri.com/metadata. A more detailed description of the metadata key words and Arc Catalog metadata stylesheet can be found in Appendix 2, which shows screen captures of the metadata menus.

3.8. Data Quality Assurance

Consensus definitions of spatial data quality for most E&P site data will not well developed. Different data themes can be expected to require different methods for assessing spatial data quality.

In processing and displaying digital data, we often recognize and treat features differently based on the relative importance or uncertainty associated with various spatial characteristics.

When creating a GIS for an E&P site, attempts should be made to use data whose lineage, spatial resolution, and accuracy characteristics are well known. Errors can be corrected where necessary. When deciding to devote time and resources to error correction, the effects of greater accuracy on the results of any anticipated ecological modeling or evaluation should be one of the guiding criteria. An example of a quality assurance and error correction process we have developed and applied to contour data is discussed in the appendix. For example, for the

ecological framework project, we are seeking the most recent and corrected data at the appropriate scale to support our anticipated modeling effort.

4. Possible Data Structures

It may be desirable to capture detailed information for certain locations besides just a spatial representation on a landscape. This could include plant or wildlife species attributes, or attributes associated with soil or water chemistry.

4.1. Biological Data

For species attributes, a detailed database system exists which was first developed by The Nature Conservancy and called "The Heritage Methodology." The database was further developed by the California Department of Fish and Game's Natural Heritage Division, and subsequently called the California Natural Diversity Database (CNDDB) (http://www.dfg.ca.gov/whdab/cnddb.htm). This database system offers a GIS-ready structure for organizing biological information for large areas such as many E&P sites. The basic system is an ArcInfo-7.1.2-readable dataset that makes extensive use of the ESRI ArcInfo region feature class.

The CNDDB model allows an element occurrence portrayed in a geographic information system to be represented by a spatial feature with areal extent, as opposed to a point or line. To accurately depict the complex biological situations inherent in the Natural Heritage element occurrence model these features are:

- Capable of overlapping with other features without loss of unique identity.
- Capable of containing voids or "doughnut holes."
- Capable of representing complex situations containing several spatial components, or parts, while still being considered a single occurrence.
- Capable of simultaneously representing the location of several element occurrences which share the same geographic location.

The CNDDB system is implemented in software called Rarefind 2. As used by the California of Fish and Game, it currently contains over 33,000 records on more than 3,000 of California's rare native plants, animals, and natural communities in a convenient, searchable database. Offering all textual data associated with the California Department of Fish and Game's Natural Diversity Database, RareFind 2 can either be used as a stand-alone research tool or linked with the GIS application ArcView for even greater flexibility.

The CNDDB data are organized geographically and taxonomically. Information can be retrieved by taxa or by United States Geological Survey (USGS) map sheet (1:24,000, 1:62,500, 1:100,000 or 1:250,000 scale).

The system includes a very detailed set of data fields and codes a sample report shows the level of detail the system is designed for.

Developers of E&P sites GIS should consider Rarefind and whether it offers advantages that are worth the complexity, effort, and cost as compared with simpler approaches to support landscape-level ecological evaluations.

4.2. Chemical Data

For the storage of chemistry data associated with environmental samples, several location-based relational databases are available. For example, LLNL Environmental Restoration Division is developing a location-based chemistry database for environmental data for the Army based on our in-house database developed and used for environmental cleanup activities. As with Rarefind, developers of E&P sites GIS should evaluate whether compiling detailed environmental chemistry data offers advantages that are worth the complexity, effort, and cost as compared with simpler approaches to support landscape-level ecological evaluations. If a location-based chemistry database already exists for an E&P site, it should be linked to the site GIS.

5. Database Management

Microsoft Access can be used to manage general data not archived in ArcCatalog™ or other databases. We will be using this data base management system (DBMS) in our ecological framework project. We recommended its use for other E&P sites because it is flexible and easy to work with, is compatible with ArcInfo, and is adequate for the size and number of datasets typically used at most E&P sites. A more elaborate DBMS, such as Informix or Oracle, should only be considered if smaller systems have inadequate capacity.

6. Acknowledgments

The authors would like to thank Pat O'Brien and Sara McMillen of Chevron, and other members of the PERF 99-01 team for intellectual support and discussions while developing our project to investigate the role of size and distribution of remediation sites in exploration and production facilities. The authors would also like to thank Nancy Comstock of the Department of Energy's National Petroleum Technology Office for financial support through the Natural Gas and Oil Technology Partnership Program.

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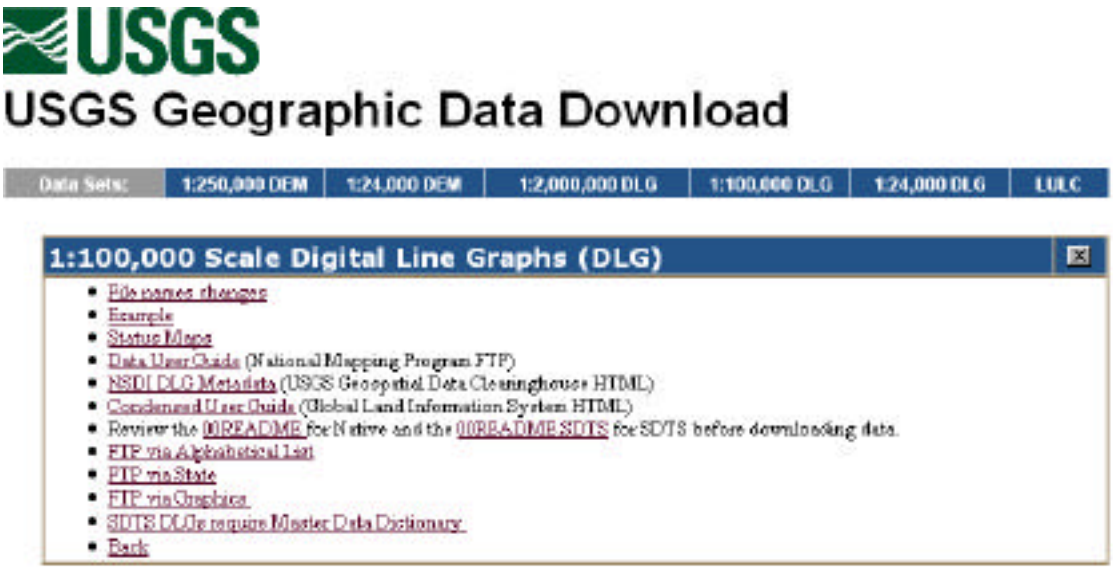
Appendix 1
Data Preprocessing on DLG Elevation Values

Appendix 1
Data Preprocessing to Correct Errors in DLG Elevation Values

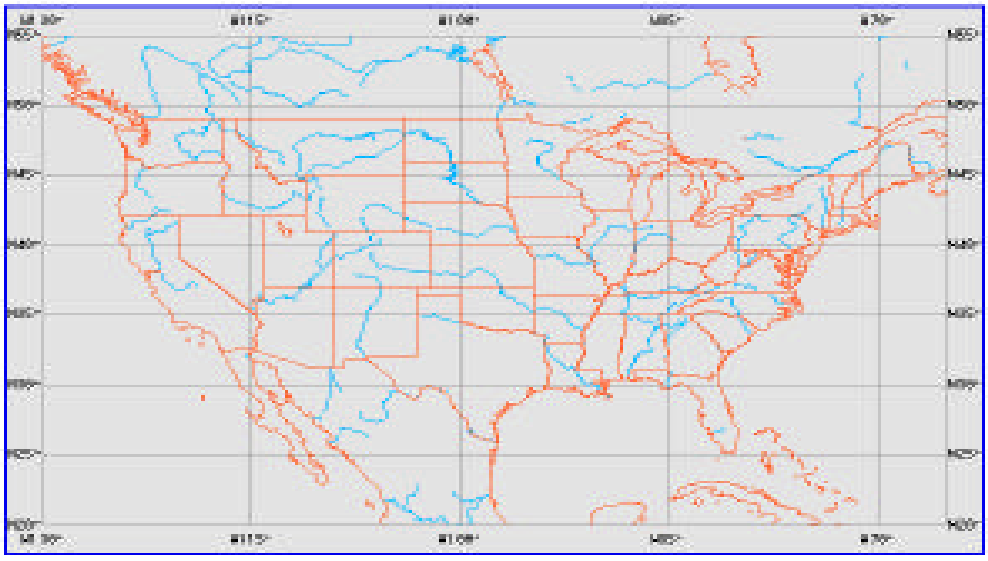
The following assumes that the user has access to ArcToolbox, ArcInfo and the Internet. This is a set of procedures we have used to correct elevation errors on USGS DLGs.

Digital Line Graph:

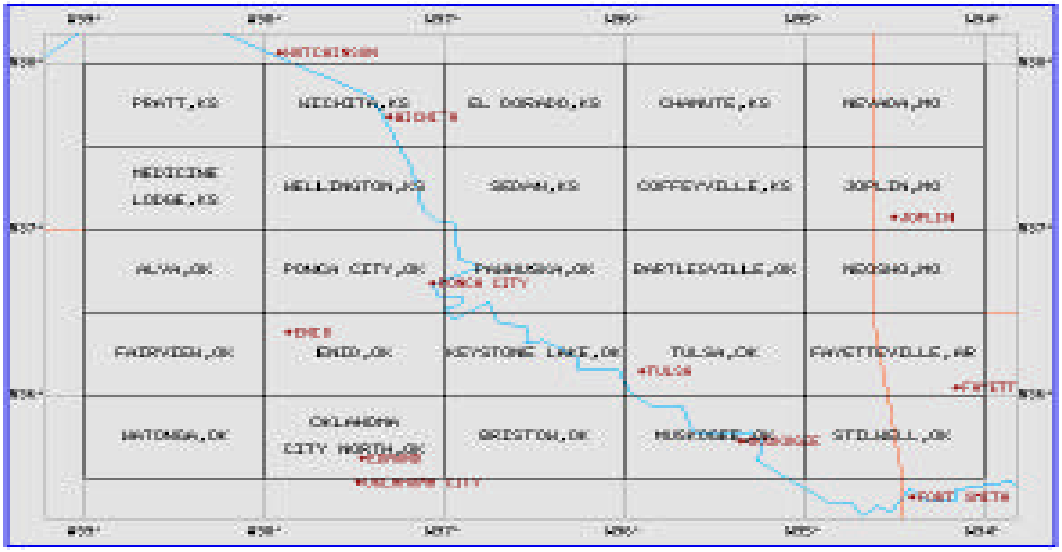
In this case, we will be processing the 1:100,000 DLG's from the USGS website http://edcwww.cr.usgs.gov/doc/edchome/ndcdb/ndcdb.html



Begin by selecting 1:100,000 DLG – FTP via Graphics and a map of the United States displays.



Point to your area of interest or site to select a map to access the data for that area.



The next screen will show you two FTP files for the area, an east and west that represents half of the 1:100,000 quad.

USGS

1:100,000-scale Digital Line Graph Data for N36.28 W98.40

The DLG files listed below are named after the 1:100,000-scale quadrangles that fall within the region you selected. The "e" or "w" appended at the end of each file represents the east or west half of the quad.

These files are sent with a MIME type of application/x-gzip. Please set your browser accordingly.

For more information about the DLG Data Set see the Digital Line Graph GLIS User Guide.

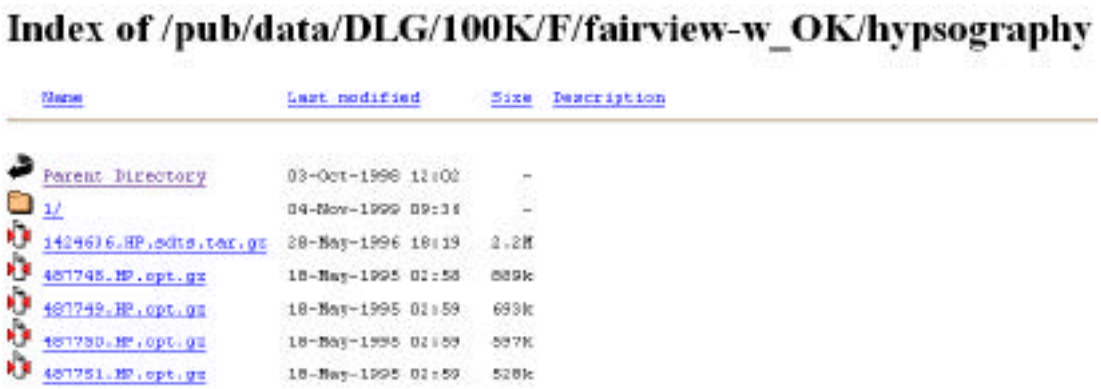
- FAIRVIEW.OK.Esg
- FAIRVIEW.OK.West

The following screens list the files that are available for the area. Select Hypsography.

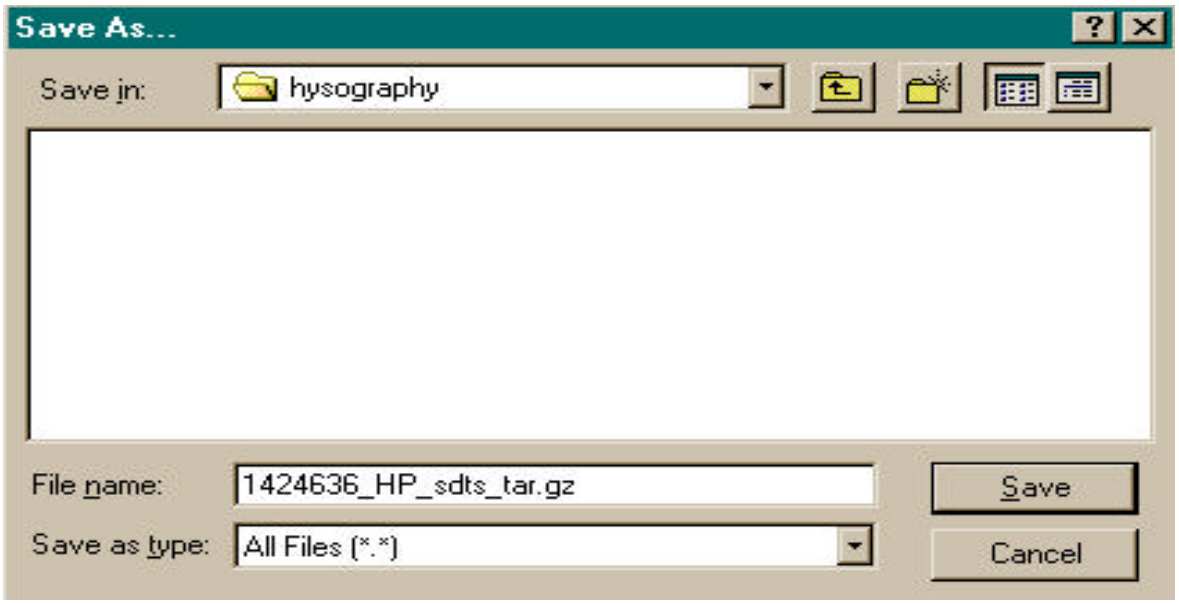
Index of /pub/data/DLG/100K/F/fairview-w_OK

Name	Last modified	Size	Description
Parent Directory	05-Nov-1999 15:48	-	
boundaries/	04-Nov-1999 09:36	-	
hydrography/	04-Nov-1999 09:36	-	
hypsography/	04-Nov-1999 09:36	-	
public_lands/	04-Nov-1999 09:36	-	
transportation/	04-Nov-1999 09:36	-	

Then select the SDTS (Spatial Data Transfer Standard).



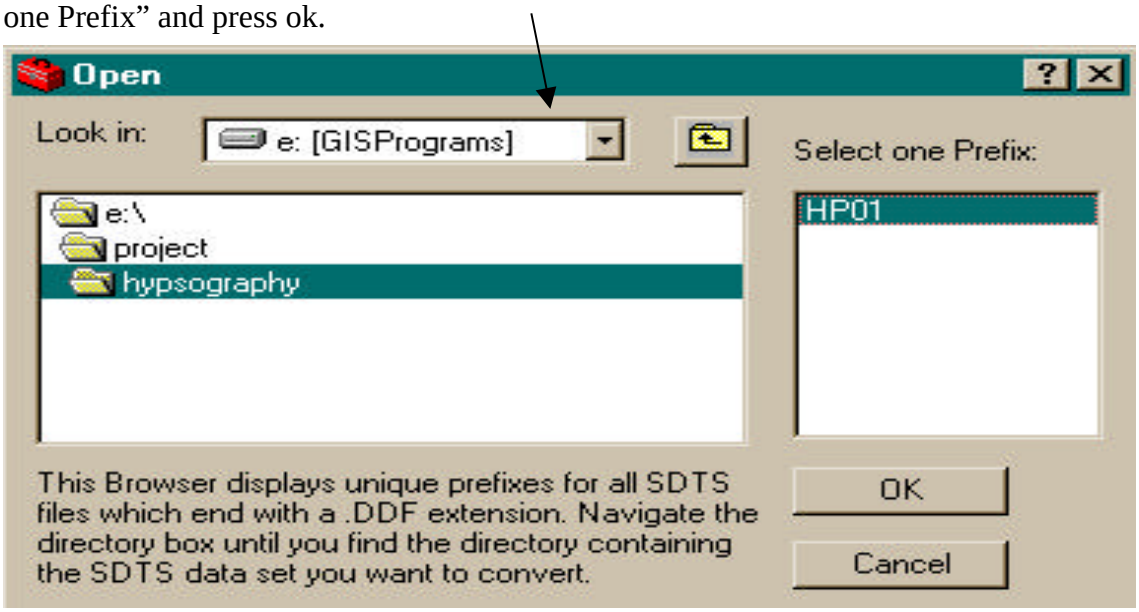
Save the file in a folder that has already been created for the project.



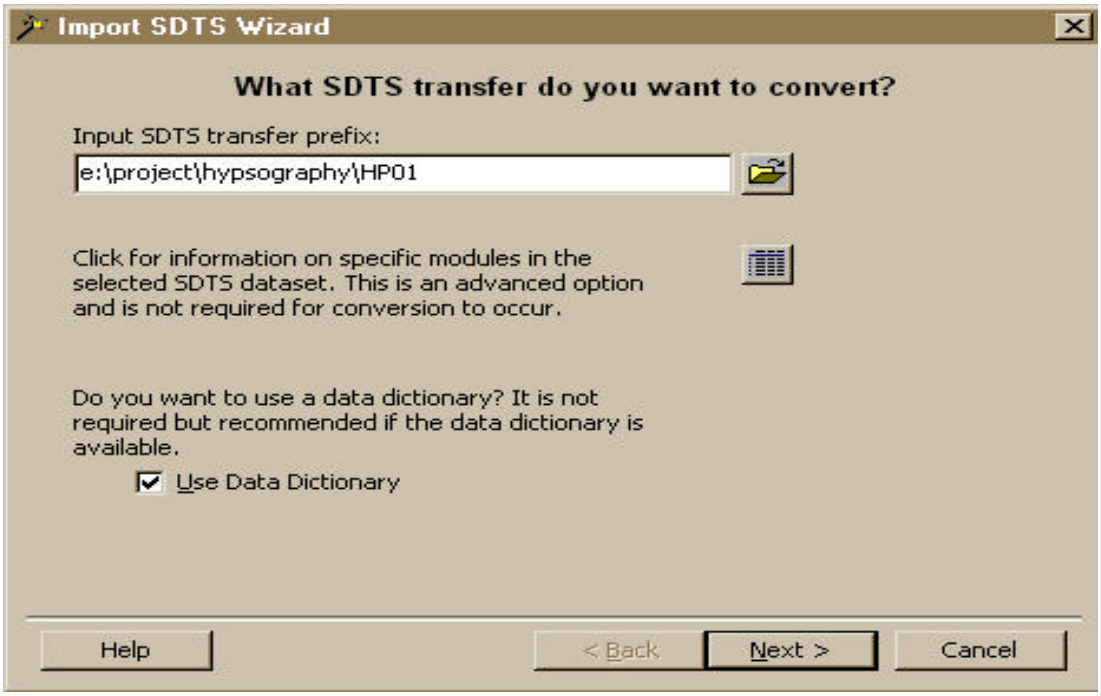
Open your Korn shell and navigate to the folder you just saved and “untar” the file

Open ArcToolbox. Select Conversion Tools. Select SDTS to Coverage Wizard.

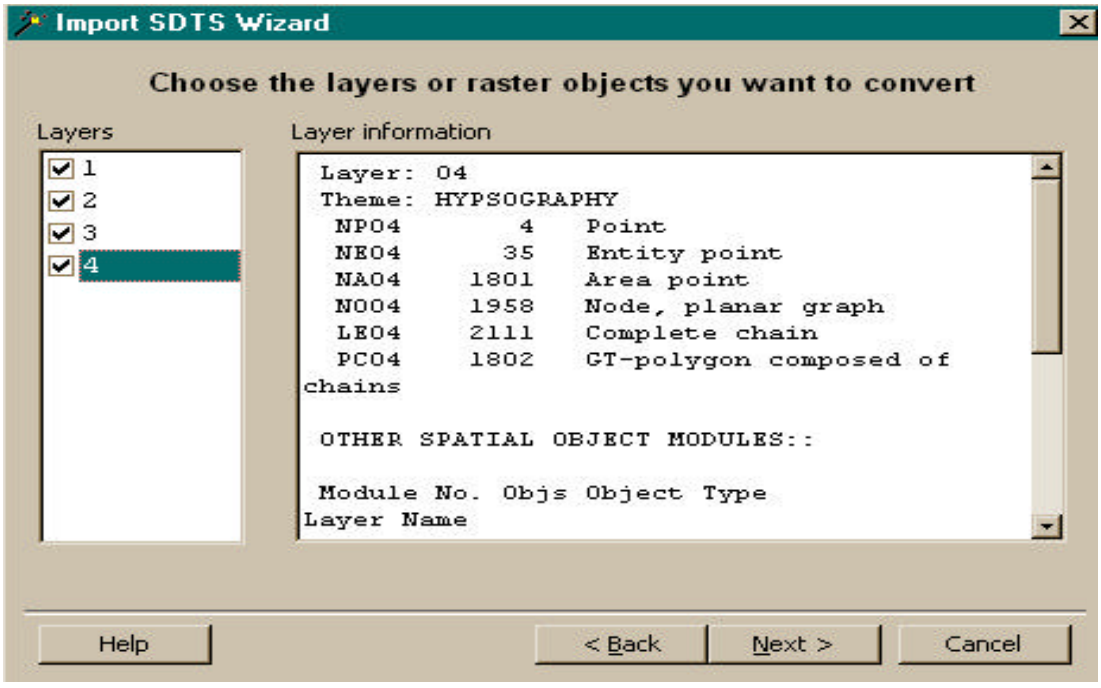
In the window that opens, navigate to the folder where you put the file. Highlight "Select one Prefix" and press ok.



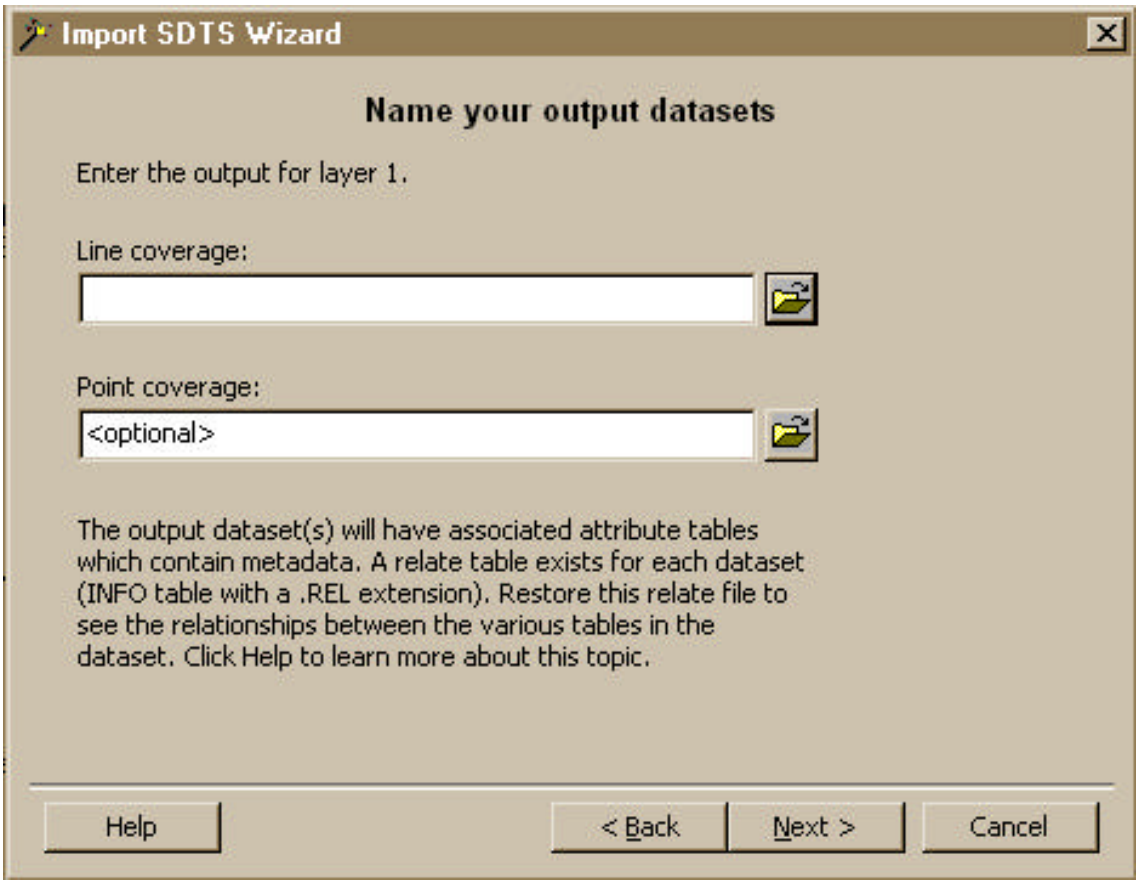
Navigate to where the data is stored to get the input file and select next.



Select all four layers by clicking on all of them. Select next.



Name all of your coverages. You will have four of them.



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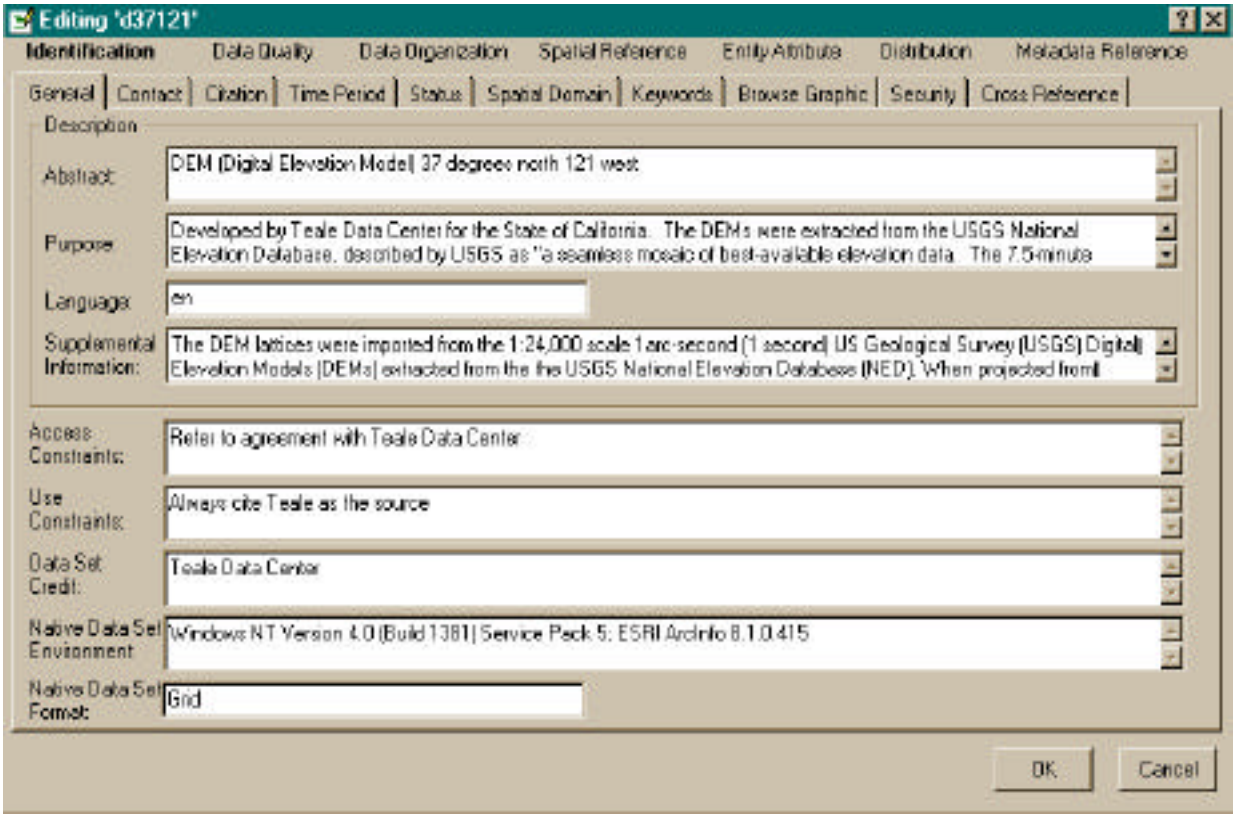
Appendix 2
Arc Catalog™ Metadata Key Words and Style Sheet

Appendix 2

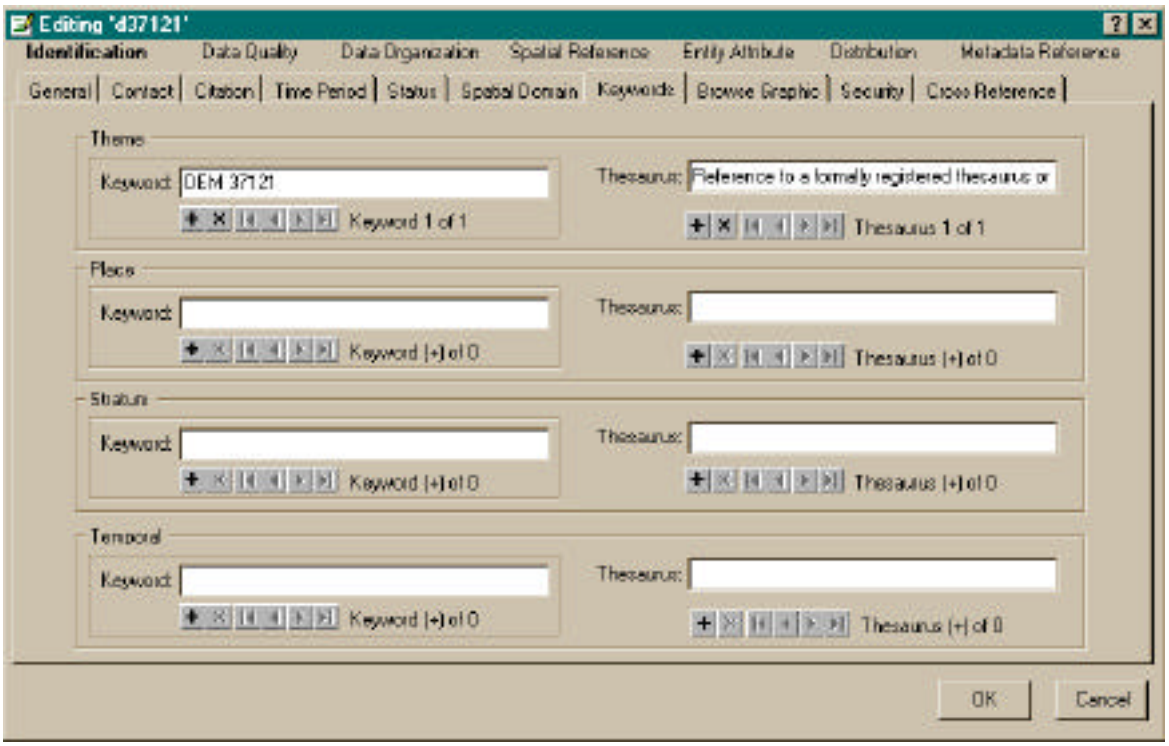
Arc Catalog™ Metadata Key Words and Style Sheet

The FGDC-compliant metadata style sheet in Arc Catalog has a menu-driven interface that greatly simplifies the complex requirements of the standards and includes certain ESRI developed features included in the metadata stylesheet while remaining FGDC compliant. The Arc Catalog metadata stylesheet has numerous tabs and is illustrated in the following images:

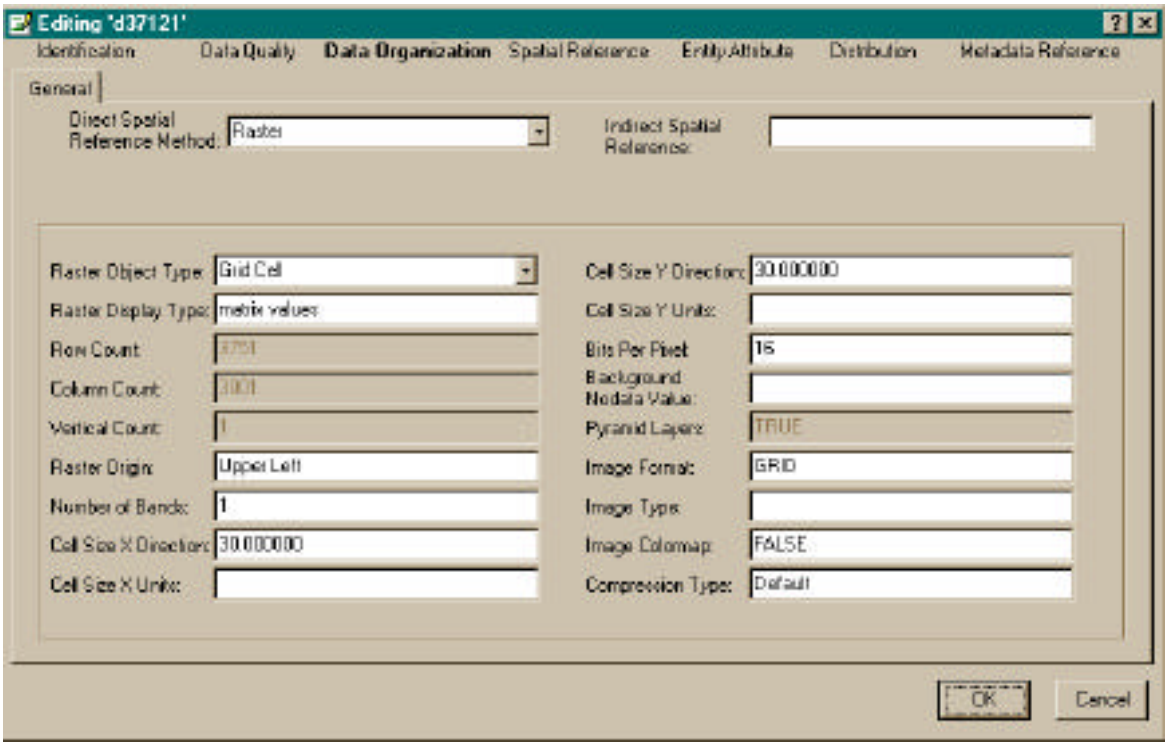
There is a general description section covering items shown in the Identification tab.



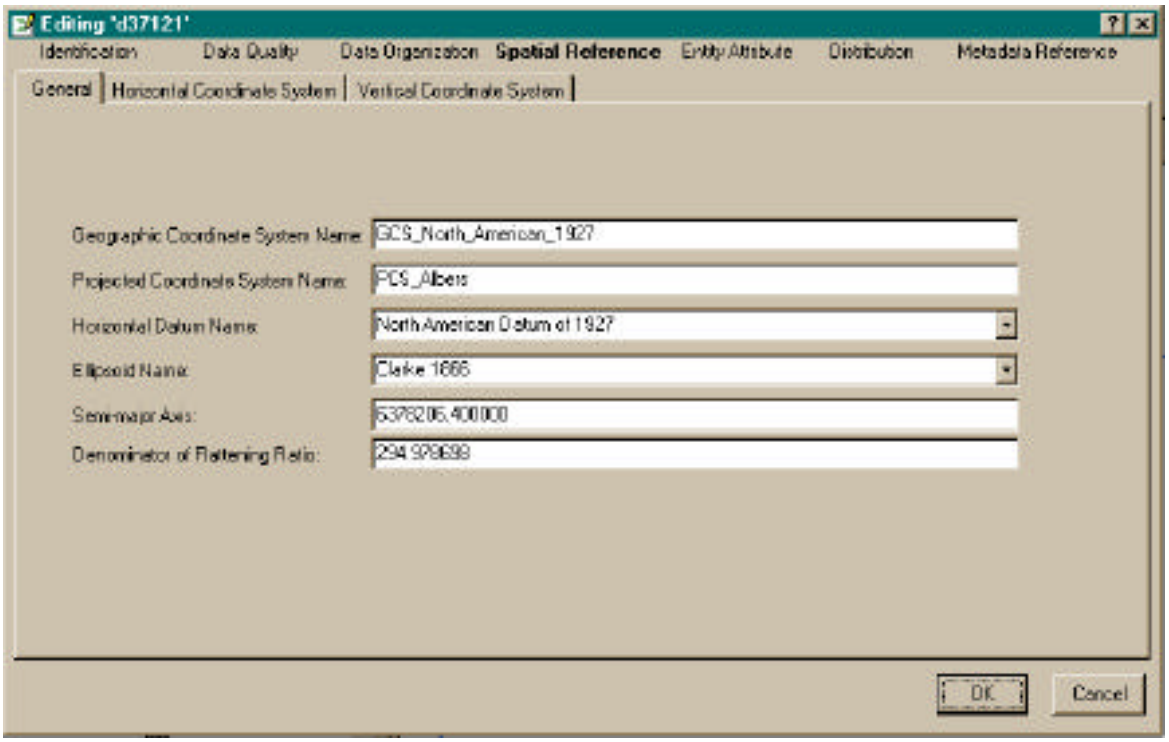
The Keywords tab can accept keywords by theme, location, stratum, or time.



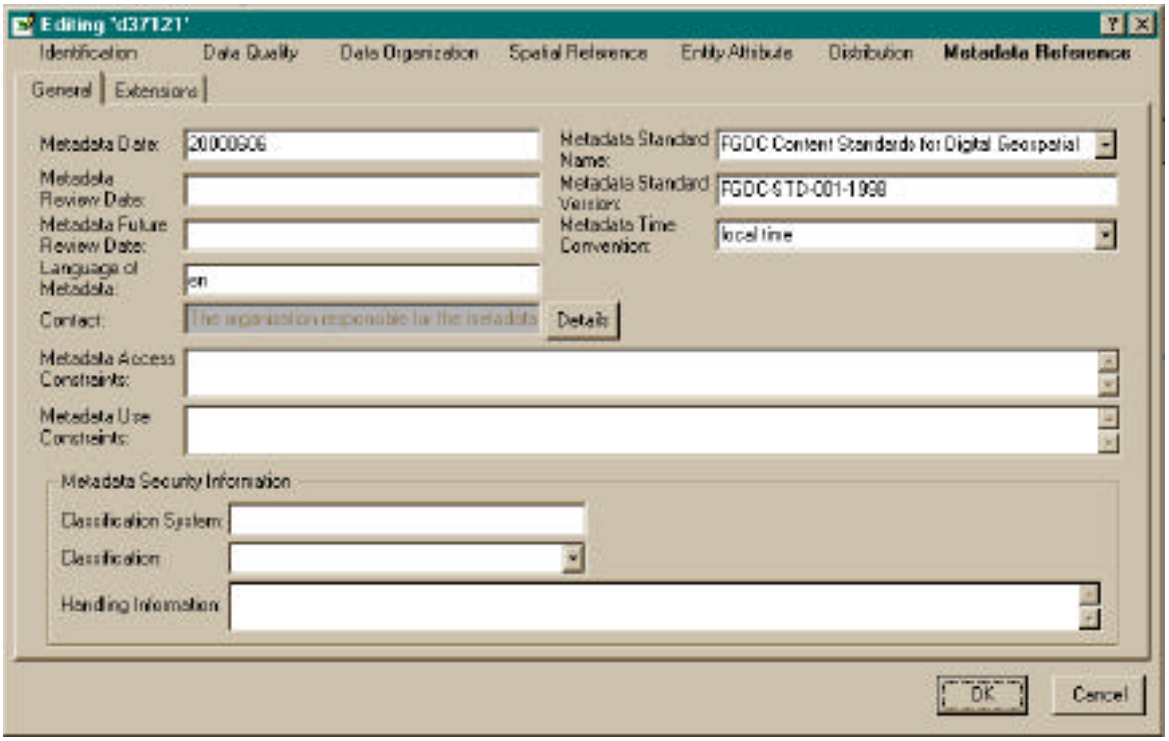
The Data Organization menu receives information describing the type of data, origin cell, cell size, and other details describing the data type.



Information describing the coordinate and projection systems is entered in the Spatial Reference tab.



Information describing the metadata itself is entered in the Metadata Reference tab.

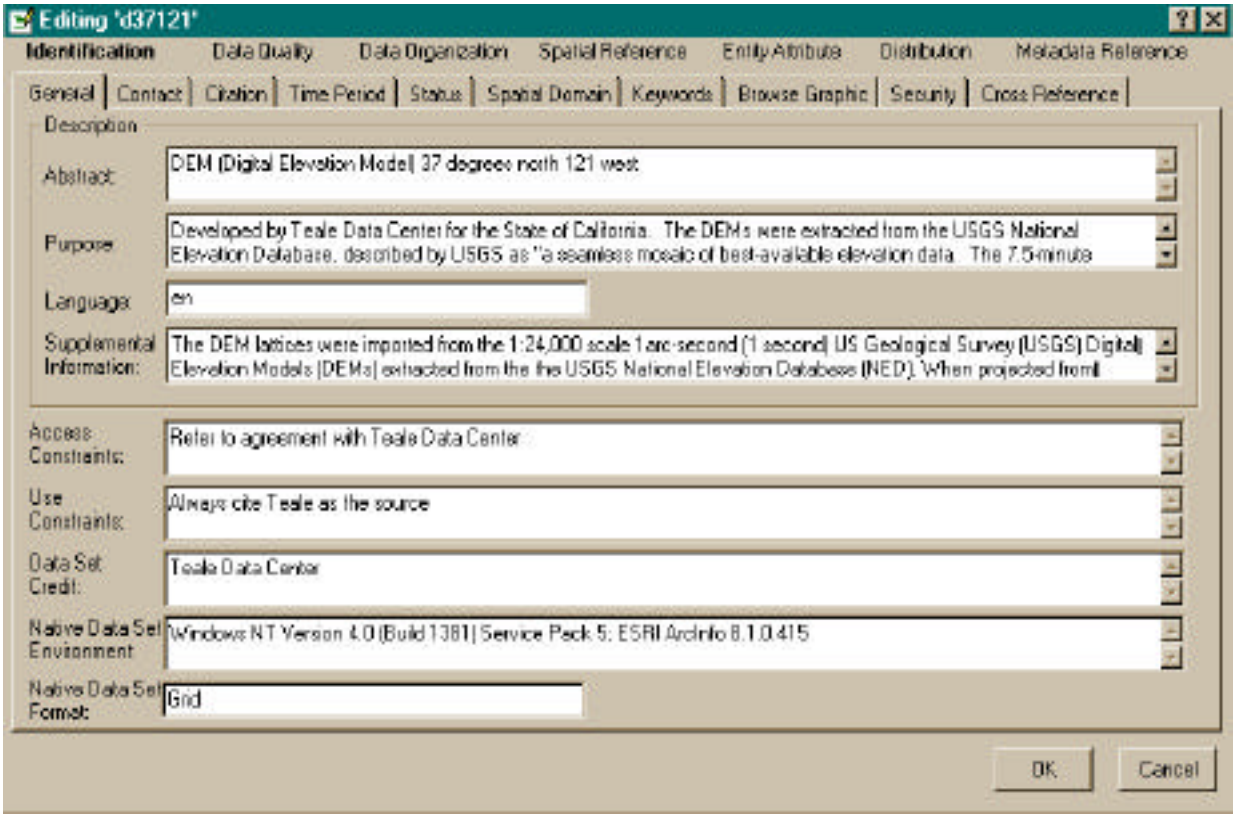


Appendix 2

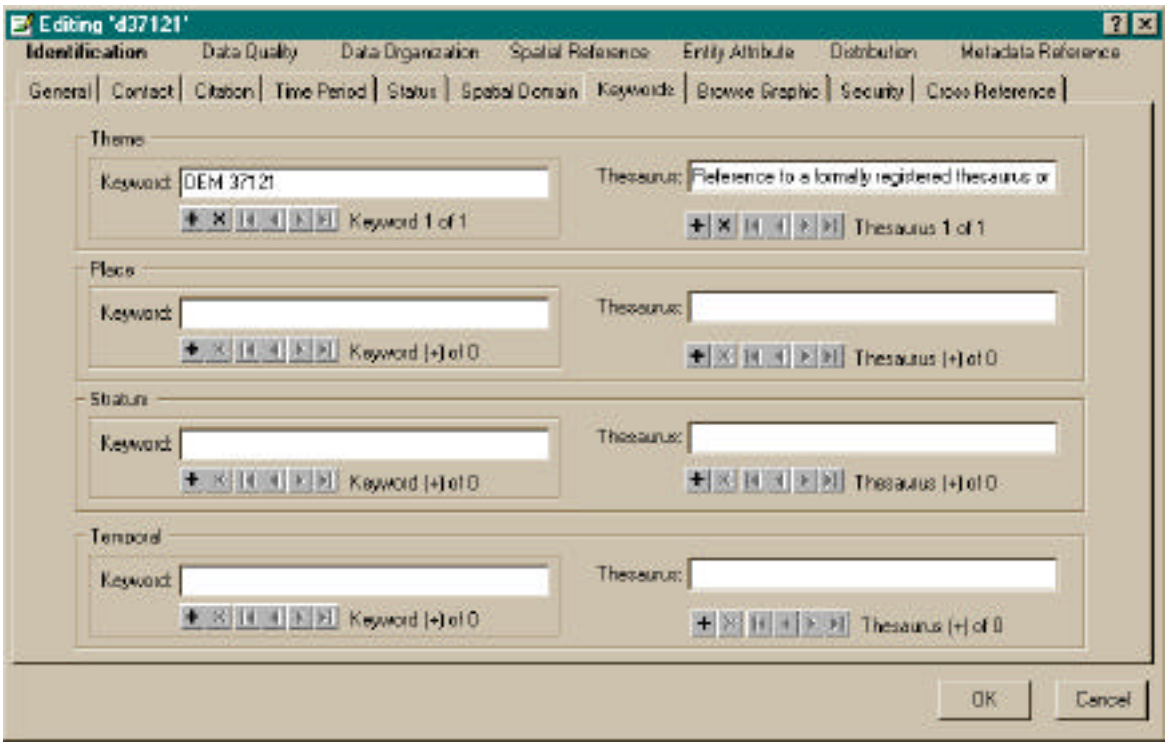
Arc Catalog™ Metadata Key Words and Style Sheet

The FGDC-compliant metadata style sheet in Arc Catalog has a menu-driven interface that greatly simplifies the complex requirements of the standards and includes certain ESRI developed features included in the metadata stylesheet while remaining FGDC compliant. The Arc Catalog metadata stylesheet has numerous tabs and is illustrated in the following images:

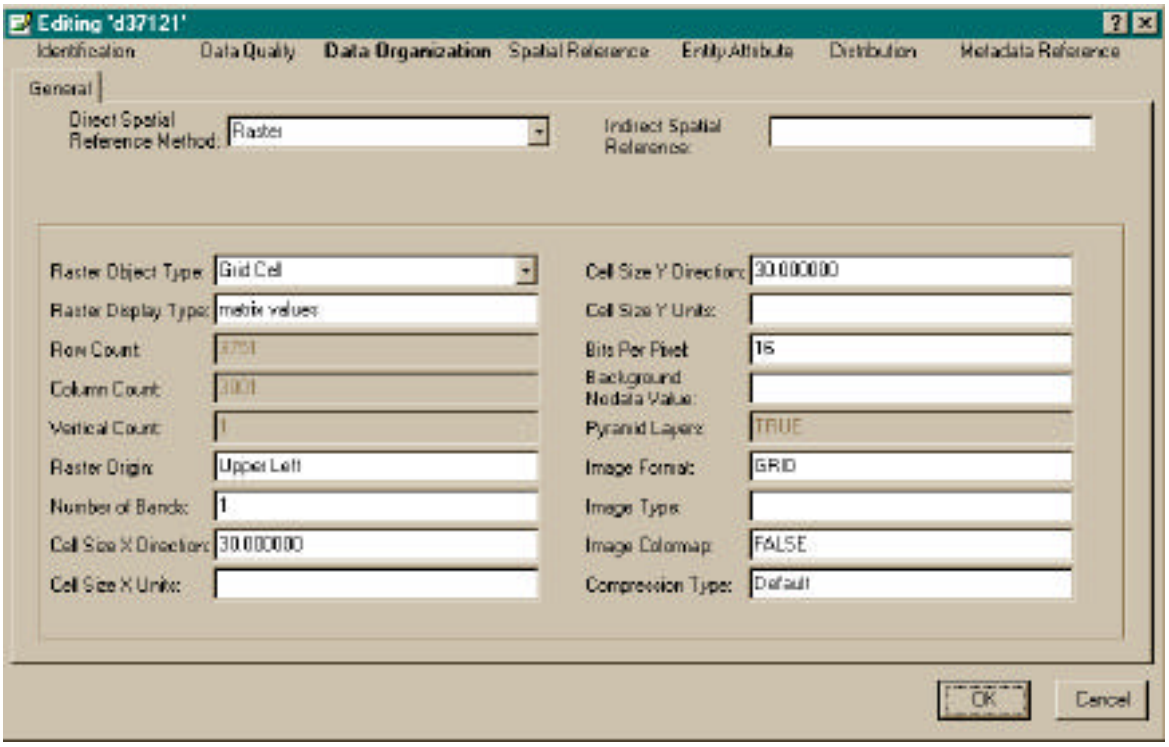
There is a general description section covering items shown in the Identification tab.



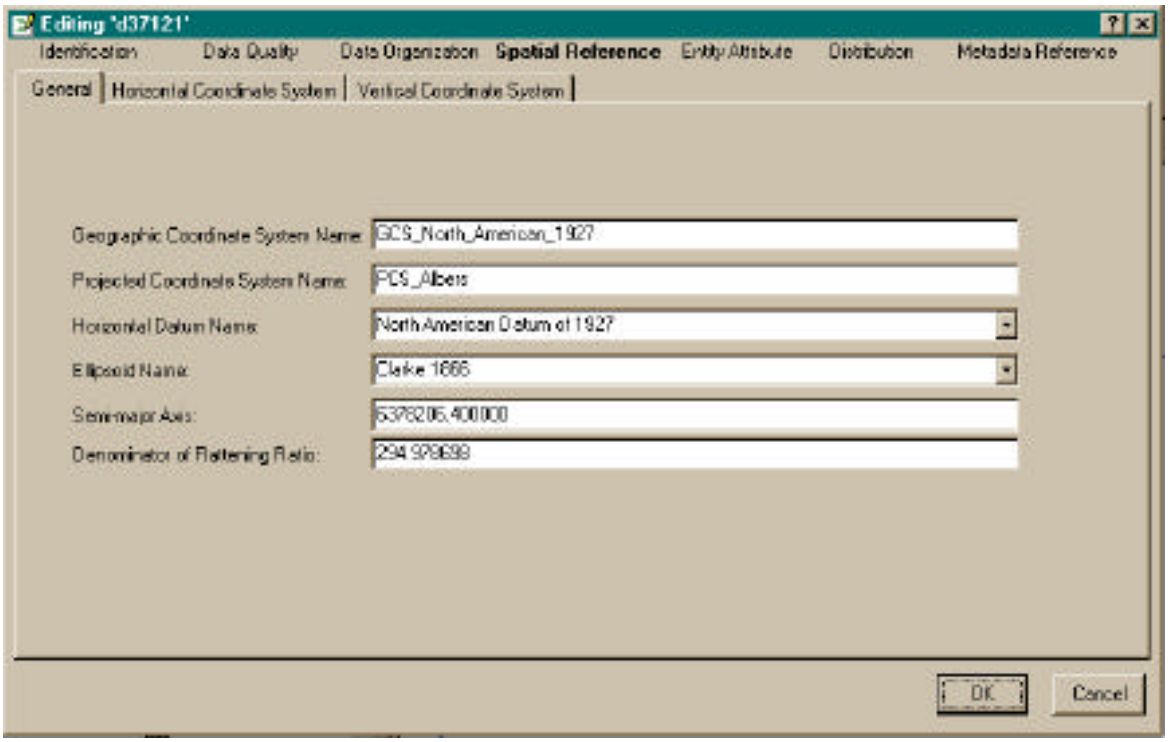
The Keywords tab can accept keywords by theme, location, stratum, or time.



The Data Organization menu receives information describing the type of data, origin cell, cell size, and other details describing the data type.



Information describing the coordinate and projection systems is entered in the Spatial Reference tab.



Information describing the metadata itself is entered in the Metadata Reference tab.