

**Use of Geographic Information Systems and Relational Databases for
Resource Management: Design and Implementation of an
ArcView/Access Application for Groundwater Management**

by

Robert Paul Czaja

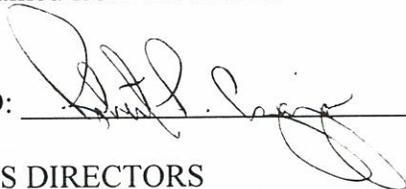
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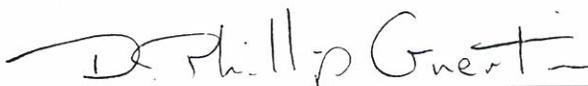
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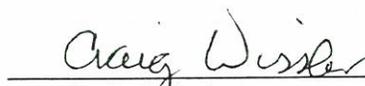
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LIST OF ABBREVIATIONS

1NF	First Normal Form
2NF	Second Normal Form
3NF	Third Normal Form
AML	Arc Macro Language
BLM	Bureau of Land Management
CLNAWS	China Lake Naval Air Weapons Station
COGO	Coordinate Geometry
DEM	Digital Elevation Model
DOQQ	Digital Orthographic Quarter Quadrangle
DRG	Digital Raster Graphic
DSN	Data Source Name
DXF	Digital Exchange Format
ESRI	Environmental Systems Research Institute
FGDC	Federal Geographic Data Committee
GIS	Geographic Information System
GMS	Groundwater Modeling System
GPS	Global Positioning System
GUI	Graphical User Interface
HTML	Hypertext Markup Language
IWV	Indian Wells Valley
MCL	Maximum Contaminant Level
NAD83	North American Datum of 1983
ODBC	Open Database Connectivity Standard
PLSS	Public Land Survey System
QBE	Query By Example
RDBMS	Relational Database Management System
SDTS	Spatial Data Transfer Standard
SDWAA	Safe Drinking Water Act Amendments
SQL	Structured Query Language
TDS	Total Dissolved Solids
USEPA	United State Environmental Protection Agency
USGS	United States Geological Survey
UTM	Universal Transverse Mercator

ABSTRACT

Environmental projects can be difficult to manage given the amount of data generated with long-term monitoring. The problem is exacerbated when the study area covers a large geographic area with numerous agencies and personnel involved in data collection. As data sets become larger, data storage becomes increasingly important to minimize redundancy in the data and ease its retrieval for use by environmental managers.

Design and implementation of a relational database/geographic information system application is described for use by water resource managers at the China Lake Naval Air Weapons Station in Ridgecrest, California. Data such as well locations, construction details and water quality for over 2600 wells were normalized and added to a relational database. A customized GIS application allows visualization and spatial analysis of the data. The GIS application also allows visualization of the output from groundwater analyses performed using MODFLOW.

1.0 INTRODUCTION

1.1 Problem Statement

Decisions affecting resource management must be made based on regulations promulgated at the Federal, State and local levels. Constantly revised scientific evidence on the environment, and changes in public opinion regarding environmental concerns also affect resource management. Effective decision making requires that accurate and current information be readily available to simplify the decision making process.

Hydrologists at China Lake Naval Air Weapons Station (CLNAWS) receive a large amount of hydrologic data in disparate formats from numerous sources. Information regarding a single location may be distributed among numerous individual documents. Traditional data storage techniques such as hard copy reports and spreadsheets provide few options for maintaining data consistency and minimizing redundancy. Spatial analysis of data is not facilitated by traditional data storage techniques.

Geographic Information System (GIS) technology is well suited as a tool for environmental management since it allows the integration of disparate data types into a single readily accessible resource. Using a GIS, an environmental professional can simultaneously review numerous forms of relevant information from a single workstation. Analysis of the spatial relationships between data points such as wells can be made based on the values of attributes assigned to the data points such as groundwater elevation or chemical concentrations.

1.2 Objectives

The objectives of this project were threefold:

- To improve storage and access of hydrologic data by consolidating existing data and UofA research data in a relational database.
- To allow spatial analysis and display of the data using a GIS.
- To accomplish the above using computer applications that are easy to use and scalable.

1.3 Project Description

An information management system has been created for CLNAWS personnel. It consists of two customized software applications and associated data supplied on a personal computer.

The first application is a relational database created using the Access relational database management system by Microsoft Corporation. The Indian Wells Valley (IWV) database contains historic data provided by CLNAWS and other public and private entities located in IWV. The IWV database also contains data generated during completion of research at The University of Arizona. Two separate research projects were conducted, hydrologic

modeling of the IWV aquifer (Clark, 1999), and a geochemical analysis of the IWV aquifer (Einloth, in progress).

The second application is a customized GIS created using ArcView by Environmental Systems Research Institute (ESRI). The GIS application provides access to geospatial data for IWV, the output of the hydrologic model and to the data contained in the IWV database. The GIS has been linked to the IWV database so that the user can display the results of queries performed in Access and combine these results with other geospatial data.

2.0 BACKGROUND

2.1 Physical Setting of Indian Wells Valley

Indian Wells Valley is located in southern California (Figure 1).

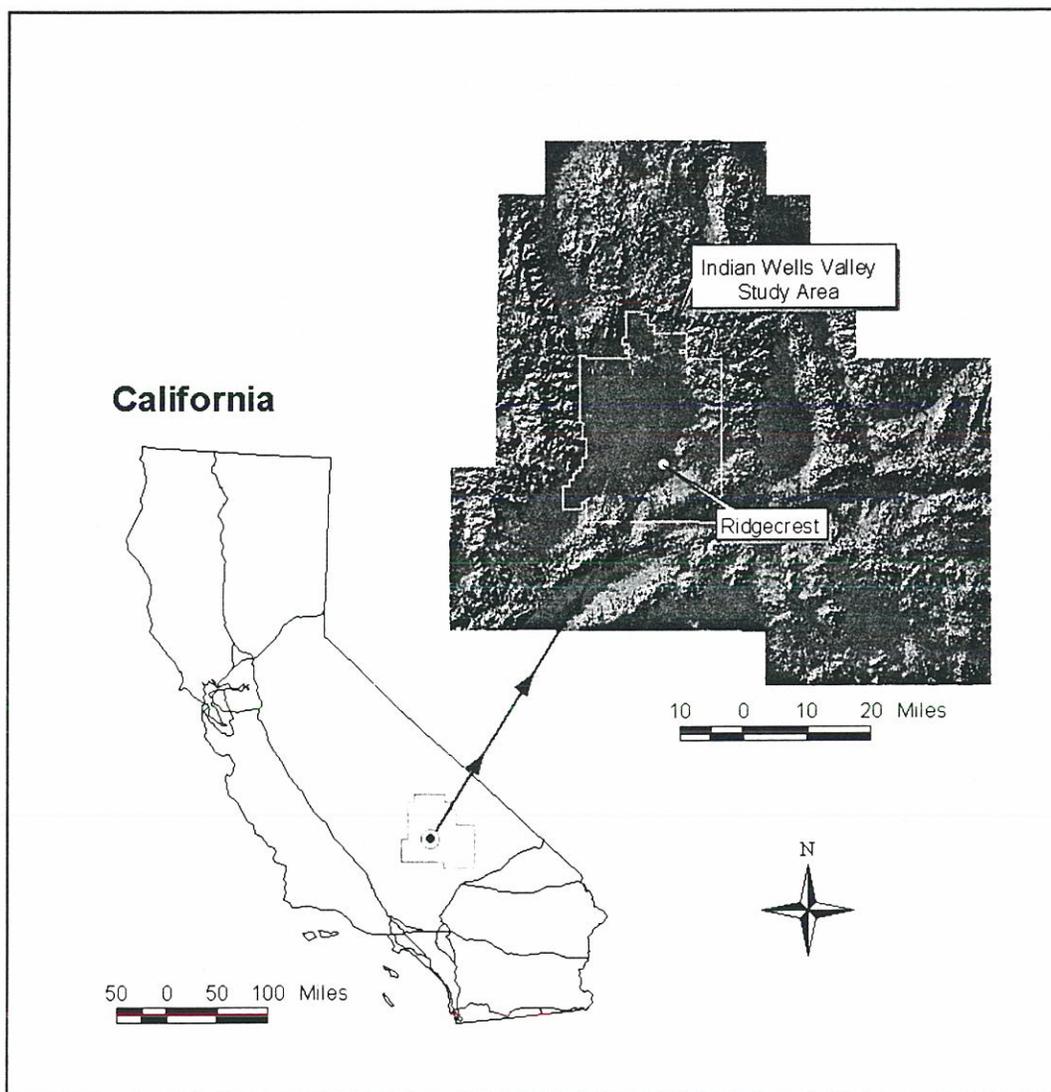


Figure 1: Location map.

It is bounded by the Coso Range to the north, El Paso mountains to the south, Argus mountains to the east, and Sierra Nevada mountains to the west. The cities of Ridgecrest and Inyokern and the CLNAWS are located within the IWV. Residents of the IWV are dependant on groundwater for municipal, industrial and agricultural uses. Concern has developed on both regional and local scales over the last several decades regarding the sustainability of the water supply and water quality.

Unconsolidated deposits within the IWV basin are heterogeneous, especially in the area around the China Lake playa. The basin consists predominantly of alluvial fill and Pleistocene lacustrine deposits. The subsurface can be broadly categorized as interfingered deposits of high permeability sands and low permeability clays (Clark, 1999).

2.2 Groundwater Use in Indian Wells Valley

A detailed analysis of groundwater use in the IWV basin was conducted by Clark (Clark, 1999). The following discussion regarding groundwater use in IWV is paraphrased from Clark's work.

Excessive groundwater pumping, primarily in the intermediate region between Ridgecrest and Inyokern, located approximately 13 miles west-northwest of Ridgecrest, has produced a net negative water budget balance. Since 1966 groundwater extraction by wells has exceeded natural discharge by evapotranspiration (Dutcher and Moyle, 1973).

Berenbrock and Martin (1991) claim that by 1959 annual ground-water pumpage exceeded the estimated annual natural recharge of 9,850 acre-ft/yr. Under steady-state conditions, according to Berenbrock and Schroeder (1994), Berenbrock and Martin (1991), and Bloyd and Robson (1971), the overall dominant groundwater flow direction in Indian Wells Valley was toward the topographic low in the basin (China Lake) from the deeper aquifer to the shallow, upper aquifer. Pumping has produced a gradient reversal such that flow currently is directed towards the intermediate region with flow from the shallow aquifer to the lower aquifer (Berenbrock and Schroeder, 1994).

The introduction of water from the shallow to the deep aquifer is of concern due to the contamination of the upper, shallow unit. Zellmer (1988), notes the Total Dissolved Solids (TDS) of the upper aquifer exceeds 67,000 parts per million (ppm), rendering it non-potable, while that of the potable waters in the deep aquifer overall is less than 500 ppm. Known contaminants in the upper aquifer include "aviation fuels, solvents, beryllium, propellants, explosives, pyrotechnics, laboratory waste, heavy metals, cyanide, industrial detergents, degreasers and other materials" (Zellmer, 1988, pg. 449).

2.3 Data Source Studies

Data from two research projects conducted by The University of Arizona has been incorporated into this project (Clark 1999; Einloth, in progress).

The major emphasis of Clark's research was to assess the potential volume of water that may be utilized by the IWV community and to identify the flow paths where this water may be intercepted. Clark's raw data has been included in the IWV database. The output of Clark's groundwater model is represented in the GIS as data themes containing contours for groundwater levels and drawdown over time.

Einloth constructed a geochemical model of the groundwater in IWV as it travels radially inward towards the China Lake playa by evaluating the chemistry and isotopic signature of groundwater samples collected from multiple wells. The intent of the geochemical model is to evaluate the interaction between the deep and shallow aquifers and therefore assess the potential for shallow aquifer contamination to spread into the lower aquifer water supply. The chemical data used by Einloth is included in the IWV database.

Einloth used Stratamodel, by Landmark Graphics Corporation, to visualize the high and low permeability zones, and to assess the connectivity of the clay layers so as to estimate their capacity as a confining layer between the shallow and deep aquifers. Stratamodel is a subsurface imaging program used primarily by the petroleum industry to model heterogeneous rock and fluid properties in three dimensions for geological analysis and visualization. The program creates a three dimensional grid of cells, arranged in stratigraphically related layers which are constrained as defined by faults and other reservoir features. The model can resolve up to 100 attributes, each of which can be

visualized and rotated in three dimensions as cross sections, fence diagrams, stratigraphic slices, and geobodies.

3.0 LITERATURE REVIEW

3.1 Natural Resource Management

Effective management of natural resources such as groundwater, requires integration of large amounts of disparate data from numerous sources (Fedra, 1995). As the population of a community served by groundwater increases, increasing pressure is placed on the groundwater resource. Additionally, regulatory changes such as the Safe Drinking Water Act Amendments of 1996 (SDWAA, 1996) make it imperative that resource managers be aware of the condition and potential impacts to the groundwater resource under their control.

Over time, the monitoring and assessment of a groundwater resource generates a large volume of data from many sampling locations (Vaughan and Corwin, 1994; Fedra, 1995 and Richards et al., 1996). As the volume of data increases, it can become difficult to track, maintain and interpret. A single sampling location such as a well may have data collected from it by numerous individuals or agencies, each with their own archiving and reporting formats.

Although data may be placed in digital format at some point in time during a project, the final report or submittal is generally presented as a paper report, the format of which can be as varied as the organizations collecting the data (Palmisano et al., 1989). Frequent problems that occur when data is collected by independent sources include differing map

projections, measurement units, hard to trace paper documents and missing information (Fedra, 1995).

As the amount of data increases over time, the resource manager is forced to rely on an increasing inefficient system of paper documentation. Data gets lost in reports and becomes inaccessible for easy use (Trotta, 1990). Under these conditions, managers are required to work with subsets of the data since it is likely that no one report includes all of the data in a useful format. Although most resource management problems have an obvious spatial dimension, spatial analysis of the data is not easily performed when data is stored in hard copy format (Fedra, 1995).

Computer software and hardware have advanced to the state where powerful applications can be run on a personal computer (Palmisano et al., 1989). The following sections describe how two applications, relational database management systems and geographic information systems, can be used to make resource management more efficient and effective.

3.2 The Relational Model and Database Management Systems

A database may be defined as a collection of persistent data. Data that is stored on a computer's hard drive, on a compact disk or on paper in a filing cabinet is persistent, i.e. semi-permanent (Date, 1995; Roman, 1997). Data that are simply stored in a computer's memory are generally not considered to be persistent.

The relational model for data storage was first proposed by E. F. Codd in 1970 (Codd, 1970). Codd, a mathematician by training, first realized that mathematics could be used to add rigor to the field of database management (Date, 1995). In the relational model, data in the database is stored in a series of relations that are linked by relationships.

A *relation* can be considered to be a table with a series of columns called *attributes* and rows referred to as *tuples*. The number of attributes in a relation represents its *degree*.

The number of tuples in the relation represents its *cardinality*. Relations must contain the following four properties (Date, 1995):

- There are no duplicate tuples (rows).
- Tuples are unordered, top to bottom.
- Attributes (fields) are unordered left to right.
- All attribute values are atomic (i.e. are not a collection of values such as both first and last name in the same field).

Relations that contain all of the above properties are said to be normalized, or equivalently to be in first normal form. Normal forms are discussed in detail below.

3.2.1 Primary and Foreign Keys

Normally, each table will contain one column or collection of columns that contain values which will uniquely identify each row (Codd, 1970). For example, a state well identification number in a well table or the combination of supplier name and part

number in an auto parts table. A column or combination of columns that uniquely identify a row are referred to as the *primary key*. If more than one column is needed to uniquely identify a record the primary key is referred to as a *composite key*.

The primary key from one table which serve as a non-key value in another table is said to be a *foreign key*. Assume that we have two tables called “WellLocations” and “WaterLevels” with the field [StateWellId] serving as the primary key in “WellLocations”. An example of a foreign key is the inclusion of [StateWellId] from “WellLocations” in the “WaterLevels” table. The inclusion, or *posting*, of foreign keys in a table is a common way to link the data in two or more tables. In this case, the relationship would be of the “one to many” type since one well can have many water level measurements.

The definitions discussed above are presented graphically in Figure 2.

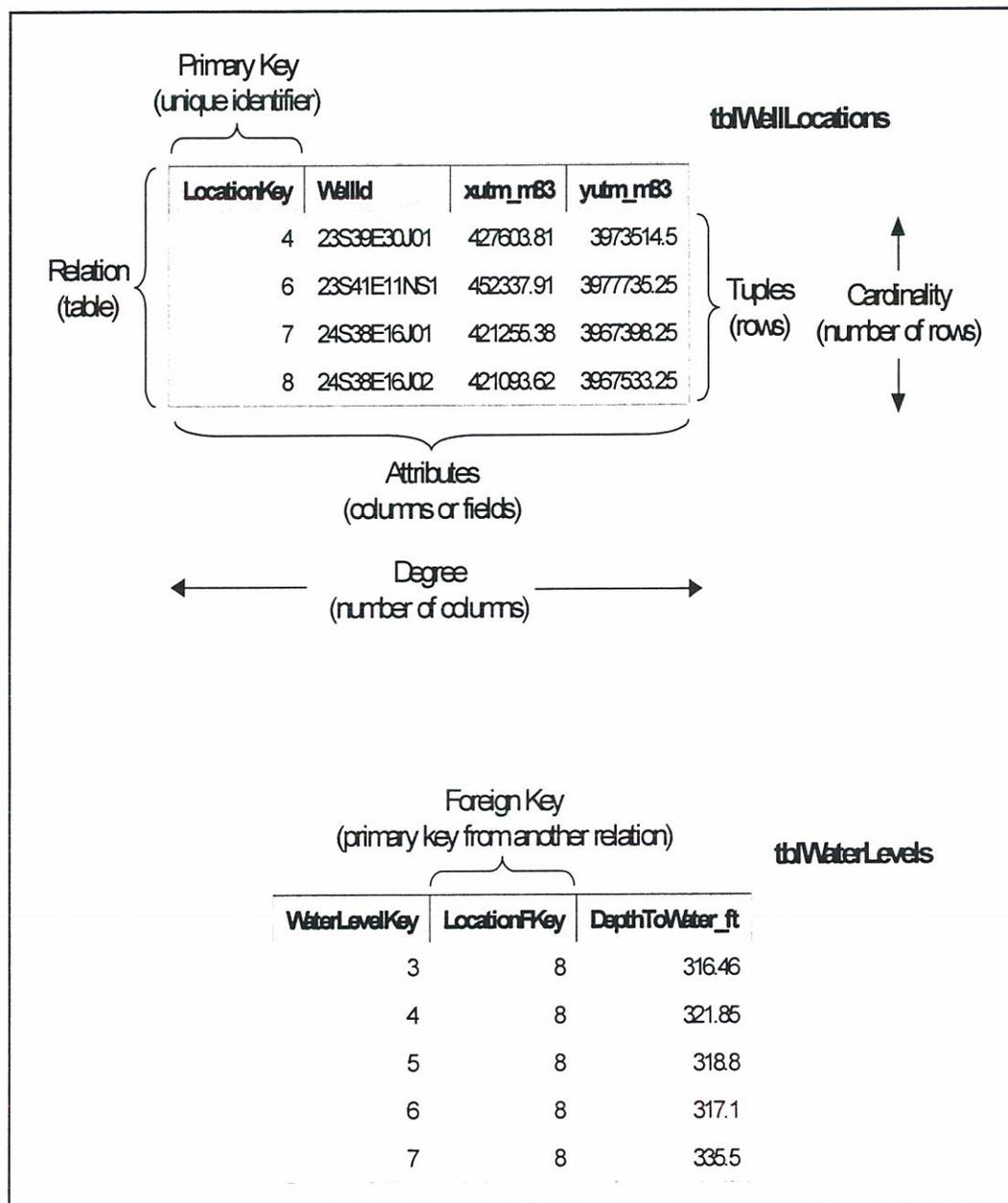


Figure 2: Relational database terms and informal equivalents.

Notice that the LocationKey value "8" appears in tblWellLocations once and that the same value appears many times in the field [LocationFKKey] in tblWaterLevels. This

occurs because tblWellLocations and tblWaterLevels are linked with a “one to many” relationship.

3.2.2 Normal Forms

Those who study database theory have identified six common *forms* that a table may possess to reduce redundancy in the database or achieve certain other goals.

Normalization of a table is the modification the table’s structure and content to comply with these various forms. Normalization reduces, but does not eliminate, redundancy in the data. An informal description of the first three normal forms is provided below

(Date, 1970; Townsend, 1992; Roman 1997):

- First normal form (1NF): All data is atomic. For example, the date March 1999 would be stored as separate month and year columns as opposed to a single date column. There are no repeating columns in the table.
- Second Normal Form (2NF): The table is in 1NF and each non-key column is an attribute of the table in which it is included and not some other table. For example, an table about clothing would not be in 2NF if it contained a column describing house color.
- Third Normal Form (3NF): The table is in 2NF and each non-key column must be fully dependent on the primary key for the table. To phrase it colloquially, each non-key column must be dependent on the key, the whole key, and nothing but the key.

3.2.3 Implementing the Relational Model

The relational model as described above is implemented using a relational database management system (RDBMS). A RDBMS is a software application which is designed for two main purposes: to add, delete or update records in a database; and to provide methods to view or print the data contained in the database (Roman, 1997).

Most relational databases are created using existing data (Delorme, 1998). Preparation and conversion of the data into a relational format can be a difficult and time consuming task (Delorme, 1998; Codd, 1990a, 1990b). However, implementation of the relational model through the use of a RDBMS provides significant advantages for resource management.

Use of a RDBMS provides ease and speed in accessing data (Edwards et al., 1987). Prior to the use of databases, many agencies records were kept in paper format, requiring searches through thousands of pages to locate the desired data (Trotta, 1990). Most RDBMS applications have functionality that allow users to quickly create input forms and formatted reports for data output.

Properly designed, a relational database is scalable, new records and tables can be added as needed (Edwards et al., 1987). Modern RDBMS products easily handle the large amounts of data generated by groundwater studies (Richards et al., 1996; Bollinger and Hiergesell, 1997). Up to 100 tables per database, 250 attributes per table and 150 million

records per table are not unreasonable for existing RDBMS products (Edwards et al., 1987).

A RDBMS helps maintain the integrity of the data by allowing constraints on the format of the data entered into the database. Data entry rules can be integrated into data input forms which force the user to add data in a consistent format or limit the acceptable entries (Aspbury and Nelson, 1995). An example from the IWV database is the entry of new water level measurements. Prior to entering water levels, the user selects the well associated with the measurements from a pull down list. Only wells with known locations are presented to the user. The user is thus prevented from entering water levels into the database that are not associated with a well. Additionally, this method ensures that the format of the well name is consistent for all associated records.

Updating and retrieval of records is made easier when data formats and values are controlled to help ensure consistency (vonPlaten, 1994). The user is more likely to retrieve the desired records when they know the well name is stored only as "Well6" and not as a various other forms such as "Well-6", "Well #6" or "WellSix".

The security of data can be maintained using a RDBMS (Dimond and Abate, 1996; Date, 1995). All common RDBMS allow security restrictions to be placed on what features are available to individual users. Certain users may be have full control of the database, others may be able to add or delete records, but not tables or input forms.

Security restrictions help maintain the integrity of the data by limiting the users who can modify the data.

3.3 Combining GIS and Relational Databases

A GIS is a powerful group of tools that allow collecting, storing, retrieving, transforming and displaying of spatial data from the real world for a particular purpose (Burrough and McDonnell, 1998). A GIS allows analysis of spatial distributions and relationships (Dutta et al., 1998). New information can be generated as a result of the analysis of existing datasets (Hiscock et al., 1995). In recent years, GIS has matured into an industry of its own with the number of system installations doubling every two years (Tsihrintzis et al., 1997).

Environmental management as related to groundwater is concerned with state, expressed as chemical concentrations, depths or process rates. The overlap between GIS and groundwater management is apparent and the integration of the two has great potential (Fedra, 1995). GIS is an effective tool for the storing, managing and displaying of water resource spatial data and its use is on the rise (Canter et al., 1994, and Tsihrintzis et al., 1996, 1997).

In the geo-relational model, used by most popular GIS applications, the positional portion of the data is stored in a proprietary format while the attribute information stored in a relational database included as part of the GIS software. Information is stored in the GIS

as a series of static files which can be thought of as a series of layers. Modification of these files can only be accomplished using the GIS application. Although the position and attribute data can be exported into other formats, the process is not easily performed except by persons with extensive training and experience.

Studies show that the integration of GIS with a relational database that is separate from the GIS software is versatile, flexible and efficient (Richards et al., 1996; Bollinger and Hiergesell, 1996). Under this scenario, the data is stored in the relational database independent from the GIS application and the GIS application is used to display the data (Tsihrintzis et al., 1997; Presley, 1996; Richards et al., 1996; Barazzuoli et al., 1999).

The advantages to this method are significant. Information displayed by the GIS always reflects the current status of the database (Dimond and Abate, 1996). The GIS layers are now dynamic rather than static and do not require GIS skills to add or modify data. Additionally, storage of the data using a common RDBMS such as Access, or Oracle by Oracle Corporation, allows use and maintenance of the data by non-GIS professionals.

4.0 RELATIONAL DATABASE DESIGN

4.1 Data Sources

Data to be included in the IWV database was provided by China Lake Naval Air Weapons Station, United States Geological Survey, California Department of Water Resources, Houghton Hydro-Geo-Logic, TetraTech, Inc., Kern County Water Agency, Indian Wells Valley Water District, and IMC Chemicals. The type of data provided included, but was not limited to: well locations, construction details, electronic and physical logs, analytical data for soil and groundwater, pump test data, and aquifer data. Data from the Clark and Einloth studies is also included in the IWV database.

The data was provided in disparate formats which included hard copy, various word process formats, spreadsheets, text files and database files. Much of the information had been previously shared between the sources. Since most of the sources were not using a relational database to maintain the data, duplication of the data was common. In many cases, the format of the data varied between sources. For example, it was common for positional information about a particular well to be maintained by each source using a different number of decimal places. The conventions used to identify individual wells also was not consistent between sources. The most significant portion of work on the IWV database was the normalization of the data to enforce consistent formatting and the identification and removal of duplicate records.

4.2 Creation of Entity Sets

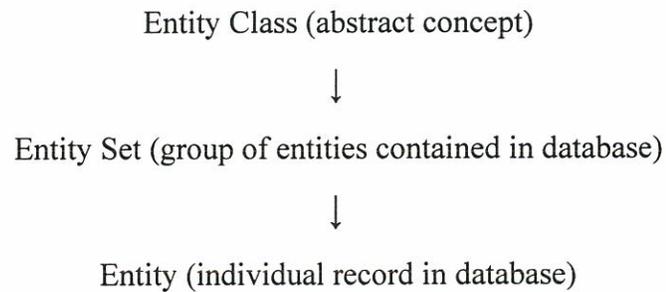
4.2.1 Conceptual framework

A relational database stores information about things referred to as *entities*. Entities can be thought of as real-world objects such as groundwater samples or wells. An *entity class* is an abstract concept that includes all of the possible entities of a specific type. Thus, the wells entity class would consist of all possible wells (Townsend, 1992 and Roman, 1997).

Entity classes possess certain properties called *attributes*. The database designer determines the attributes associated with each entity class in the database. The attributes associated with an entity class serve three main purposes (Roman, 1997):

- To include information that we want in the database. For example, the Universal Transverse Mercator (UTM) coordinates of the entities contained in the wells entity class.
- To uniquely identify each entity contained in the entity class. For example, the attribute [WellId] could contain the unique State well identification number assigned to the well.
- To describe the relationships between entities in different entity classes. For example, using the [WellId] attribute from the well entity class as an attribute in the analytical results entity class to relate the analytical results to a particular well.

Entity sets are a collection of entities that actually exist in the database at some point in time. These concepts are described graphically as:



A common spreadsheet table provides a useful, though imprecise, analogy for the above concepts. In the table analogy, the table name represents the entity class. A table about wells would include data about all possible wells. The columns of the table would represent the attributes. The creator of the table decides what columns to include in the table. The rows of the table represent the individual entities within the entity class, while the group of all rows represents the entity set at that point in time. Although a useful analogy, a spreadsheet table can violate many properties required for a database table and a spreadsheet may require a large amount of restructuring to be placed in relational format.

4.2.2 Structuring of Source Data

As the first stage in the creation of entity sets all of the data was entered into a spreadsheet application. Microsoft Excel was selected since it is part of the application suite that includes Access. A spreadsheet application was used because it allows easier conversion and manipulation of data since relational database rules do not apply. Once added to the Excel workbook, the data was reviewed to determine logical groupings of the data types (entity classes).

Figure 3 shows the entity classes in the IWV database and their relationships to each other as implemented in the IWV database.

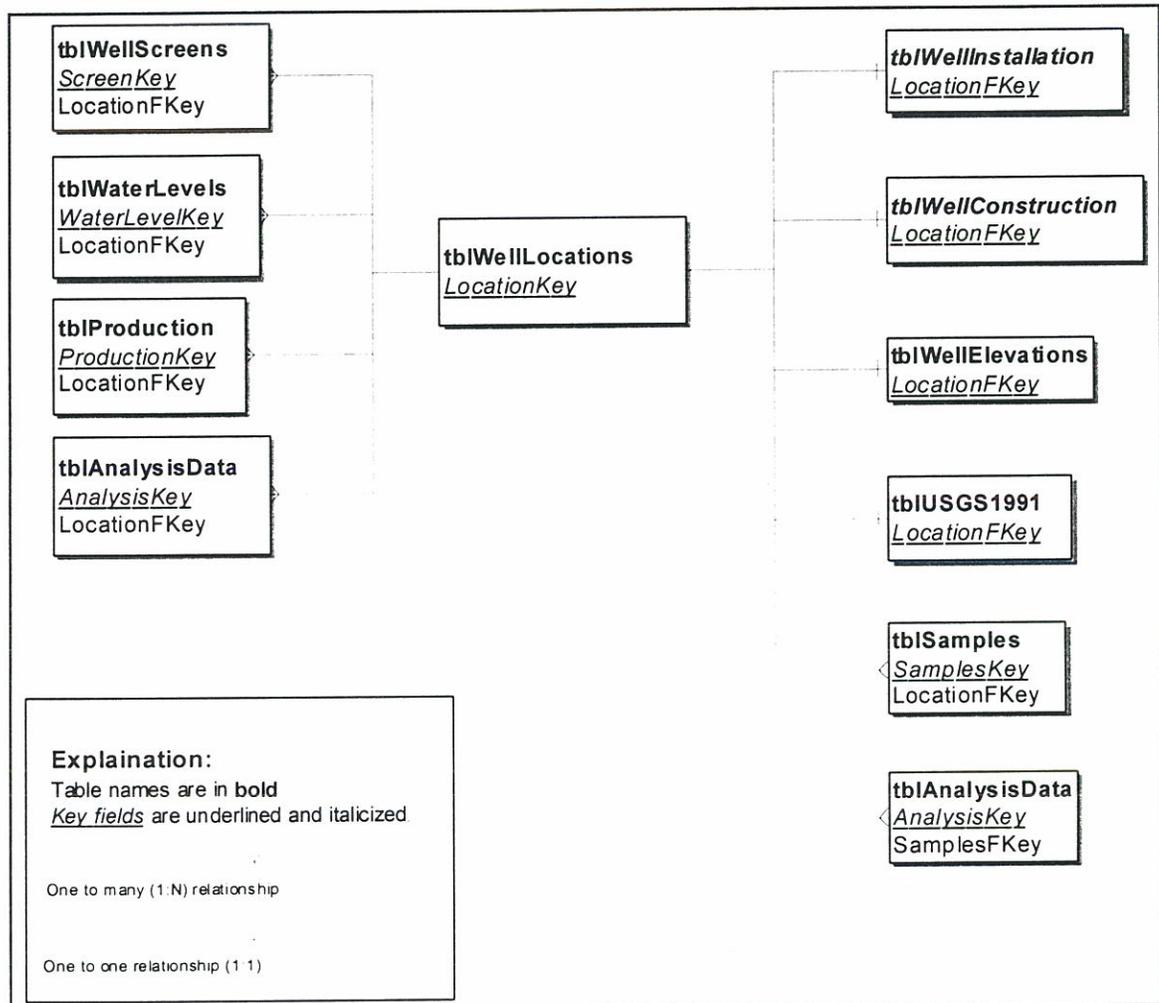


Figure 3: IWV database schema.

For clarity, only the attributes serving as primary and foreign key values have been included in Figure 3.

Table 1 in Appendix A summarizes the schema for the IWV database data tables.

Lookup tables are used to provide consistent values for certain fields in the data tables such as well type and drilling company. A list of the lookup tables used in the IWV database is provided in Table 2 (Appendix A).

Entity sets were created by rearranging the data so that the data in each entity class was on a separate workbook page. For example, all of the water level measurements were placed together as were all of the well construction details. Field headings were modified to increase clarity and ensure consistency between worksheets for the fields that would serve as primary or foreign keys in the IWV database. Since some of the IWV data was collected in the 1920's all dates were modified to a four digit year using the format mm/dd/yyyy. Modification of the dates was required since Access and Excel consider two digit years prior to 1930 to be in the 21st rather than the 20th century, e.g. a two digit year of 25 would be considered to be 2025 rather than 1925.

Positional information in degrees, minutes and seconds was converted to longitude and latitude in decimal degrees using Excel. Excel was also used to convert all elevations to feet. Well positions with only one data source were assumed to be correct. Conflicting positions were noted for many of the wells and were handled in several ways. If the conflict in longitude and latitude did not exceed the area of a $\frac{1}{4}$, $\frac{1}{4}$ section (40 acres) the

values were averaged. This distance was selected to conform with the level of precision used in the State of California well identification system (Clark, 1999).

The UTM coordinates were determined for all wells where the positional data was provided in decimal degrees or State Plane coordinates. A text file containing the coordinates was created and re-projected into UTM zone 11, North American Datum of 1983 (NAD83) using ARC/INFO. The projected coordinates were then added to the appropriate worksheet. The original decimal degree or State Plane coordinates were retained in the database.

In some cases position coordinates and elevation information was not provided, or the variation in reported positions was beyond the project tolerances. In these cases the position and elevation of the wells were determined from 1:24000 or 1:62500 scale topographic maps. Several wells were located on both map scales to determine the sensitivity of this estimation method to map scale. Values of longitude and latitude were in good agreement, but the accuracy of elevation increased with smaller contour intervals for obvious reasons. Conflicting elevations not varying by more than five feet were averaged (Clark, 1999). Location quality information is contained in the [LocQuality] field present in relevant tables, thereby allowing a qualitative assessment of the accuracy of the position.

4.3 Normalization of Data

Normalization reduces, but does not eliminate, redundancy in the data. The IWV data was generally normalized to the third normal form (3NF). With the exception of duplicate record removal, normalization of the data was performed in Excel. Duplicate record removal was performed using a series of select queries in Access.

5.0 IMPLEMENTATION OF RELATIONAL DATABASE DESIGN

5.1 Naming Conventions for IWV Database Objects

All of the objects created in the RDB, i.e. tables, queries, forms etc., have been named using a modified version of Hungarian notation (Leszynski and Reddick, 1994).

Hungarian notation, named for the nationality of its inventor Charles Simonyi, uses standardized conventions for naming objects (Simonyi, 1999). One of the conventions is to begin each object name with a prefix which denotes the object type. For example, table object names begin with "tbl" and select query object names begin with "qry". In the remainder of the object name each major portion begins with a capital letter. Spaces, underscores, or dashes are not used in the object names. Examples of object names used in this database are "tblWellProduction" and "qryAllWellLocations". Using Hungarian notation makes the object type easy to identify and causes all objects of the same type to sort together. A list of all prefixes used in the IWV database are included in Table 3.

5.2 Lookup Tables

Lookup tables were created for attributes that appear in more than one table or which have a limited number of acceptable values. Selected fields in the main IWV database tables include a pull down list of values from which the user selects the desired value. The lookup tables are the source of the values presented to the user. The lookup table method ensures consistency in the entries and prevents problems such as one user using

"M" for monitoring well and another using "MW" for the same well type. The lookup tables are not accessed directly by the user except to edit an existing value or to add new values.

5.3 Identification and Removal of Duplicate Data

The final step in normalization of the Access database tables was to locate and delete duplicated data to ensure that each non-primary key item related to an individual well appeared only once in the database. This final step in the normalization process was conducted in Access.

A series of Structured Query Language (SQL) statements were used to determine the duplicated records in each table based on the table's primary key. For example, the well usage table was searched for duplicate records based on the well identification number, and the day, month and year of pumping. The duplicated information was compared and a decision as to what data to keep was made. In some cases the records were true duplicates and one of the records was deleted. In other cases a judgement about what data to keep was made based on the perceived quality of the data. For example, one of the common problems in this table was that the same well identification would be listed numerous times with different position information. In this case the decision of which records to delete was based on the method used to determine the position of the well. Preference

was given to positions determined by post-processed global positioning system (GPS) methods and surveying techniques.

5.4 Creation of Etable Database

During the normalization process some records were removed from the database due to missing information. Examples include annual production data that was not referenced to a well name or other identifier, or water level data for wells without positional information. Error tables containing records with data errors such as these were created using make table queries in Access. Once the error table was created the data was deleted from the IWV database.

All of the error tables have been preserved in a separate database named IwvErrorTables.mdb included in Appendix B. All error tables use the name prefix “etbl”. Table 4 presents the names and a brief description of the tables contained in the IwvErrorTables.mdb database. The data contained in any of the error tables can be re-integrated into the IWV database if additional data becomes available to correct the error causing its removal.

6.0 ADDING OR MODIFYING DATABASE DATA

6.1 Switchboard Forms

Data entry is accomplished by entering data directly into various forms created from the database tables. Two types of forms are used in the database. Switchboard forms allow the user to navigate the database. Data entry forms allow the user to modify existing data or to add new data to the database. Direct manipulation of the database tables is not recommended except by experienced users.

Upon opening the database file, the user is presented with the main switchboard form (Figure 4).

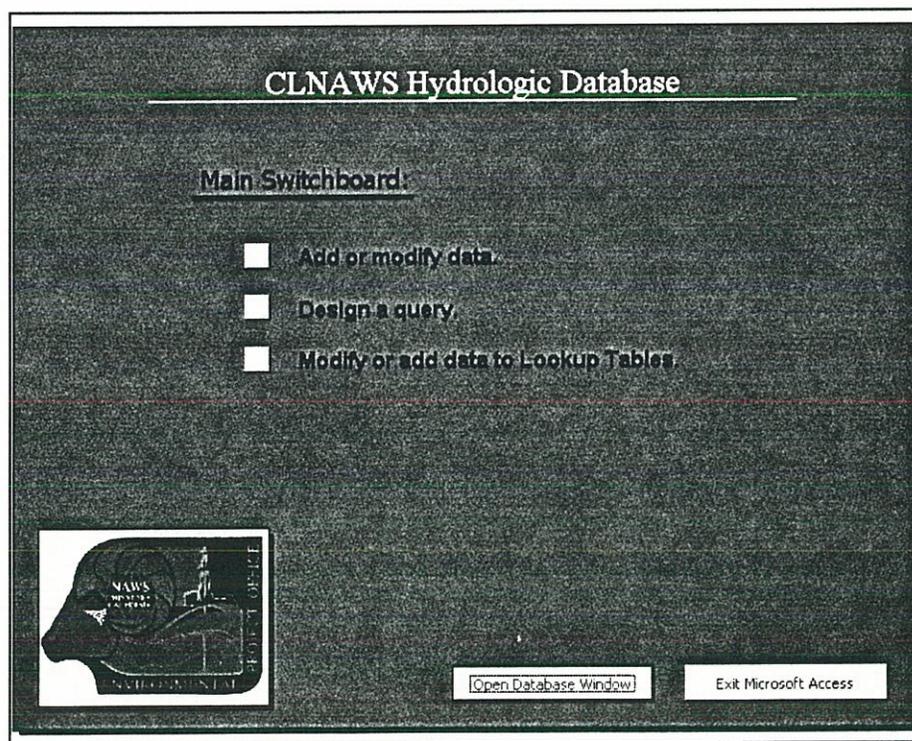


Figure 4: Opening screen of IWV database.

The main switchboard allows the user to maneuver to a series of forms used to add data to any of the tables in the database, or to switch to the Access query design window. Selecting “Add or modify data” from the main switchboard moved the user to the “Add or Modify Data” switchboard shown in Figure 5.

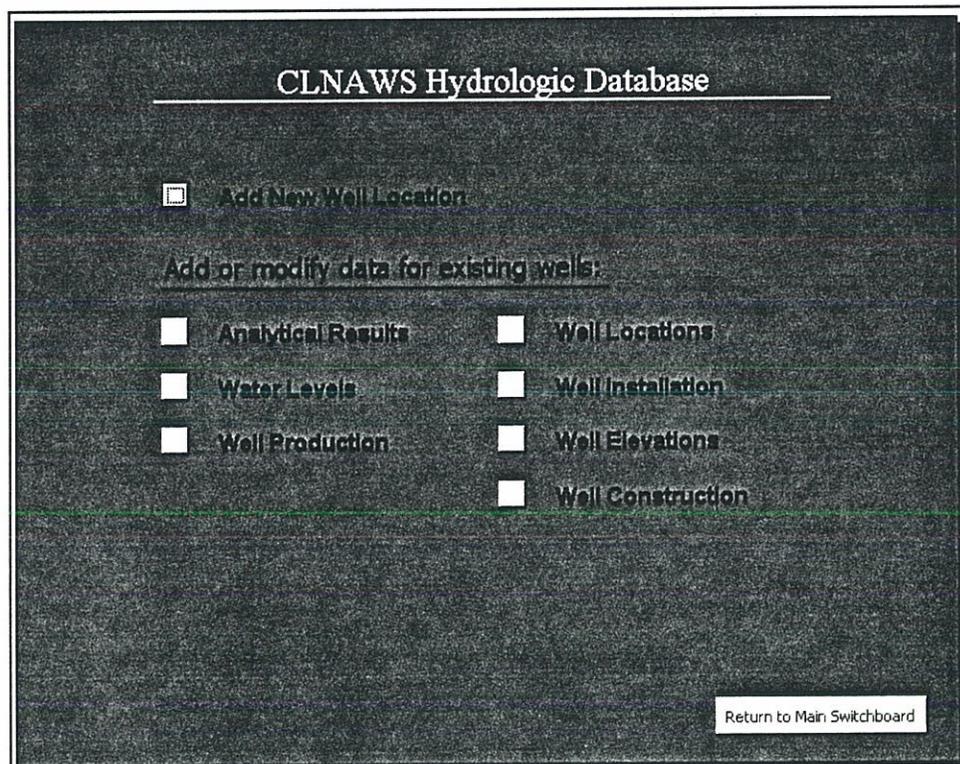


Figure 5: Switchboard for data entry forms.

Selecting any of the choices on the “Add or Modify Data” switchboard will take the user to an appropriate data entry form. With the exception of the “Add New Well Location” form, all of the data entry forms allow the user to review and modify existing data, or to add new data to the database. The “Add New Well Location” form only allows the user

to add new wells to the database. All data entry forms work in a similar manner. The “Analytical Results” form is the most complex and is used in the following example.

6.2 Data Entry Forms

Forms are a convenient method to add or modify data to an Access database. Users unfamiliar with relational databases can find the structure confusing, especially if one is used to spreadsheets where all of the information related to a topic is likely to be located in a single table. Forms allow the user to be insulated from the potentially confusing structure of the database. Forms also allow the information in the database to be presented to the user in an easy to understand manner. Figure 6 presents an example of one of the data entry forms, based on the ongoing work by Einloth (Einloth, no date).

Add or Modify Data for Existing Wells

Select an existing well:

Well Id

Return to Modify Switchboard

LocationKey:

Sample Information

Collection Date	<input type="text" value="9/1/1992"/>	SampleKey	<input type="text" value="6"/>
Collection Time	<input type="text"/>	LocationFKKey	<input type="text" value="11"/>
Data Source:	<input type="text" value="Houghton Hydro"/>		
Water Type:	<input type="text" value="Na SO4"/>		

Analytical Data

Analyte Group	<input type="text" value="Metals"/>	AnalysisKey	<input type="text" value="817"/>
Analyte	<input type="text" value="Manganese"/>	SampleFKKey	<input type="text" value="6"/>
Result	<input type="text" value="0.07"/>		
Units	<input type="text" value="mg/L"/>		
Quality Level	<input type="text"/>		
Lab	<input type="text" value="BC LABS"/>		
Filtered Sample	<input type="text"/>		

Record: of 24

Record: of 2

Figure 6: Data entry form for analytical results.

The form shown in Figure 6 is composed of three parts. The first is the main form which contains the title, “Well Id” combo box and “Return to Modify Switchboard” button. The second part is a subform labeled “Sample Information”. The third part is a subform

called “Analytical Data” nested within the “Sample Information” subform. Each well may have many samples, which in turn may have many associated analytical results.

Both subforms contain record navigation buttons along their bottom left edge used to maneuver through the records on the individual forms. The record navigation buttons in Figure 6 indicate that the selected well has two samples associated with it, and that the first sample has 24 associated analytical results.

The form prevents users from entering sample data for a well that has not been entered into the database. Combo boxes, such as the one used to enter the Well Id, restrict the users choice of values and ensure that data is input in a consistent manner. Data restrictions such as these help prevent many of the errors contained in the raw data set such as water levels or usage data not associated with a well. The use of combo boxes to restrict data entry is common to all data entry forms in the IWV database.

The forms have been designed so that the user may move from field to field using the mouse, “Tab” or “Enter” keys. The user selects an existing well by typing in its name or using a pull down list activated using the arrow on the right side of the box labeled “Well Id” at the top of the form.

After completing the “Sample Information” portion of the form, the user enters the associated analytical data. Using the “Tab” or “Enter” key to exit the “Filtered Sample” box (Figure 6) will return the cursor to the “Analyte Group” field at the top of the “Analytical Data” form. This speeds data entry since each sample is likely to have been analyzed for numerous compounds.

When using a form, records are automatically saved when the form is advanced to a new record or closed. For example, assume a user has entered data into the “Analytical Data” portion of the form. Upon using the “Tab” or “Enter” key to exit the “Filtered Sample” box the data entered is saved and the form advanced to a new blank record.

7.0 QUERYING THE DATABASE

7.1 General Considerations

Queries are powerful tools that can be used to view or modify the data contained in the database. New database tables containing data for a specific purpose can be created. The results of queries created in the IWV database can be displayed in ArcView provided the simple rules described later are followed.

Prior to creating queries, it is imperative that the user familiarize themselves with the data contained in the database and the name of the fields containing the data. For example, for a user to query the database for information about depth to groundwater, they must know

for certain that the information is in fact stored in the database and that it is stored in a the field labeled [DepthToWater_ft] located in the table named tblWaterLevels. This data familiarization requirement is a function of relational databases and is not unique to the IWV database. The information contained in Table 1 (Appendix A) will be useful during the familiarization process.

Selecting the “Open Database Window” from the main switchboard opens the database window shown in Figure 7.

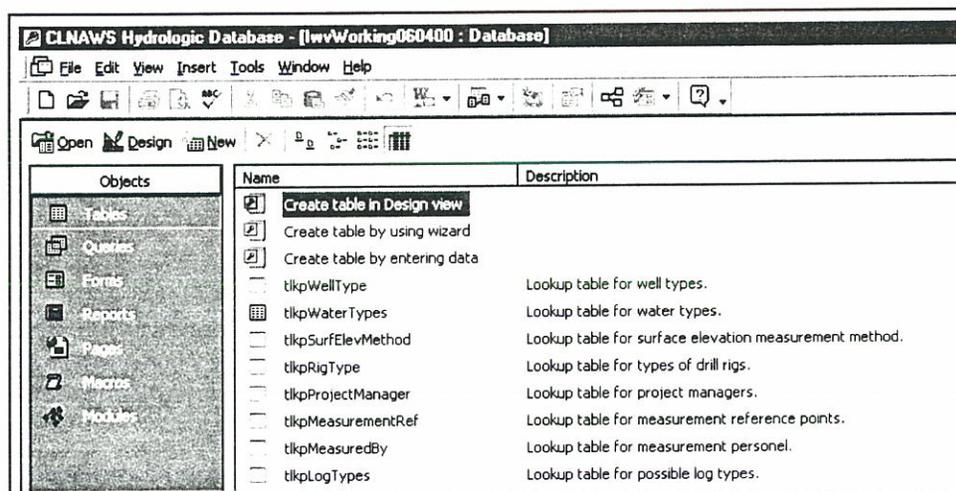


Figure 7: Database objects in Database Window.

All of the objects contained in the database, such as tables, forms and queries, can be accessed from the database window. Individual objects can be reviewed by double clicking the object or highlighting the object and selecting the “Open” or “Design” buttons located above the “Objects” list. Caution should be used since it is possible to

make changes to the database objects which could affect the performance of the application.

7.2 Constructing an Example Query

The following example illustrates using the Query by Example (QBE) feature of Access. Access also provides “Wizards” to aid in the construction of queries. The user is referred to the Access help feature for a discussion of the Query Wizard feature.

The first step is to formulate the question that the query will answer. For this example, we want to find all of the records with boron and total hardness values. The boron records are to be restricted to those where the detected concentration was less than 1.0 mg/L . The output of the query should include the common name for the analytes, result, units, well ID, well type, total depth and the UTM coordinates. The results of the query should be viewable in the IWV ArcView application.

Selecting the “Design a query” option from the main switchboard opens the “New Query” window shown in Figure 8.

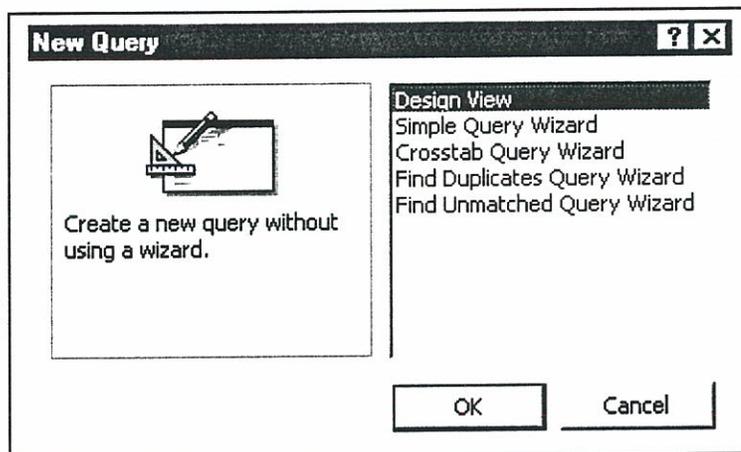


Figure 8: Designing a query.

Selecting the “Design View” item and clicking the “OK” button opens the QBE grid shown in Figure 9.

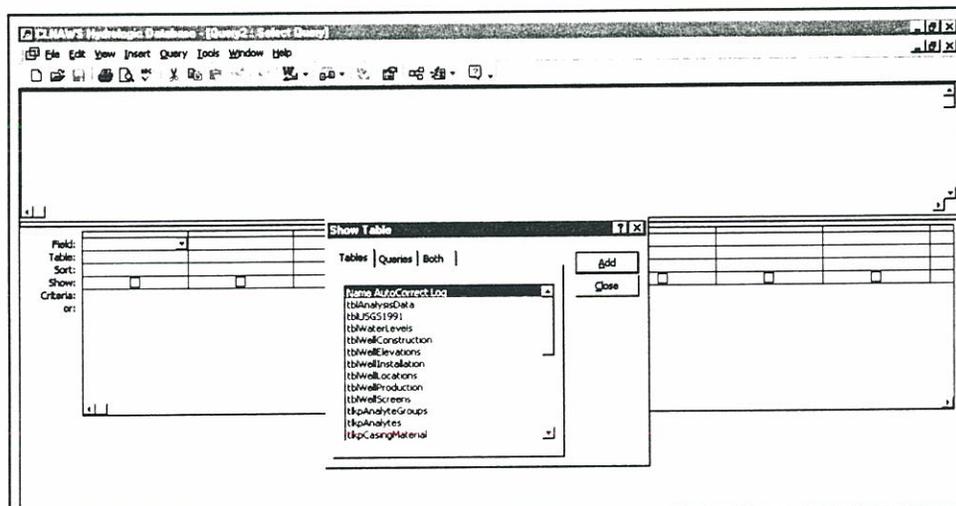


Figure 9: The query by example grid.

A query is constructed using the tables or other queries listed in the “Show Tables” box (Figure 9). The tables or queries required for the new query are selected from the “Show Table” box by double clicking each table name, or alternately highlighting the name and

clicking “Add”. Once the tables or queries have been added, the criteria can be added to the query design grid in the lower portion of the window. Figure 10 shows the QBE grid set up to run the example query.

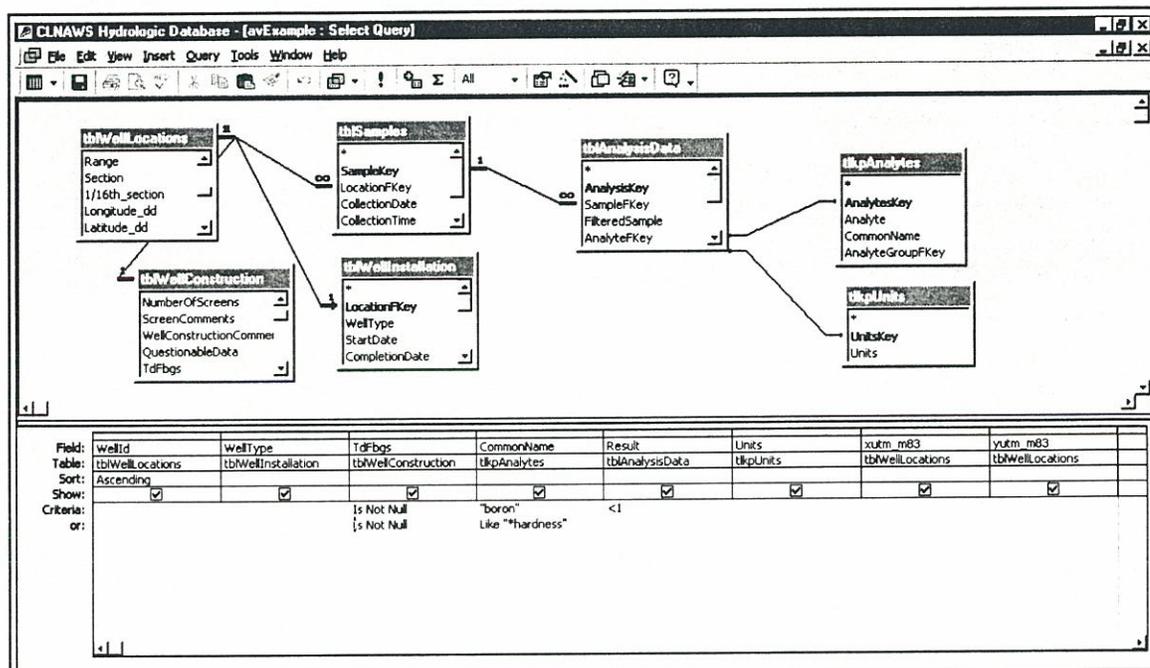


Figure 10: Setup for example query.

Seven tables are required to run the query. Five tables, tblWellLocations, tblAnalysisData, tblSamples, tblWellInstallation and tblWellConstruction provide the well ID, well type, total depth, analysis result and UTM coordinates for the wells. Two lookup tables, tlkpAnalytes and tlkpUnits are required to supply the common name for the analytes and units for the analysis results. Use of lookup tables are not required to perform queries, but allow adding useful information to the output of the query such as common analyte name and analysis units.

The fields to appear in the output of the query are “dragged” into the design grid in the lower portion of the QBE window. The criteria used to limit the records selected by the query are then added. Criteria added to the same row work as a logical “And” statement, requiring that all conditions be true for a record to be selected. In the example, all records where the value in the [CommonName] field is “boron” and the value in the [Result] field is less than 1.0 will be selected. Criteria added to the same column act as logical “Or” statements. Access uses an inclusive Or, meaning that a record is selected if any of the conditions in the statement are true. Therefore, in addition to the boron records noted above, all records where the value of the [CommonName] field is “TotalHardness” will be selected. Entries in the criteria grid portion of the QBE window are not case sensitive.

Access provides useful operators for constructing queries. In the example above, “hardness” in the second line of the QBE criteria grid could be replaced with “Like “*hardness””. This expression selects all records where the common name is composed of any number of characters, represented by the wildcard character “*”, followed by “hardness”. The result is that all records with the common name values of “CarbonateHardness”, “NonCarbonateHardness” or “TotalHardness” are selected. The same result would be obtained by entering the following on separate lines in the criteria section of the [CommonName] field in the QBE grid:

“boron”

“carbonatehardness”

“noncarbonatehardness”

“totalhardness”

Unfortunately, not all of the operators provided by Access are supported in ArcView.

Replacing “hardness” with “”Like “*hardness”“ in the example query and running the query from ArcView returns only the boron records. This problem is solved by

converting the query from a “Select” query, as described above, to a “Make Table” query.

Make Table queries are described in Section 7.4.

Other instances in which a query run from ArcView returns a subset of those returned by the same query run from within Access may exist. This incompatibility is a function of ArcView and is not specific to the IWV ArcView application.

The query is run by clicking the “!” symbol on the QBE toolbar. The first few records of the result of the query are shown in Figure 11.

Wellid	WellType	TdFbgs	CommonName	Result	Units	xutm_m83	yutm_m83
24S38E21.J01	Monitoring	660	TotalHardness	131.0000	mg/l	421190.97	3966708
24S38E21.J01	Monitoring	660	TotalHardness	52.0000	mg/l	421190.97	3966708
24S38E21.J02	Monitoring	1200	TotalHardness	31.8000	mg/l	421115.31	3965568.25
24S38E21.J03	Monitoring	1580	TotalHardness	550.0000	mg/l	421115.31	3965568.25
24S38E21.J04	Monitoring	1950	TotalHardness	576.0000	mg/l	421115.31	3965568.25
24S38E21.J04	Monitoring	275	TotalHardness	51.0000	mg/l	421214.81	3967764.8

Figure 11: Query output window.

7.3 Saving the Query

The query is saved by selecting File → Save As from the QBE menu bar. Two conventions must be followed if the query is to be accessed from the IWV ArcView application:

- 1) The query must be named with the prefix “av” (no quotes). Using any other letters at the start of the query name will result in the query not being listed in the ArcView application as described below. Query names are not case sensitive.
- 2) Special characters such as “>”, “<”, “-” and spaces should not be used in query names. The results of running a query that contains special characters from the IWV ArcView application are unpredictable. This characteristic is not a function of the IWV applications, but a function of the underlying computer language used to perform the queries from ArcView.

The example query used in the discussion above has been included in the IWV database as “avExample”. A list of other queries included in the IWV database is provided in Table 5 (Appendix A).

7.4 Make Table Queries

Make Table queries are used to create new tables in a database. Make Table queries are used when Access operators such as “Like” have been used in the query and the results are to be displayed in the IWV ArcView application.

The first step in creating a Make table query is to create a Select query as described in Section 7.2. The Select query is then converted to a Make Table query by selecting Query → Make-Table Query from the QBE menu bar. Creating a Select query first allows the user to determine that the desired set of records is being selected before creating a new table.

When a Select query is converted to a Make Table query, the user is prompted to enter the desired name for the table. The table is created when the query is executed using the “!” icon on the QBE toolbar. The resulting table is updated each time the Make Table query is executed. The definition of the Make Table query is saved separately from the table that it creates. The user is prompted to save the query when closing the query. The query may be also be saved by selecting File → Save As from the QBE menu bar.

Make Table queries will not be displayed in the ArcView application, even if the query is named using the criteria outlined in Section 7.3. However, the table created by the Make Table query will be displayed in the ArcView application provided it is saved with the

“av” prefix. Selection of the table from the ArcView application does not update the data in the table. Updating the data in the table can only be accomplished by re-executing the Make Table query in Access.

8.0 CREATION OF GIS THEMES

A total of 70 GIS data files were created for this project. The data layer name and a brief description of the file are summarized in Table 6 (Appendix A).

8.1 Groundwater Model Output

One of the goals of this project was to make water level and drawdown contour data generated by Clark's (Clark, 1999) model useable in a GIS. Two water level contour themes for each of the following years were produced for this project: 1953, 1965, 1975, 1985, and 1997. Two water level drawdown contour themes were produced for both 1985 and 1997. Numerous layers associated with the sensitivity analysis of Clark's model were produced and are included as GIS themes with the IWV application. The reader is referred to Clark's thesis for a detailed description of the above themes (Clark, 1999).

Clark used the Groundwater Modeling System (GMS) Version 2.1 interface in conjunction with MODFLOW to facilitate input file construction and to automate construction of the three-dimensional grid necessary for MODFLOW. GMS was developed by the Brigham Young University Engineering Computer Graphics Laboratory (1988) in conjunction with the U.S. Army Engineer Waterways Experiment Station, and it is distributed by the Department of Defense. GMS consists of a graphical user interface for use with several numerical models in addition to MODFLOW including: MT3D,

MODPATH, and FEMWATER. Use of the GMS interface assists in integrating MODFLOW with GIS applications. A detailed description of the use of GMS and MODFLOW is provided in the document entitled: "A Groundwater Flow Model of Indian Wells Valley, California, Utilizing GMS with GIS Applications" (Clark, 1999).

Data layers can be imported into, or exported from GMS Version 2.1 as Data Exchange Format (DXF) files. However, only annotations are maintained, attributes associated with polygons or lines are lost in the conversion process. Version 3.0 of GMS is expected to support importing and exporting of attributes however, the release of this version occurred subsequent to Clark's (1999) modeling effort.

The use of annotations alone was determined to be insufficient for this project. While viewing the contour themes in ArcView, it is possible to zoom into an area without annotations, thereby losing the elevation reference within the view extent. This problem was corrected by converting the DXF files into ARC/INFO coverages. Basic conversion of the GMS output files was performed by Clark (1999) using the internal ARC/INFO conversion routine called by the command *dxfarc*. Additional processing of the coverages was required to allow attributes to be assigned in an orderly and efficient manner. In some cases the number of contours was reduced to improve the readability of the coverage.

Additional processing included building line topology and annotation features, un-splitting of arcs and cleaning of the coverages. These additional processing steps were automated in the AML *waterlevels.aml* included in Appendix C. Once processed, the coverages were attributed by Clark using ArcEdit.

8.2 Coverages From Other Sources

Numerous themes were created for use in the ArcView application. These themes provide location references to be used in conjunction with the well data contained in the RDB. Due to the complexity of the processing steps, many of the themes were produced in ARC/INFO and later added to the ArcView application as themes. Descriptions of the themes and details of the processing methods used to create them is provided in the following sections. To provide consistency with GIS products already in use by the CLNAWS, all of the coverages/themes created for this project use the UTM projection and 1983 North American Datum (NAD83).

8.2.1 Roads

A coverage containing road locations within IWV was created using 1:100,000 Spatial Data Transfer Standard (SDTS) formatted files acquired from the USGS (USGS, No Date). The SDTS formatted files were converted to ARC/INFO line coverages using *sds2cov.aml*, an ARC/INFO AML utility provided by the USGS. A copy of *sds2cov.aml* is included in Appendix B.

Once converted into coverages, the 24 separate files were appended together in Arc Info to produce the *roads* coverage. Arcs representing the neatlines from the individual coverages were removed. The coverage was then projected and the portion of the coverage outside IWV was removed. The coverage was then cleaned using the default values and line topology built.

Due to the rural nature of the IWV, many of the roads in the USGS files did not contain attributes. This was not considered to be a problem since attributes were present for the major roads through the valley. A simplified roads coverage *major_roads* was created by selecting roads which contained route numbers or names from *roads*.

8.2.2 Hydrography

The hydrography coverage consists of flowing waters, standing waters, and natural and manmade wetlands. The hydrography coverage was produced from four data sets purchased from the Teale Data Center (Teale, no date). The Teale data sets were appended together, re-projected and the portion of the coverage extending outside IWV removed.

8.2.3 Public Land Survey System

This coverage represents the Public Land Survey System (PLSS) data for IWV. The source data was obtained from a Bureau of Land Management (BLM) Geographic

Coordinate Database acquired from the California state offices Branch of Cadastral Services (BLM, No Date). The source data files are supplied by Township and Range. The coordinate files were converted to coverages using an AML supplied with the data and were appended to create a single coverage for IWV.

The TRS_REF coverage contains gaps due to lack of source data in some areas. This coverage is a revised version of a PLSS coverage previously produced by The University of Arizona. This revised coverage include additional attributes for each polygon. Each polygon is attributed with a single string indicating its township, range and section. Individual attributes for township, range and section are also included.

8.2.4 Digital Elevation Models and Hillshades

The 30 meter resolution Digital Elevation Model (DEM) files for the IWV watershed were acquired from the USGS. A mosaic of all DEMs was created along with three subset mosaics representing the individual and combined study areas of Clark and Einloth. Hillshades were produced from each mosaic DEM. A total of four DEMs and four hillshades were produced.

The IWV watershed includes 91 DEMs, each covering the same area and using the same name as the associated 7.5 minute quadrangle. A list of the quadrangles is included in Table 7. All of the DEMs except for one were available as Level 2, providing adequate

quality for this project. Several Unix shell scripts and ARC/INFO AML utilities were created to speed processing and ensure consistent treatment of the DEMs.

Initially, a Unix script was used create a text file containing basic information about each DEM. In addition to the file name used by the USGS on the CD, the Unix script extracted the following information from the header of each DEM: quadrangle name, corner coordinates, elevation unit code, and level code. Awk, named after its authors Aho, Weinberger and Kernighan, is a Unix programming language used to manipulate structured text files and produce formatted output (Dougherty and Robbins, 1997). Awk was used on the text file noted above to create various input files for the AML utilities described below. Copies of the Unix shell scripts used for this project are included in Appendix D.

An ARC/INFO AML was used to convert all of the USGS DEM files into ARC/INFO GRID formatted files. Using the information in the text file noted above, a GRID AML was used to convert any DEM with elevation units in meters to feet using GRID. A second GRID AML was then used to create a mosaic of the individual DEMs. Interior NODATA values in the mosaic DEM were filled using a GRID conditional statement. The conditional statement passes a 4 cell by 4 cell square over the mosaic. When a cell containing NODATA is encountered, the value of the cell is changed to equal the average

of the 16 cells contained in the square. A copy of *demmos.aml* is included in Appendix C.

A hillshade of the mosaic DEM was created and visually inspected for errors. In general, the quality of the mosaiced DEM was good, with some anomalies visible in portions of the seams between quadrangles covering large areas of low relief, such as the surface of a playa lake. In several instances the hard copy source maps were reviewed to assess potential reasons for the anomalies. In all cases the source maps showed features such as drainages that did not continue across the boundary of two quadrangles, or contour lines that did not edge match. It is estimated that the anomalous areas of the mosaic represent much less than one percent of the total area and do not affect the intended use of the mosaic DEM or hillshade. Further investigation would be required if the mosaic DEM were to be used for surface water modeling or analysis.

8.2.5 Quadrangle Reference

The polygonal coverage *topo_ref* contains the outlines and locations of all 7.5 minute quadrangles in the IWV watershed. The corner coordinates for each quadrangle were extracted from the DEMs using an awk script. The coordinate values were combined with attribute information in a text file which served as input to an ARC/INFO AML. The AML generated and attributed a polygonal coverage for each quadrangle and appended them together to form the quadrangle reference coverage for the entire watershed. A copy of *quadindex.aml* is included in Appendix C.

The *topo_ref* coverage serves two purposes. First, it provides a graphical index to the location of the quadrangles located within the IWV watershed. Second, it serves as an index to the DEM source data files in both their original ASCII and Arc Info Grid formats.

8.2.6 CLNAWS Boundary

A polygonal coverage of the boundary of the CLNAWS was created from survey records provided by CLNAWS. The *cl_bnd* coverage was created using the Coordinate Geometry (COGO) feature of ArcEdit which allows polygons to be created through input of traverse bearing and distances.

8.2.7 Hydrological/Geochemical Study Area Boundary

The polygonal coverage *geohydro_bnd* was created from two intermediate coverages that were not maintained. A polygonal coverage was created from the corner coordinates of the geochemical study area DEM *dem_geochem*. This coverage was combined with the bounding arcs from the water level drawdown coverage *aedd153*. The internal arcs in the resulting coverage were removed using ArcEdit.

8.2.8 Digital Raster Graphics

The Digital Raster Graphics (DRGs) for the IWV watershed were obtained from the USGS. It is expected that the DRGs will be used as an infrequent, but useful reference for the CLNAWS environmental staff. For the purpose of this project, the white border around the edge of the map or collar, has been maintained. De-collaring of the maps may be performed in the future to allow mosaicing of the maps if use of the application indicates this would be of value.

8.2.9 Digital Orthographic Quarter Quadrangles

The Digital Orthographic Quarter Quadrangles (DOQQs) for the IWV watershed were obtained from the USGS. Like the DRGs, it is expected that the DOQQs will be used as an infrequent, but useful reference for the CLNAWS environmental staff. One potential use is to allow visual assessment of remote areas of the IWV prior to performing field investigations.

9.0 METADATA

Metadata was created for all of the coverages described above using an AML written by Lockheed Martin personnel (Bice, 1999). The metadata produced by the AML contains the required elements outlined in the Federal Geographic Data Committee (FGDC) metadata standard (FGDC, 1998).

In the context of this project, the purpose of the metadata is to provide the user with a description of the coverage and basic information about how it was produced. To facilitate ease of use, the metadata text documents were converted to Hyper Text Markup Language (HTML). A HTML index page was created which contains the names and brief descriptions of the coverages (Figure 12).

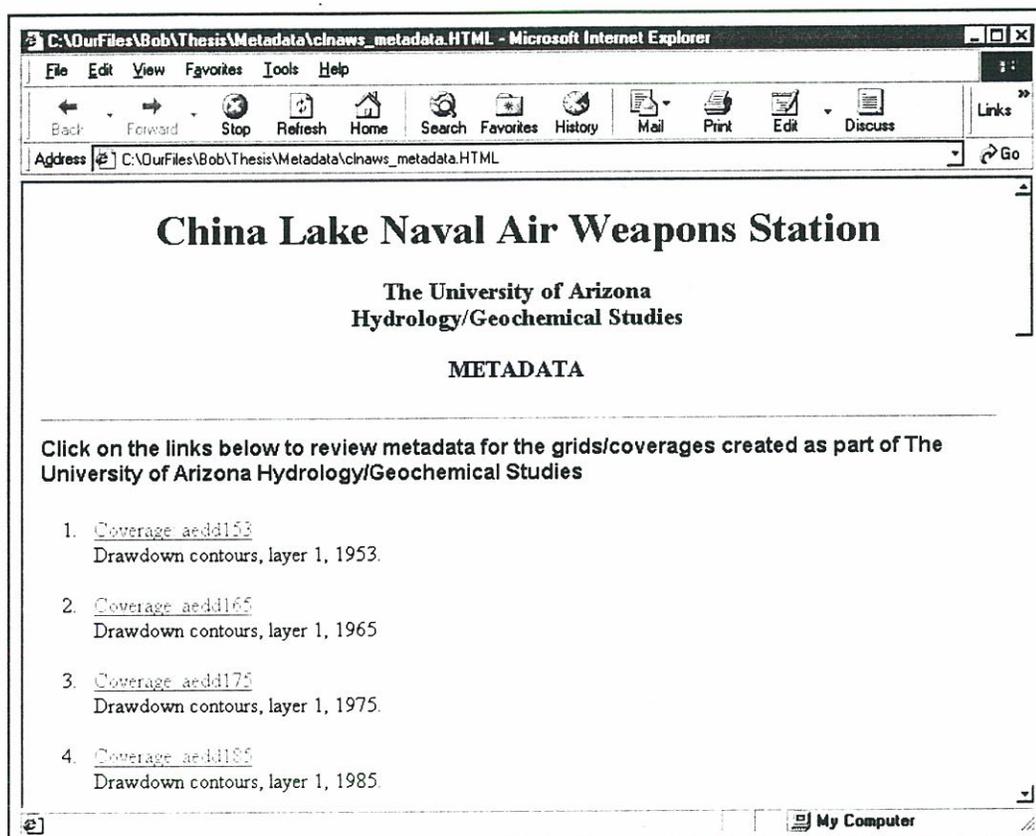


Figure 12: HTML metadata index page.

The coverage names serve as hyperlinks which display the full text of the metadata for each coverage when activated. The index page is accessed through a link in the “Favorites” section of the default web browser on the CLNAWS computer.

A hard copy sample of the metadata is included in Appendix E. Electronic copies of all the metadata files are included in Appendix B. The AML used to produce the metadata is included in Appendix B as the tar archive *ArtMetadata.tar*.

10.0 ARCVIEW APPLICATION

ArcView and the Spatial Analyst and 3D Analyst extensions are provided on the IWV computer. An ArcView project file is used to make the GIS data and Access interface available to the user. A shortcut on the Windows desktop allows direct access to the project file without first starting the ArcView application. A second shortcut is available to start ArcView without going into the IWV project file.

The IWV project file contains a startup script which requires the user to rename the project file before work can be performed. Any modifications are then made to the new project file. This technique maintains the integrity of the original project file.

10.1 IWV Project File Interface

All of the original ArcView functionality has been maintained in the IWV project file. The item, "AccessQueries" has been added to the menu bar (Figure 13).

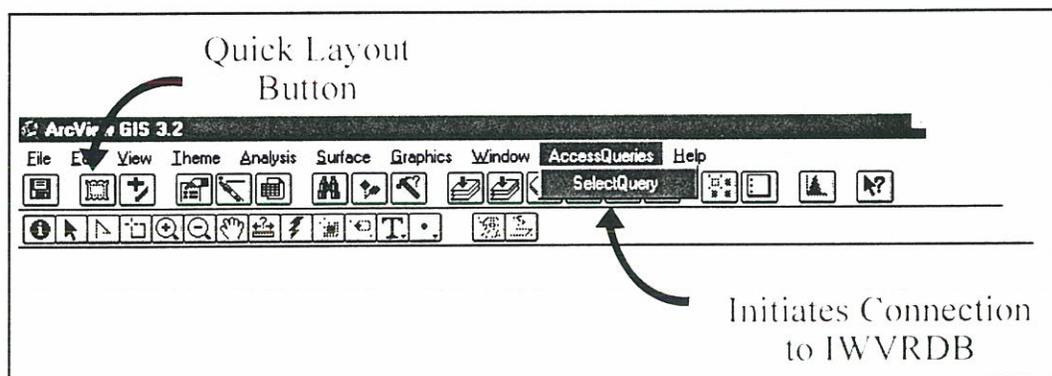


Figure 13: Modifications to ArcView interface.

The AccessQueries menu contains the item "SelectQuery" which allows the user to select an existing query in the database. A button has also been added to the interface which allows the user to quickly create a basic layout from the active View (Figure 13). The functionality of these features is discussed in detail below.

The AccessQueries menu contains the item “SelectQuery” which allows the user to select an exiting query in the database. A button has also been added to the interface which allows the user to quickly create a basic layout from the active View (Figure 13). The functionality of these features is discussed in detail below.

11.0 CONNECTING ARCVIEW AND THE IWV DATABASE

The IWV database has been connected to ArcView using Microsoft's Open Database Connectivity (ODBC) standard. The ODBC connection allows the user to access data contained in the IWV database. The user can perform queries against the IWV database and the selected record set is returned as an event theme which is displayed as points in the active View or Scene.

11.1 ODBC Connection

Connectivity to ODBC compliant databases is a standard function of the Windows operating system. Connections are created using the "ODBC Data Source Administrator" accessed through the Windows Control Panel. Figure 14 shows the ODBC Data Source Administrator window with the connection for the IWV database connection highlighted.

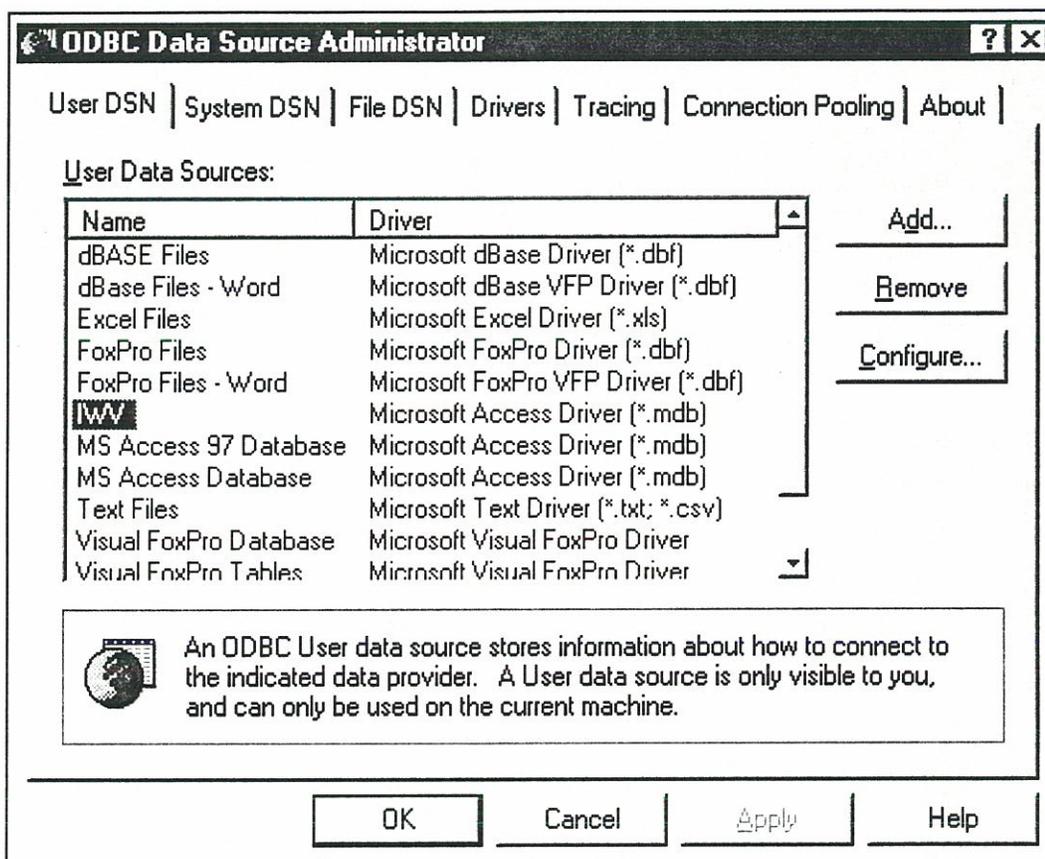


Figure 14: Example of ODBC connection.

Each ODBC connection is given a unique name, listed in “User Data Sources” in Figure 14. An ODBC connection stores information regarding the path and name of a database and the driver required to connect to the database. Existing ODBC connections are referenced by applications using the Data Source Name (DSN).

The DSN for the Iwv database is “Iwv”. Clicking the “Configure” button in the ODBC Data Source Administrator window allows the user to set the path and name of the database connected to the DSN. In the case of the Iwv database this information is: “E:/Iwv_data_e/AccessDatabase/IwvWorking.mdb”.

The DSN is used by the IWV ArcView application to connect to the external database. As delivered to CLNAWS, the ArcView application uses the IWV DSN as described above. Connections to other DSN may be made by modifying the file “iwv.ini” described in “Assigning Values to Script Variables” below.

11.2 Avenue Scripts

Avenue, the ArcView scripting language, is used to initiate the connection to the IWV database and to display the results of the Access queries in ArcView. The IWV project file has been modified so that the “AccessQueries” menu becomes available only when the active document is a View or Scene. The “AccessQueries” menu contains one item “SelectQuery”, which has been linked to an Avenue script. Although the menu items remain the same, the script that the “SelectQueries” item is attached to is dependent on the active document type, i.e. a View or Scene. Clicking on the “SelectQueries” item calls the *iwvodsq.ave* script from a View and *iwv3dsq.ave* from a Scene. Copies of the scripts are included in Appendix F.

11.2.1 Retrieving List of Queries

When initiated by clicking on the “SelectQuery” menu item, the scripts use the DSN to establish the ODBC connection to the IWV database. The script retrieves a list of all table objects from the database listed in the DSN. When connecting to an Access database, the resulting list includes all tables and queries in the database. For the IWV database project, a new list containing only queries is created by filtering the original list for object names beginning with “av”. For this reason, it is important that the Hungarian notation used to name the objects in the IWV database be maintained, especially for queries.

11.2.2 Assigning Values to Script Variables

The Avenue scripts contain variables which are set by the file *iwv.ini*. *Iwv.ini* is a plain text file with lines in the form of: `VariableName&VariableValue`. The ampersand serves as a token value used by the scripts to parse each line into the variable name and value. Both *iwvodsq.ave* and *iwv3dsq.ave* obtain the values for their variables from *iwv.ini*. A copy of *iwv.ini* is included in Appendix F.

The following information is provided to the scripts from *iwv.ini*:

- Database path and file name;
- Data Source Name (DSN);
- Field names for X, Y and Z coordinate values;
- Field name for well type information;

- Elevation reference surface path and file name;
- User identification; and
- User password.

By default, the scripts look for *iwv.ini* in: “E:/IWV_data_e/AccessDatabase”. This is not an automatic process and the scripts must be updated if the location of *iwv.ini* is modified.

The *iwv.ini* file must contain valid entries for the database path and file name, DSN, X, and Y field names for either script to run correctly. The well type data may be omitted, but the wells will not be color coded by type in the theme produced by the script.

The Z coordinate and elevation surface information are required only for displaying the results of a query in a Scene. The user identification and password information is not used, but has been included for convenience should IWV personnel choose to password protect the database.

Use of a separate file to set the variable values has two advantages. Firstly, it eliminates the need for the user to modify the scripts if the value of a variable changes. For example, the user may want to plot the locations of the wells using geographic coordinates rather than Universal Transverse Mercator (UTM) coordinates. In the case of IWV database, the following modifications to *iwv.ini* would be made:

Original	Modified
xfield&xutm_m83	xfield&Longitude_dd
yfield&yutm_m83	yfield&Latitude_dd

The separate variable value file method is convenient because the user does not need to seek out each occurrence of a variable in the script, modify its value and recompile the script, a process that can be time consuming and frustrating if an instance of a variable is overlooked, or a typographic error goes undetected. Secondly, the use of a separate variable value file makes the scripts more portable between computers. The scripts can easily be loaded into another copy of ArcView and linked to a menu item or button. The variable values contained in *iwv.ini* are modified and the file saved to the new computer's Windows directory. The scripts would then be available for use with virtually no modification.

11.2.3 Error Checking

Both scripts perform error checking to ensure that required fields, as defined in *iwv.ini*, are present in the selected query. Both scripts require that the xfield and yfield variables have valid values assigned to them. Additionally, *iwv3dsq1.ave* requires that the zfield has a valid value assigned to it. If any of the above fields are missing from the selected query the user is prompted with a error message which indicates the specific problem (Figure 15).

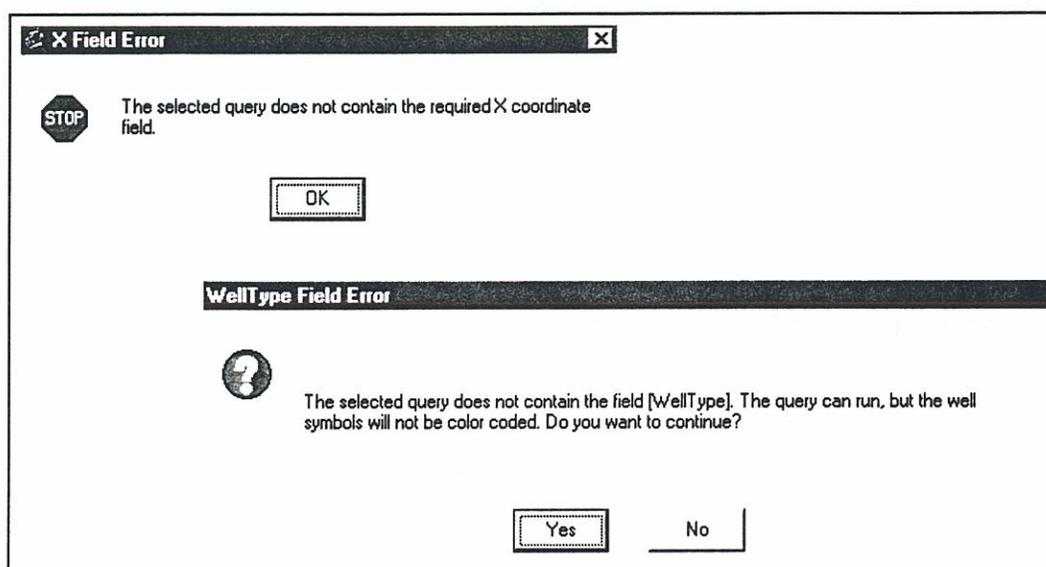


Figure 15: Sample error messages resulting from missing fields in queries.

A missing value for the xfield, yfield or zfield variables will return an error message and then terminate the script. Both scripts will check if the welltypefield variable contains a value. A missing value for the welltypefield variable will notify the user that the wells will not be color coded in the View or Scene, and will give the user the option to continue or exit the script.

If a query is initiated for a theme that already exists in the active View or Scene, a message box informing the user of the situation is displayed (Figure 16).

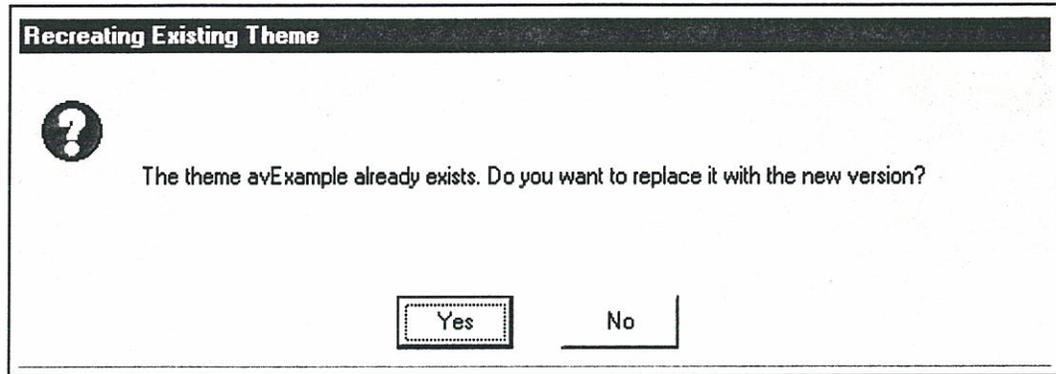


Figure 16: Replacement of existing themes.

The message box requests the user to indicate if the existing theme should be replaced. The default selection is “Yes” which results in the replacement of the theme and related table document. The new theme is placed into the Table of Contents in the same location as the replaced version. This ensures that the drawing order of the themes established by the user is maintained. Additionally, the feature attribute table for the replaced version, if present, is deleted from the table of contents. Selecting “No” terminates the script.

12.0 PERFORMING QUERIES

All of ArcView's original functionality for performing queries against ODBC compliant databases has been retained in the IWV ArcView project. Additional functionality has been added to facilitate displaying the results of Access queries using ArcView. The user has been provided with the ability to display data from the Access database in both two dimensional Views and three dimensional Scenes. Error checking is performed to ensure the queries contain the fields necessary to display the data. The user is prompted if the query does not contain the necessary data, or if the data is already present in the View or Scene.

12.1 Executing a Query

The query to be executed is selected by clicking on AccessQueries → SelectQuery from the ArcView menu bar. The user is presented with a filtered list of the query objects in the IWV database (Figure 17).

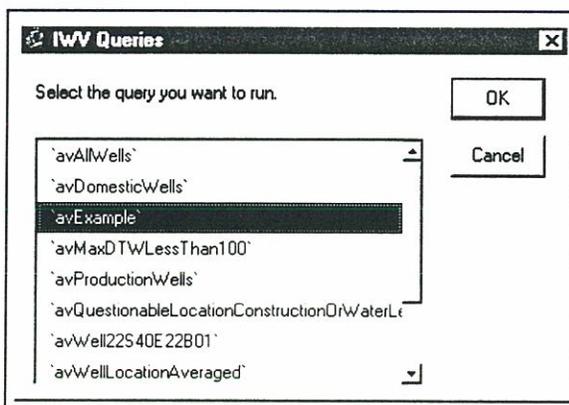


Figure 17: Listing query objects in database.

The user selects the desired query and the results are added to the active View as an event theme (Figure 18).

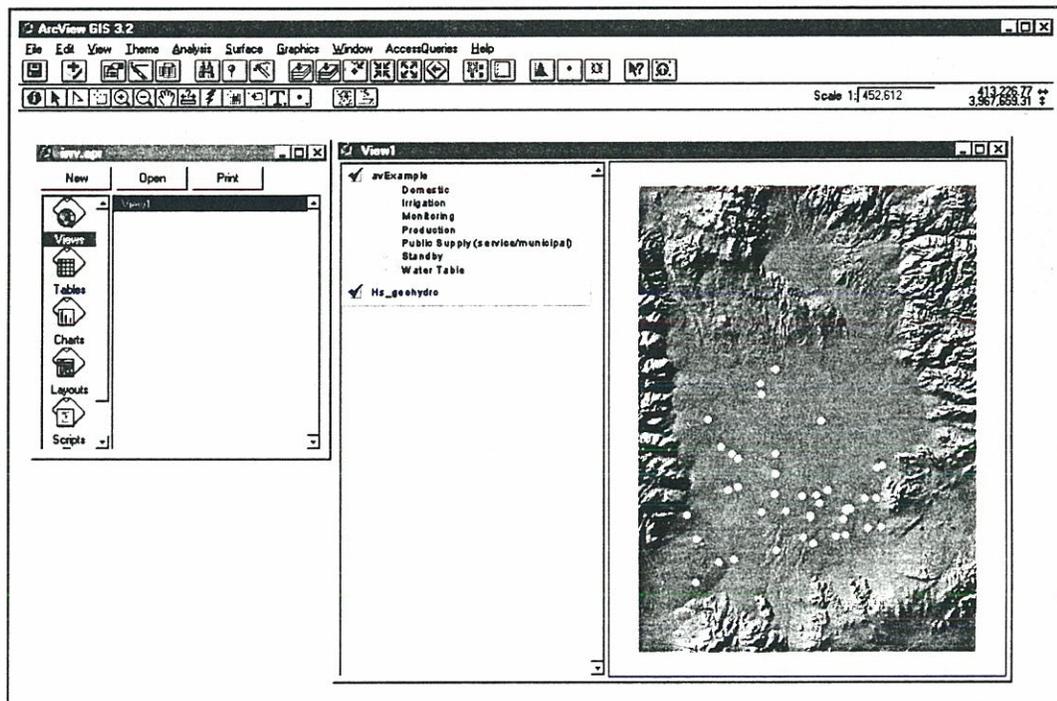


Figure 18: Event theme created from Access database: View.

The same functionality is available to the user when the active document is a Scene (Figure 19).

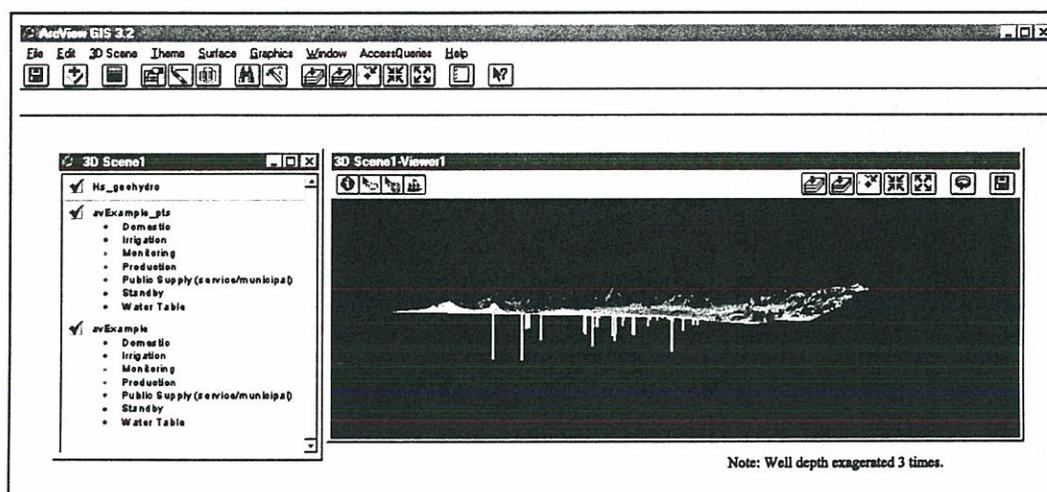


Figure 19: Event theme created from Access database: Scene.

When an Access Table query is initiated from a Scene, two themes are added. The first theme displays the well in three dimensions with the well features extruded to the depth value contained in the database field referenced by the *iwv.ini* zfield variable. The second theme represents the same data set as points. When referencing a theme to an elevation surface in ArcView, the referenced theme can intersect the surface resulting in a portion of the referenced theme being hidden beneath the surface. Using the two theme method ensures that each well location is visible in plan view.

13.0 CREATING LAYOUTS

The IWV project file contains a “Quick Layout” button to automatically create a layout from the active View (Figure 13). The button is linked to a modified version of a script created by Howie Sternberg (Sternberg, 1999). A copy of the script *iwvqmap.ave* is included in Appendix F. Refer to the script header for modifications to Sternberg’s script.

The purpose of the “Quick Layout” button is to allow the user to create a layout with a minimum of effort. Once created, the layout may be modified using standard ArcView functionality.

13.1 Using Quick Layout

Upon clicking the “Quick Layout” button the user is presented with a series of dialog boxes. The first dialog box allows the user to select a printer and modify the printer settings such as paper size.

Figure 20 presents the second dialog box displayed to the user.

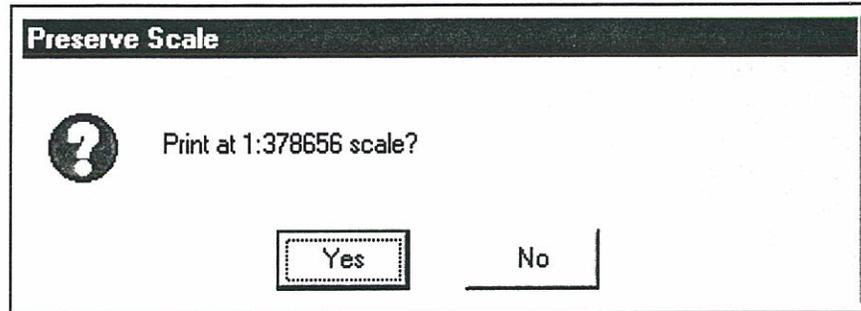
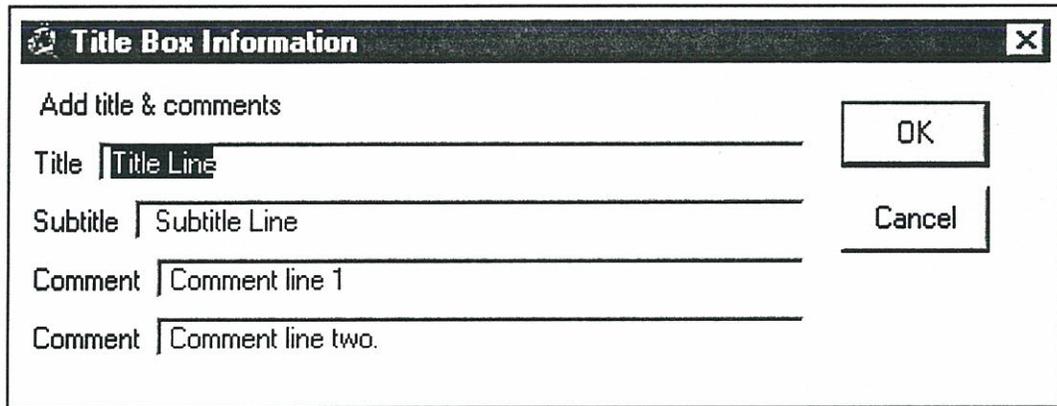


Figure 20: Maintaining View scale in Layout.

The scale presented in the “Preserve Scale” dialog box is derived from the active view. Selecting “Yes” will maintain the same scale in the Layout. Decreasing the size of the view frame in the layout will result in cropping of the image since the scale is held constant. Increasing the size of the view frame in the layout will have no effect on the image extent since the full extent of the image, as seen in the active view, is presented in the layout by default.

Selecting “No” from the Preserve Scale dialog box will allow changing the scale of the view frame in the Layout. The image extent, as seen in the active View, will be maintained in the Layout regardless of changes made to the size of the View frame in the Layout. The size of the scalebar will adjust automatically to changes made in the size of the View frame. The interval and number of divisions on the scalebar will remain constant unless modified by the user.

The user is next presented with a dialog box which allows addition of a title and comments to the layout (Figure 21).



Title Box Information [X]

Add title & comments

Title | Title Line

Subtitle | Subtitle Line

Comment | Comment line 1

Comment | Comment line two.

OK

Cancel

Figure 21: Adding Title and Comments to Quick Layout.

The information that is entered into the “Title Box Information” dialog box is maintained until changed by the user.

The user is next presented with simple “Yes” “No” dialog boxes which provide the option to preview and print the layout. The final dialog box allows the user to delete or rename and save the layout.

Figure 22 presents an example of the layout produced by using the “Quick Layout” button.

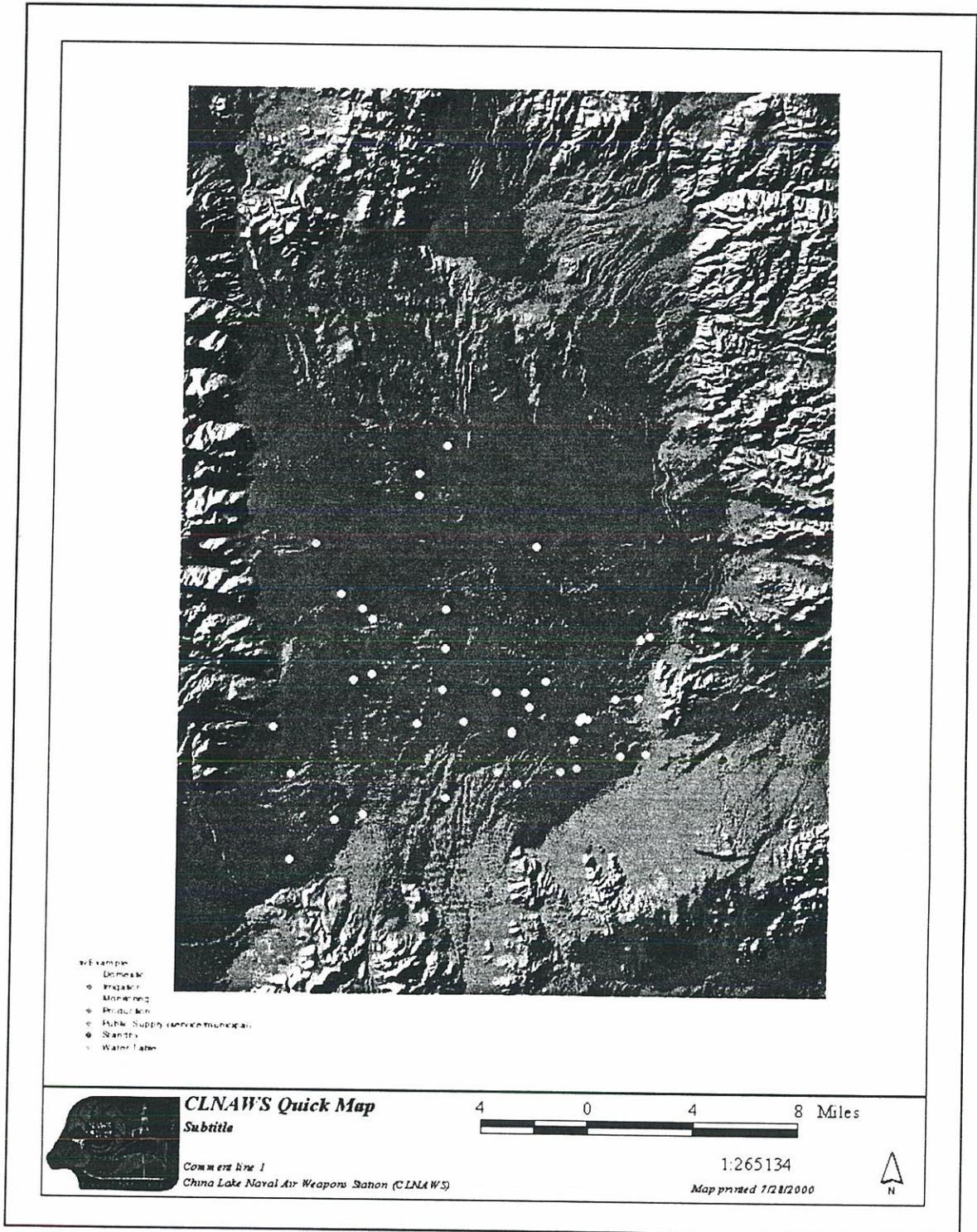


Figure 22: Example of layout using Quick Layout function.

The scalebar interval is automatically set to $1/20$ the visible portion of the View. This works well for most scales, but in some cases the position of the scalebar may need to be dragged to a new location to improve appearance of the Layout.

14.0 EXAMPLE APPLICATION OF THE SYSTEM

While both the ArcView and Access applications are useful on their own, it is hoped that the combination of two will prove to be a valuable tool for CLNAWS personnel. The example provided in this chapter illustrates how the two applications together can be used to answer resource questions.

14.1 Resource Question

The following hypothetical question will be used to demonstrate application of the system:

An arsenic level of 2.2 milligrams per liter (mg/L) has recently been detected in the monitoring well designated 26S40E22B01. The United States Environmental Protection Agency (USEPA) is considering changing the Maximum Concentration Level (MCL) for arsenic from 50 micrograms per liter ($\mu\text{g/L}$) to 5 $\mu\text{g/L}$. Our hypothetical resource manager would like to know the location of all wells that could be used for groundwater production located within a 10 kilometer radius of the monitoring well, and how the minimum recorded depth to water in those wells compares to the average depth to water recorded in the monitoring well.

14.2 Processing Steps

The processing steps used to solve the question posed above are as follows:

- 1) Define the data sets required and construct the Access queries to extract the required data from the IWV database.
- 2) Create themes in the IWV ArcView based on the queries created in Step 1.

3) Perform the spatial analysis using the ArcView application.

These steps are described in detail in the following sections.

14.2.1 Defining Queries

The final answer to the resource question posed above will be solved using a “Theme-on-Theme” analysis in ArcView. A Theme-on-Theme analysis selects features in one theme based on their relationship to features in a second theme. For this example, the first theme contains the location of the monitoring well 26S40E22B01, its average depth to water and maximum detected arsenic concentration. The second theme contains all of the production wells with their arsenic levels and minimum depth to water measurement.

Figure 23 shows the QBE grid for the select query that extracts the data for well 26S40E22B01.

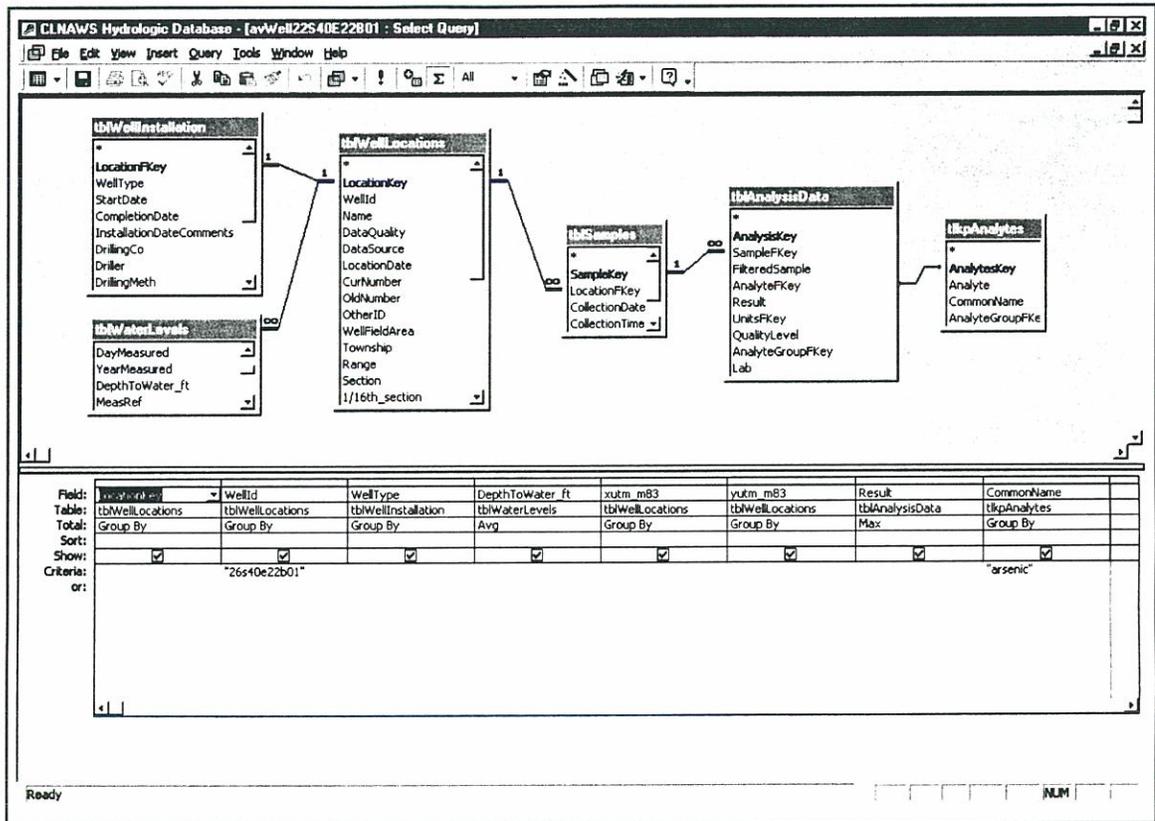


Figure 23: Setup for “avWell26S40E22B01” query.

The query is then saved using the procedures outlined in Section 7.3 as “avWell26S40E22B01”.

Figure 24 shows the QBE grid setup for the select query that summarized the production wells in the IWV database.

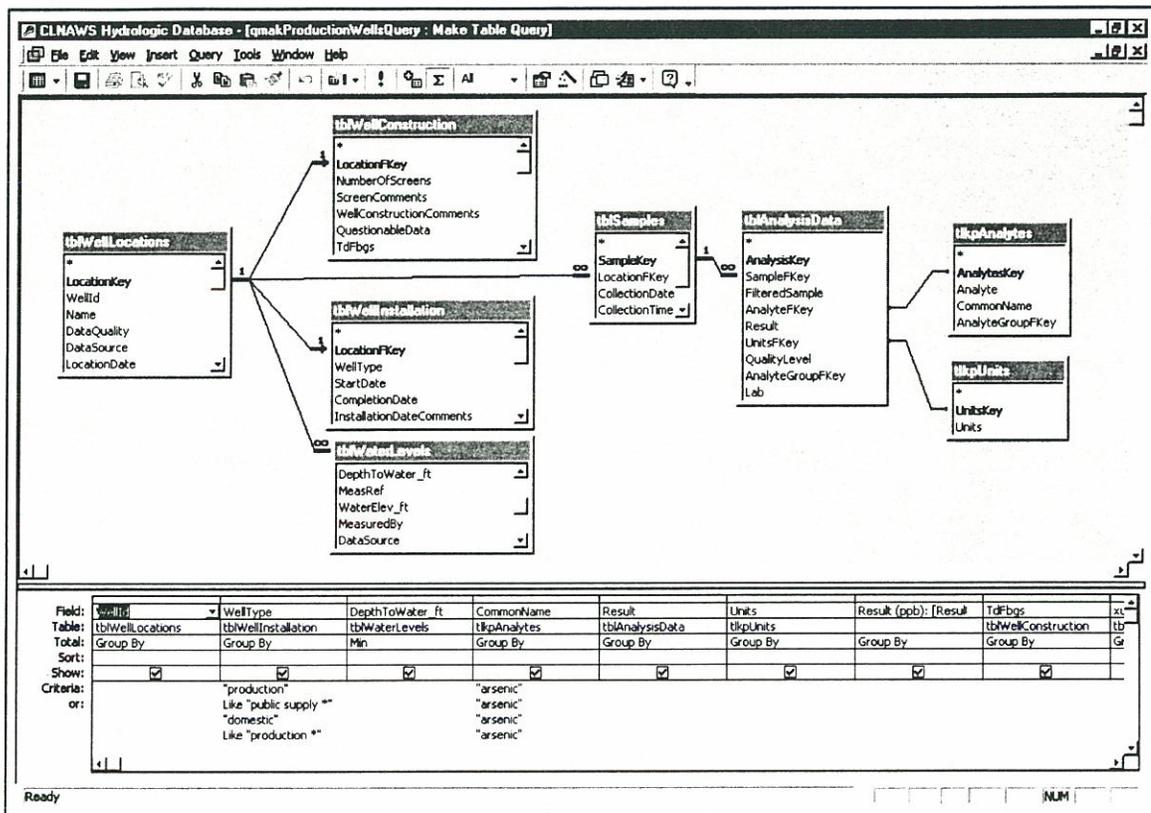


Figure 24: Setup for “qmakProductionWells” query.

The Make Table query shown in Figure 24 creates the new database table called “avProductionWells” which is accessible from the IWV ArcView application. The Make Table query “qmakProductionWells” selects all of the wells that have been analyzed for arsenic where the well type fulfills the following criteria: “production”, “production *”, “domestic” or “public supply *”. Since it is likely that numerous depth to water measurements have been collected for each well, the query also filters the records so that only the record with the minimum depth to water is added to the table.

14.2.2 Creating Themes

Themes containing the data from the Access objects “avAllWells” and “avProductionWells” are added to the ArcView project using the methods described in Section 12.1. Figure 25 shows the resulting View in the ArcView application.

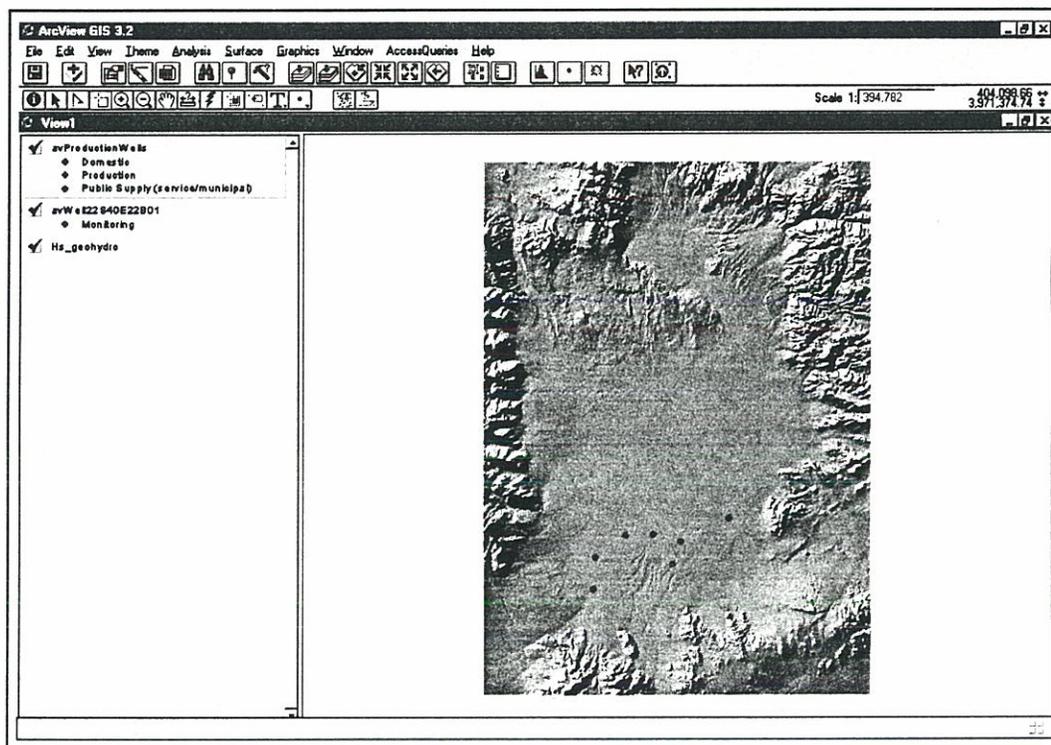


Figure 25: Themes for Theme-on-Theme analysis.

14.2.3 Performing the Theme-on-Theme Analysis

Performing a theme on theme analysis is a two step process. Step 1 is to select the item or items in the first theme that will be related to the second theme. Step 2 is to define the second theme and type of analysis to be performed. These steps are describe in detail below.

Step 1) Make the "avWell26S40E22B01" theme active by clicking on the theme title until it is the only theme that appears to be "raised". Well "26S40E22B01" is selected by querying the theme using the ArcView query builder accessed by selecting Theme → Query from the ArcView menu bar. Figure 26 shows the query builder window with the desired query already constructed. Note the raised appearance of the avWell26S40E22B01 theme which signifies that it is active.

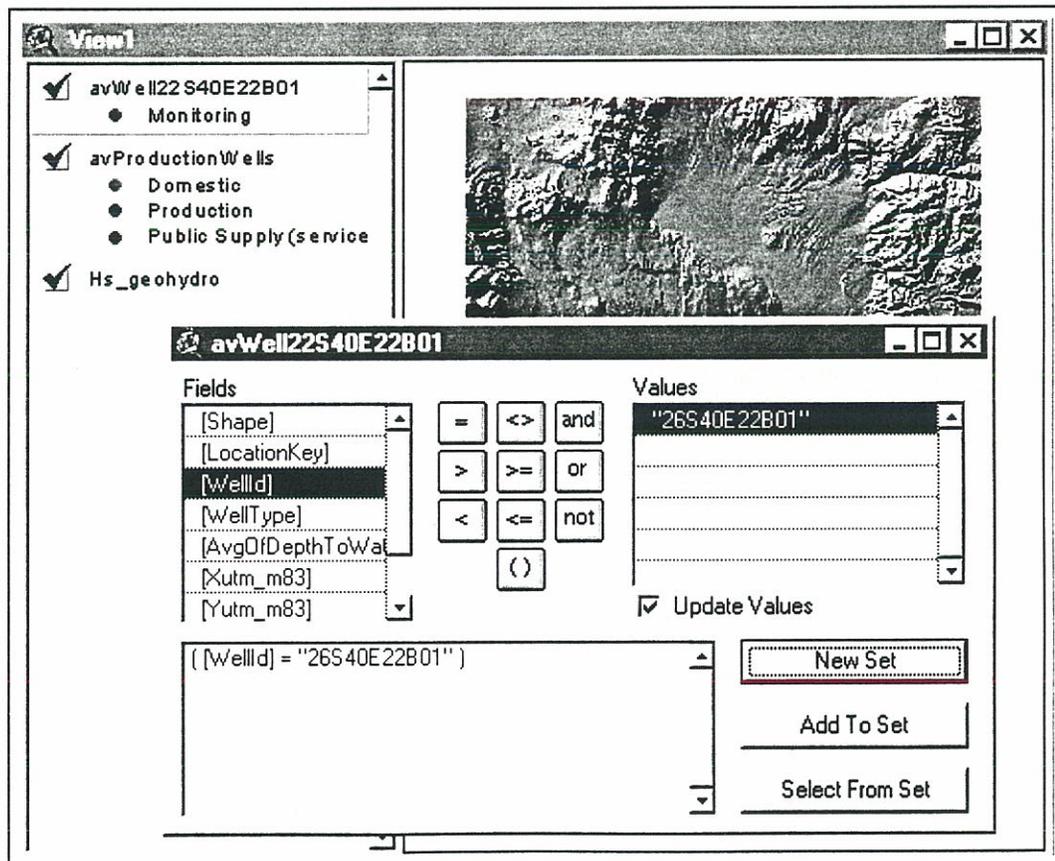


Figure 26: ArcView Query Builder window.

The query to select well 26S40E22B01 was created by selecting the desired field, logical operator and value from the appropriate sections of the query builder window. The query is

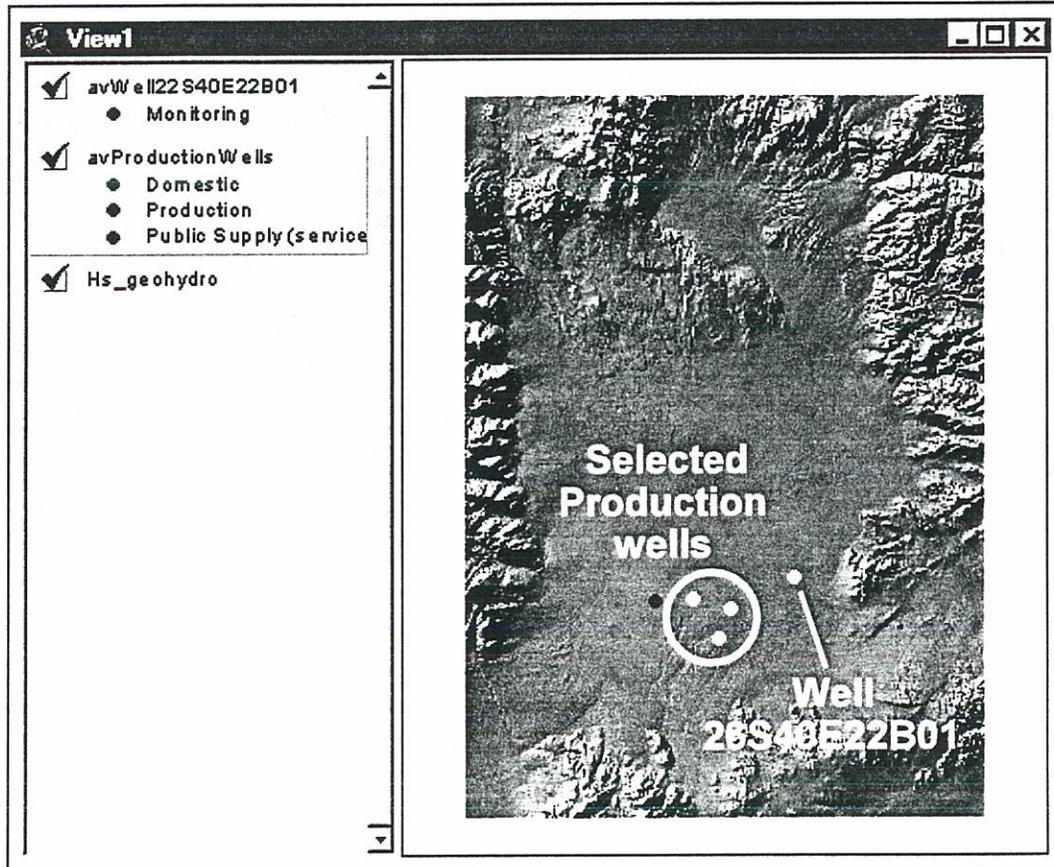


Figure 28: Results of Theme-on-Theme analysis.

The data associate with the selected wells can be viewed by selecting Theme → Table from the ArcView menu bar. Figure 29 shows the attribute table with the records for the production wells that are within 10 Km of well 26S40E22B01.

Shape	WellId	WellType	MinDistToWater	Concentration	Result	Units	QualityLevel	Leads
Point	26S39E26A01	Public Supply (service/municip)	245.000000	Arsenic	0.000000	mg/L		1030.000000
Point	26S39E27D01	Production	240.639999	Arsenic	0.030000	mg/L		380.000000
Point	26S39E32M00	Domestic	316.000000	Arsenic	0.050000	mg/L		
Point	26S40E30K01	Production	165.000000	Arsenic	0.010000	mg/L		730.000000
Point	26S40E30K01	Production	165.000000	Arsenic	0.015000	mg/L		730.000000
Point	26S40E30K01	Production	165.000000	Arsenic	0.020000	mg/L		730.000000
Point	26S40E30K01	Production	165.000000	Arsenic	0.040000	mg/L		730.000000
Point	27S39E08M01	Domestic	364.000000	Arsenic	0.000000	mg/L		1020.000000
Point	27S40E06D01	Production	260.200012	Arsenic	0.040000	mg/L		720.000000
Point	27S40E06D01	Production	260.200012	Arsenic	0.050000	mg/L		720.000000

Figure 29: Attribute table with records selected by Theme-on-Theme analysis.

In this example, all of the selected records are visible, although not grouped together.

Records can be grouped together by clicking the “Promote” tool  from the ArcView button bar while viewing the table.

15.0 CONCLUSIONS

15.1 Fulfillment of Objectives

The combined ArcView and Access applications created for CLNAWS have fulfilled the stated objectives of the project. The objectives of this project were threefold:

- To improve storage and access of hydrologic data by consolidating existing data and UofA research data in a relational database.
- To allow spatial analysis and display of the data using a GIS.
- To accomplish the above using computer applications that are easy to use and scalable.

The original data supplied by CLNAWS and other sources was formatted using a variety of disparate methods. Duplication of data was common and labels used to refer to unique items, such as wells, were inconsistent. It has been shown that the quality of the data has been significantly improved by placing it into a relational database. Duplication of data has been minimized and controls have been placed on data entry to help prevent errors from being re-introduced into the data. The original data set has been expanded through inclusion of data provided by UofA researchers.

Spatial analysis of the data has been made possible by using a GIS. A total of 69 “static” themes have been included for use with the GIS. Reference themes for such features as roads and quadrangle boundaries have been included along with themes created from the output

of a groundwater model created by UofA researchers. Metadata for all of the static themes is provided as individual hypertext markup language (HTML) files viewable with common Web browsers. The functionality of the GIS has been extended by linking it to the relational database. This link allows users to create “dynamic” themes based on the data currently stored in the database.

The computer software applications used in this project, ArcView and Access, both have a large user base. Extensive training and documentation is available for both products through the Internet, third party publications and training classes offered by both the manufactures and independent consultants. The volume of data currently stored in the applications is well below their respective limits, allowing the data set to expand without adversely affecting the functionality of either.

15.2 Considerations for Use

ArcView and Access are both powerful software applications with considerable functionality. Both applications take full advantage of a Graphical User Interface (GUI) consistent with the Microsoft Windows operating system. Although the GUI makes the applications easy to use, their extensive functionality requires that the user invest some time learning to use the applications. The amount of time required is dependant on the complexity of the tasks that the user wishes to perform. Creating simple maps in ArcView or performing select queries in Access can be accomplished with little investment of time. Learning to

perform spatial analyses between data themes in ArcView, or creating multi-table queries with complex criteria in Access, will require a more serious time commitment from the user.

The IWV relational database contains data from numerous sources. Every effort has been made to maintain the integrity of the data while converting it into the relational format. However, it is possible that discrepancies may be observed between the data in the database and other sources. These discrepancies may have occurred due to conflicts between the original data sources. The following fields have been included to assist in locating records where conflicts in the original data existed:

[tblWaterLevels].[QuestionableMeas]
[tblWellConstruction].[QuestionableData]
[tblWellLocations].[LocationAveraged]

The query “avQuestionableLocationConstructionOrWaterLevels” has been included in the Access application to identify these records for the user.

It is expected that the number of discrepancies encountered by the user will be small. The relational structure used in the IWV database will help prevent future discrepancies.

15.3 Future Work

It is expected that with time, users of the applications described herein will find aspects which they would like to change, or additional functionality which would increase the usefulness of the application(s). Changes and modifications to both applications can be made using the Avenue scripting language for ArcView and the Visual Basic programming language for Access. Both Avenue and Visual Basic are relatively easy to learn with a minimum of effort when compared to other scripting/programming languages such as “C”.

Modifications that may improve the usefulness of the IWV database can be made without knowledge of Visual Basic. Several potential modifications are outlined below. The following list is not meant to be exhaustive, but rather provide insight into the type of modifications that may be performed.

- *Enforcement of logical consistency.* The IWV database contains many features to help prevent erroneous data entry, such as water level readings being entered for a well that does not exist, or addition of a new well without entering its UTM coordinates. Additional controls can be added to further limit errors such as a well's total depth exceeding the total depth drilled, or the well casing diameter exceeding the borehole diameter.
- *Combine redundant fields.* The original notation used in the source data has been maintained in the IWV database. For example, the lookup table tlkpWellTypes contains

designations for “Public Service” and “Public Supply (service/municipal)”. It may be that the difference between these well types does not warrant separate classifications, in which case they could be combined.

- *Removal of unused data.* One of the purposes of the IWV database was to assemble the historic data into a more useable format. It may be that some of the data is of little use to the hydrologists at CLNAWS and merely adds to the size of the database. Fields that do not serve as primary or foreign keys may be removed without affecting the functionality of the database. Removal of fields from data tables may also require the modification of queries or forms linked to the tables and should only be undertaken after a reasonable understanding of Access and relational databases is obtained.

APPENDIX A: Tables

Table 1: Summary of Table Schema: tblSamples	
Field Name	Description
SampleKey	Primary key for this table.
LocationFKey	Foreign key. Relates table to tblWellLocations.
CollectionDate	Sample collection date.
CollectionTime	Sample collection time.
DataSourceFKey	Foreign key. Relates table to tlkpDataSources.
WaterTypeFKey	Foreign key. Relates table to tlkpWaterTypes.

Table 1(cont.): Summary of Table Schema: tblAnalysisData	
Field Name	Description
AnalysisKey	Primary key for this table.
SampleFKKey	Foreign key. Relates table to tblSamples.
FilteredSample	Yes or no.
AnalyteFKKey	Foreign key. Relates table to tlkpAnalytes.
Result	Detected concentration.
UnitsFKKey	Foreign key. Relates table to tlkpUnits.
QualityLevel	Quality information for sample.
AnalyteGroupFKKey	Foreign key. Relates table to tlkpAnalyteGroups.
LabFKKey	Foreign key. Relates table to tlkpLaboratories.

Table 1 (cont.): Summary of Table Schema: tblUSGS1991	
Field Name	Description
LocationFKKey	Primary key for this table.
USGS1991CalibrationWell	Calibration well used in USGS 1991 study.
USGS1991PumpWell	Pumping well used in USGS 1991 study.

Table 1 (cont.): Summary of Table Schema: tblWaterLevels	
Field Name	Description
WaterLevelKey	Primary key for this table.
LocationFKKey	Foreign key. Relates table to tblWellLocations.
MonthMeasured	Month water level collected.
DayMeasured	Day water level collected.
YearMeasured	Year water level collected.
DepthToWater_ft	Depth to water measurement.
MeasRef	Foreign key. Relates table to tlkpMeasurementRef.
WaterElev_ft	Groundwater elevation.
MeasuredBy	Foreign key. Relates table to tlkpMeasuredBy
DataSource	Foreign key. Relates table to tlkpDataSources.
QuestionableMeas	Yes, no. Indicates discrepancy in data sources.
AverageTaken	Yes, no. Were the measurements averaged.
DescriptionOfAverage	Foreign key. Relates table to tlkpDataQuality.
WLComments	Water level comments.
WLReferenceComments	Water level reference point comments.
SiteStatus	Status of site.

Table 1 (cont.): Summary of Table Schema: tblWellConstruction	
Field Name	Description
LocationFKKey	Primary key for this table. Relates table to tblWellLocations.
NumberOfScreens	Number of screens in well.
ScreenComments	Screen comments.
WellConstructionComments	Well construction comments.
QuestionableData	Indicates discrepancy in data sources.
TdFbgs	Total depth of well in feet below ground surface.
TdSource	Foreign key. Relates table to tlkpDataSources.
TdComments	Total depth comments.
MeasRef	Foreign key. Relates table to tlkpMeasurementRef.
DepthDrilled_ft	Total depth drilled in feet.
MotorSetDepth_ft	Depth to motor.
PumpSetDepth_ft	Depth to pump.
BoreholeDiameter_in	Borehole diameter in inches.
CasingDiameter_in	Casing diameter in inches.
CasingComments	Casing comments.
CasingMaterial	Foreign key. Relates table to tlkpCasingMaterial.
TopOfGrout_ft	Depth to top of grout in feet.
BottomOfGrout_ft	Depth to bottom of grout in feet.
MeasuredBy	Foreign key. Relates table to tlkpMeasuredBy.
WellSealed	Yes, no.
SealingMethod	Sealing method
TOSeal_ft	Depth to top of seal in feet.
BOSeal_ft	Depth to bottom of seal in feet.
TOSump_ft	Depth to top of sump in feet.
BOSump_ft	Depth to bottom of sump in feet.
NumberOfGravelPacks	Number of gravel packs.
GravelPackType	Type of gravel pack.

Table 1 (cont.): Summary of Table Schema: tblWellElevations	
Field Name	Description
LocationFKKey	Primary key for this table. Relates table to tblWellLocations.
TopOfCasing_ft	Elevation of top of casing in feet above mean sea level.
PadElev_ft	Elevation of pad in feet above mean sea level.
TOC-TOP	Top of casing elevation minus top of pad elevation. Not auto-calculated.
WellElevSource	Foreign key. Relates table to tlkpDataSources.
WellElevComments	Well elevation comments.
RPElev_ft	Elevation reference point.
AssumedRPElev_ft	Values assumed to be reference point elevations.
RPElevSource	Foreign key. Relates table to tlkpDataSources.
SurfaceElev_ft	Elevation of ground surface in feet above mean sea level.
SurfElevMeth	Foreign key. Relates table to tlkpSurfElevMethod.
SurfaceElevSource	Foreign key. Relates table to tlkpDataSources.
Elevation_ft-ambiguous	Elevation data assumed to be well elevations.

Table 1 (cont.): Summary of Table Schema: tblWellInstallation	
Field Name	Description
LocationFKKey	Primary key for this table. Relates table to tblWellLocations.
WellType	Foreign key. Relates table to tlkpWellType.
StartDate	Start date of installation.
CompletionDate	Completion date of installation.
InstallationDateComments	Installation comments.
DrillingCo	Foreign key. Relates table to tlkpDrillingCompanies.
Driller	Foreign key. Relates table to tlkpDrillers.
DrillingMeth	Foreign key. Relates table to tlkpDrillingMethod.
RigType	Foreign key. Relates table to tlkpRigType.
LogType	Foreign key. Relates table to tlkpLogTypes.
LithologicLogger	Foreign key. Relates table to tlkpLoggers.
ElectricLogger	Foreign key. Relates table to tlkpLoggers.
GammaLogger	Foreign key. Relates table to tlkpLoggers.
ProjManager	Foreign key. Relates table to tlkpProjectManagers.
DataSource	Foreign key. Relates table to tlkpDataSources.

Table 1 (cont.): Summary of Table Schema: tblWellLocations	
Field Name	Description
LocationKey	Primary key for this table.
WellId	Unique well identifier, may be any meaningful unique value.
Name	Well name.
DataQuality	Foreign key. Relates table to tlkpDataQuality.
DataSource	Foreign key. Relates table to tlkpDataSources.
LocationDate	Date of well location.
CurNumber	Current well number.
OldNumber	Old well number.
OtherID	Other well identifier.
WellFieldArea	Well field area.
Township	Township.
Range	Range.
Section	Section.
1/16th_section	1/4, 1/4 section.
Longitude_dd	Longitude in decimal degrees.
Latitude_dd	Latitude in decimal degrees.
xutm_m83	UTM X coordinate. NAD 83 datum.
yutm_m83	UTM Y coordinate. NAD 83 datum.
Northing	Northing values.
Easting	Easting values.
NERefSource	Foreign key. Relates table to tlkpDataSources.
LocationDescription	Description of well location.
LocationComments	Location comments.
LocationAveraged	Yes, no. Indicates if source data was averaged.
OwnerUser	Well owner or user.
GPSModel	Foreign key. Relates table to tlkpGpsModelUsed.
GPSComments	GPS comments.
PDOP	PDOP value for GPS measurements.
Comments	Comments.

Table 1 (cont.): Summary of Table Schema: tblWellProduction	
Field Name	Description
ProductionKey	Primary key for this table.
LocationFKKey	Foreign key. Relates table to tblWellLocations.
DayMeasured	Day production measured.
MonthMeasured	Month production measured.
YearMeasured	Year production measured.
SiteStatus	Status of site.
UsageSource	Foreign key. Relates table to tlkp.
Comments	Comments.
TotalProd1	Production values. These values came from original usage data.
TotalProd2	These values came from tblAnnualProd which was then removed from database since it contained no other data.
TotProd2Source	Source for total production 2 field. This data source code is for the TotalProd2 field only. Future source data should be added to [UsageSource] field.
Reading_ft3*100	Production reading in cubic feet * 100. Used by Clark.
TotalProd_gal/month	Total production in gallons per month.
TotalProd_ft3/month	Total production in cubic feet per month.
ProdCapCapability_gpm	Production capability capacity.
GPM	Gallons per minute.
ProdComments	Production comments.