

AUTOMATING TEXAS' FIRST AND LARGEST UNDERGROUND WATER DISTRICT: A WELL PERMIT MANAGEMENT APPLICATION AND DATABASE

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Abstract

The High Plains Underground Water Conservation District (HPWD) is the groundwater management agency responsible for a 6.8 million acre service area covering over 10,700 square miles in a 15-county region of West Texas. It is one of the oldest in the country and the largest of 88 such districts in Texas. Established in 1951 the HPWD managed their wells and permit applications using USGS quad maps and an extensive cross-filing system. In 2004 the HPWD began implementing a new GIS database and their first application to manage well permits. The purpose of this paper is to describe the procedures developed to automate the maps used by the District to manage wells.

The Permit Management Application (PeMA) and GIS database integrates a web-based interface for MS Access and ArcGIS for non-GIS staff to efficiently manage well permits for compliance with district regulations. A groundwater database design was developed and a database of over 72,000 wells was created over a period of 10 months. The wells were digitized from 328 scanned and registered USGS quads. A customized ArcGIS toolbar automatically updates well permit records and allows wells to be added, edited or removed from the database. A buffering tool enables District staff to determine compliance with distance requirements. The PeMA application generates eight letters and five reports communicating District information to the Texas Water Development Board, District board of directors, county appraisal districts and stakeholders. In this regard the GIS has allowed the District to more effectively and efficiently communicate and disseminate well data among staff, other agencies and their constituents.

In addition to water well permitting, the GIS is being used to analyze water level changes in the southern Ogallala aquifer, and is being considered for updating their water atlas'. Moreover the incorporation of GIS into the District has been instrumental in inspiring policy management decisions for conserving water in the southern Ogallala Aquifer.

INTRODUCTION

Groundwater is a critical resource in arid and semi-arid environments. In West Texas the southern Ogallala Aquifer provides water for irrigated agriculture and both industrial and domestic use. The effective management of this groundwater resource is critical to the well-being and economic future of the region.

To manage the groundwater resources of the state, underground water districts have been established and given the responsibility for permitting the development of new wells. This paper describes the work undertaken for the High Plains Underground Water Conservation District to develop a GIS database and well-permitting application. In particular, this paper describes the procedures developed to automate the maps which are used by the District to manage wells.

BACKGROUND

The High Plains Underground Water Conservation District is located on the Llano Estacado in West Texas (Figure 1). The Llano Estacado is a distinct geomorphic province that forms part of the Southern High Plains. The region is characterized as a relatively high-elevation, semi-arid landscape, with a wide range in both seasonal and diurnal temperatures.

The southern High Plains Aquifer (Ogallala) underlies the region and is the principal aquifer managed by the Water District (Figure 2). More than 22,000 playa lakes serve as the primary source for natural recharge. Agriculture dominates the region with the major irrigated crops including cotton, corn, grain sorghum, and peanuts. Irrigated crops account for more than 95 percent of the water pumped from the aquifer (PLJV 2003). The HPWD was created to provide orderly development and wise use of the underground water resources. One of its main functions is to sustain the existing groundwater reserves as far into the future as possible. The HPWD performs this function by managing wells that fall under their jurisdiction.

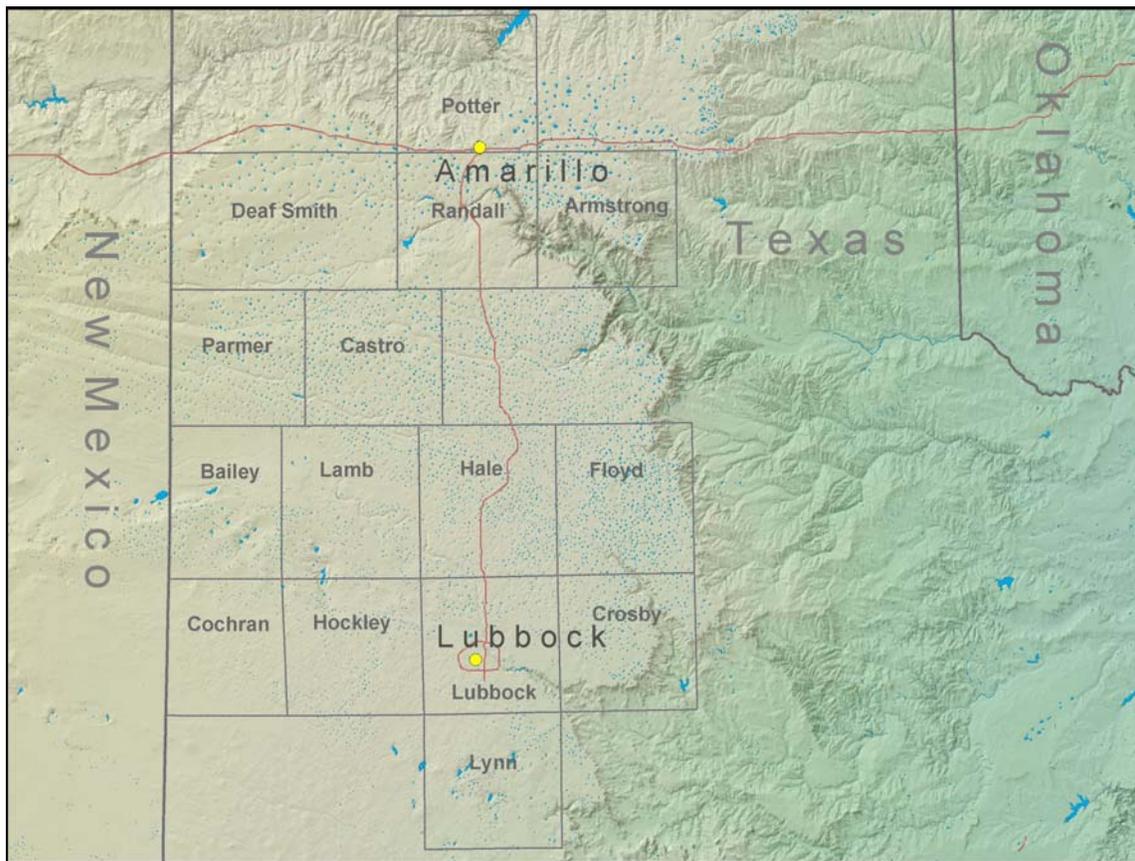


Figure 1. The HPWD jurisdiction covers all or part of 15 counties in West Texas.

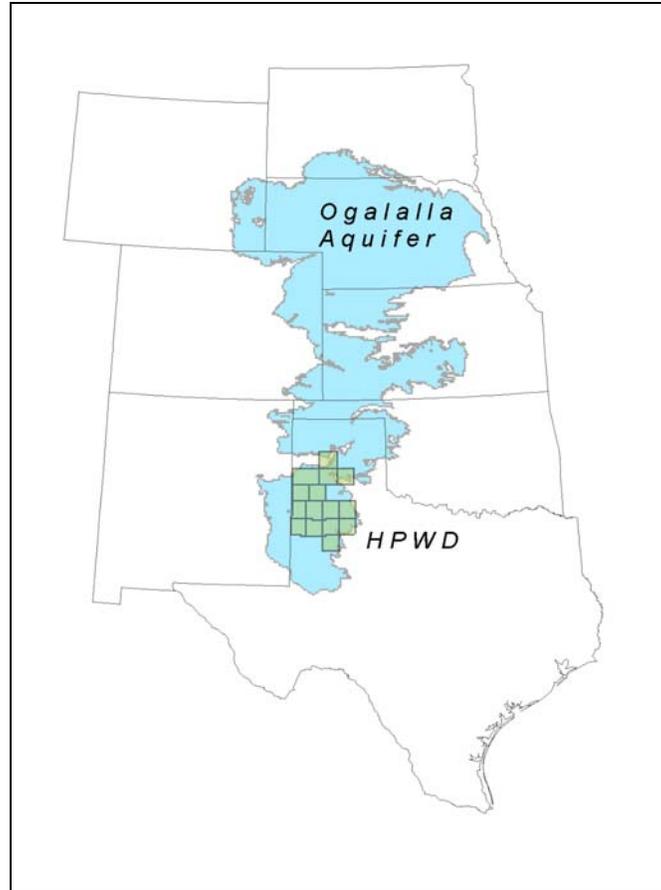


Figure 2. Location of the HPWD in relation to the High Plains (Ogallala) aquifer.

Well management involves many procedures including well permitting and well monitoring. Initially, the HPWD used pin maps to track well locations. When the pin maps became too unwieldy to maintain, this system was retired and replaced with an extensive cross-filing system based on the use of USGS topographic maps. The cross-filing system included a set of reference files, a wall of file cabinets to store permits, and a set of map drawers to store the USGS quads. Together this manual system allowed the permit secretary to look up a permit by owner name, permit number, date filed, or legal description and then find wells on the USGS quads using legal description information.

Well locations were maintained on USGS 7.5-minute quad maps or on enlarged 15-minute quad maps with collars trimmed and marginalia removed. The map cases stored over 400 USGS topographic maps. The process of plotting a well required assembling a number of items; a quad index map, the quad map, the permit application, and the legal description information. These items were placed on a table along with colored pencils and a small mylar measuring tool with a circle cut out in the middle for drawing wells (Figure 3). Once the well was located using legal and descriptive well location information, it was plotted, and then the paper products were filed in their respective filing cabinets. In place for over fifty years, maintaining and looking up information using this manual system was very time consuming.

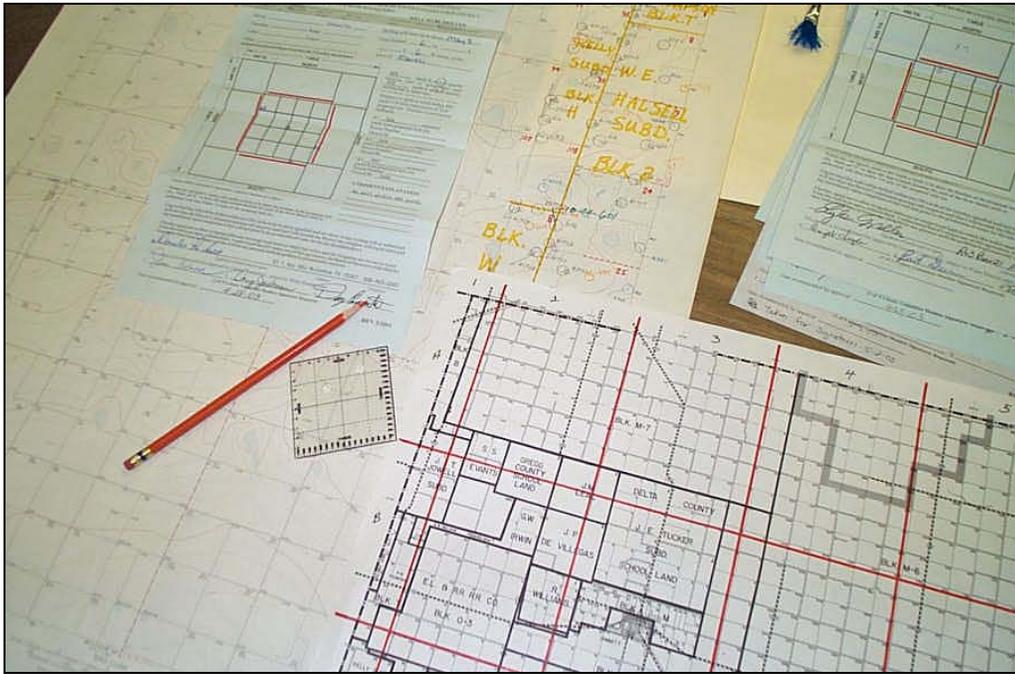


Figure 3. Items required to manually plot wells on quad maps.

METHODOLOGY

Two principal goals guided the development of this project. The first goal was to design and build a database that would serve as a robust framework for water management operations, initially for well permitting and eventually to support the other District programs. These other programs include measuring water level and water quality, hydrologic atlas development, and soil moisture/precipitation mapping. The second goal was to develop a software application to automate the well permitting process for permit record management, well location management and reporting.

To accomplish these goals the conventional database design steps were followed. These steps included a user needs assessment, data evaluation, conceptual and physical database design, database development, and application design and development. A series of prototypes were developed and demonstrated to the HPWD to incorporate their comments and gain acceptance. After the final database, application, and documentation were delivered, a series of training meetings were conducted. During the training meetings additional comments were incorporated into the documentation and enhancements were made to the permit application.

This project was conducted using a rapid prototyping approach. This approach best suited the budget, schedule and the university environment. Information was gathered from the initial design meeting, subsequent follow up meetings and conversations. These meetings formed the basis for the user needs assessment and data evaluation.

Data Evaluation

The data evaluation was conducted to determine the number of quad maps that required scanning and registering to real-world coordinates. It was also important to estimate the number of wells on the maps for the digitizing effort. The initial estimate of 50,000 wells was made based upon the number of permit records on file at the district. This number was revised upward to over 70,000 when a large number of 'grandfathered' or pre-district wells were discovered. These wells were drilled prior to the formation of the HPWD and did not have a permit on file. Capturing the locations of the grandfathered wells was important to ensure the proper spacing of new wells.

The grandfathered wells also had a numbering system that differed from the standard permit numbering system. Since the district was established, the permitted well numbering system began with the number one for each county, and was incremented by one for each subsequent permit. On the other hand, grandfathered wells were assigned numbers beginning with 40,000, 50,000, 60,000 or 70,000 depending on the well status.

The idea behind this permit numbering system was to have a unique number for each well in every county. For over 50 years, however, the permit numbering system was manually maintained, and in some counties hundreds of instances were found with duplicate permit numbers. The HPWD required that retaining their numbering system was important for maintaining a temporal framework for permit assignments. To honor the HPWD numbering system, a numeric prefix was assigned to duplicate permit numbers to uniquely identify them. At a future date the Texas state well numbering system may be implemented to compliment the district's original system. The Texas numbering system assigns values that uniquely identify a well using latitude and longitude information.

During the data evaluation over 400 quad maps were identified. For some counties duplicate sets of quad maps were found. The duplicate sets were sometimes used by field crews to map wells. Well locations plotted on these 'drive-out' maps were intended for transfer to the master set of maps. Unfortunately, in some counties the well data were not always transferred to the master set. The quality of some these drive-out maps also suffered since they were routinely taken out by field crews for validating well locations. The final evaluation identified 328 quad maps that contained all the well data. Prior to scanning these quad maps, the HPWD did not have any back up of their original maps. These 328 quad maps were slated for scanning, registering, and storing on CD-ROM as an archive.

In the course of the data evaluation it also became apparent that the names for over a dozen original quad maps had changed. Since it was desirable to have the district quad names match the DRG names, a procedure was performed to locate the old quad names on historic quad indexes and then match those locations with the corresponding DRG index to determine the new names. Finally the original quad image names were updated with the current name.

Also important in the data evaluation was determining the quality and readability of the well locations and annotation. A significant number of maps had over 500 wells plotted on them and in some cases over 800 wells with associated annotation. The annotation typically included a

permit number, a code for the status of the well (e.g. current, abandoned or destroyed), previous permit numbers, and in some cases miscellaneous notes and surface elevations. The large number of wells and associated annotation on some quad maps created challenging interpretation and readability issues. To minimize these issues the scanning resolution was set so that the well locations and annotation could be clearly read and the resulting file not exceed 50MB to the extent possible.

Another feature of many quad maps was their provisional status which made readability and interpretation difficult. Based on the US Census Bureau definition, the District includes areas that were considered “frontier”. In the 1950s and 1960s, these frontier areas did not have complete coverage of finalized USGS 7.5-minute quad maps. Some areas had only provisional USGS quads. The provisional quads were in a blue line format and they lacked features such as roads, buildings, and other cultural features.

In other areas neither a finalized nor provisional 7.5-minute quad map was available. In these situations the District used 15-minute USGS quads as the base map for wells. In most cases the 15-minute maps were also in provisional format. The 15-minute provisional quads were photo enlarged to match as closely as possible the scale of a 7.5-minute map and then they were trimmed to about the size of a 7.5-minute map. Moreover, many of these maps were trimmed to the district boundary. In this situation most of the marginalia was lost, including the corner coordinate information, the quad name, the scale and date. In other cases some photo-enlarged 15-minute maps were trimmed to show parts of two 7.5-minute quads. This made registration to the DRGs much more challenging than originally anticipated.

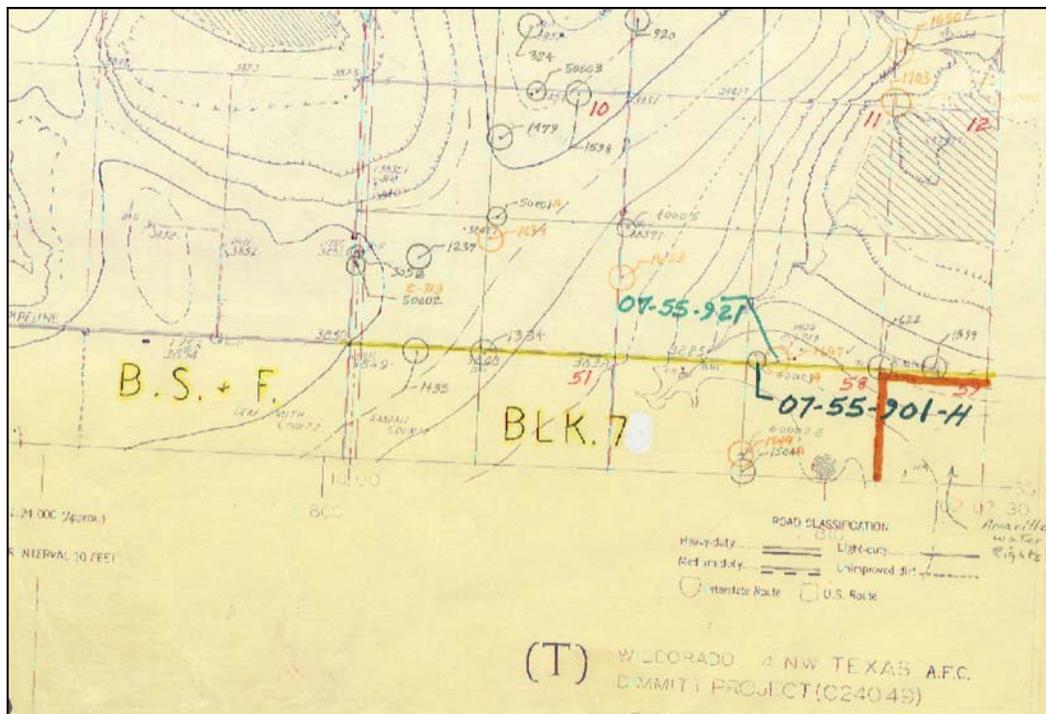


Figure 4. Example of a provisional quad with wells plotted. These maps have been continuously used since they were put into production.

Production Database Development

The 328 selected quad maps were scanned and then registered to the USGS Digital Raster Graphics index. Issues of course included the different projected coordinate systems between the two data sets. The original quads were in NAD27 versus NAD83 for the DRGs. Moreover, the original quads were not orthorectified as are the DRGs.

Using a Contex ScanPlusIV 636C large format scanner, the district's quads were scanned at a resolution of about 14 feet square per pixel which clearly showed the well locations. Registering the four corners of the scanned quads to the DRGs worked reasonably well. ArcGIS was used as the processing environment to register the quads. The RMS (in map units) for the registration was 19 feet in state plane units or about 2 1/3 pixels on average. As expected the NAD27 scanned quads showed better registration to the DRGs in the center of the quads, degrading toward the edges. Since the District is required to locate wells within 10 yards, this average RMS was acceptable.

The production database design was GIS centric. For the well data all feature classes, tables, and relationships were stored in geodatabases. The personal geodatabase was used since the District supported MS Access. Data capture was done on a county basis, with one personal geodatabase for each county. The spatial bounds were set to just beyond each county boundary to ensure there would be no problem entering data.

Before the digitizing began it was important to select a projected coordinate system. This proved interesting since the HPWD sits squarely between two UTM zones and two State Plane Zones. To digitize wells, the data frame was set to the NAD27 state plane projected coordinate system for Texas North Central 4202 in feet. This matched the projection of the scanned quads to capture the wells. Other layers added to the data frame would display in this projection. Once all wells were captured, they were converted to a NAD83 geographic coordinate system.

Initially a geodatabase template was created with empty tables, feature class definitions and defined domains. The template contained nine domains for consistent well attribute data entry and efficiency. When a new county was ready for digitizing the template was copied to create a new personal geodatabase for that county. Each GIS analyst used a single map document to capture well data on a quad by quad basis. For data capture, the GIS analyst added the DRGs, the scanned District quad, and the well feature class to the map document and then began digitizing wells. A 50% transparency was set on the scanned quad so the features on a DRG could be seen and thereby aid in data capture.

The attributes editing tool was used to capture data from the scanned quad maps (Figure 5). As each well was captured, the GIS analyst went through each field and used the pull down menus from the domains to enter the data.

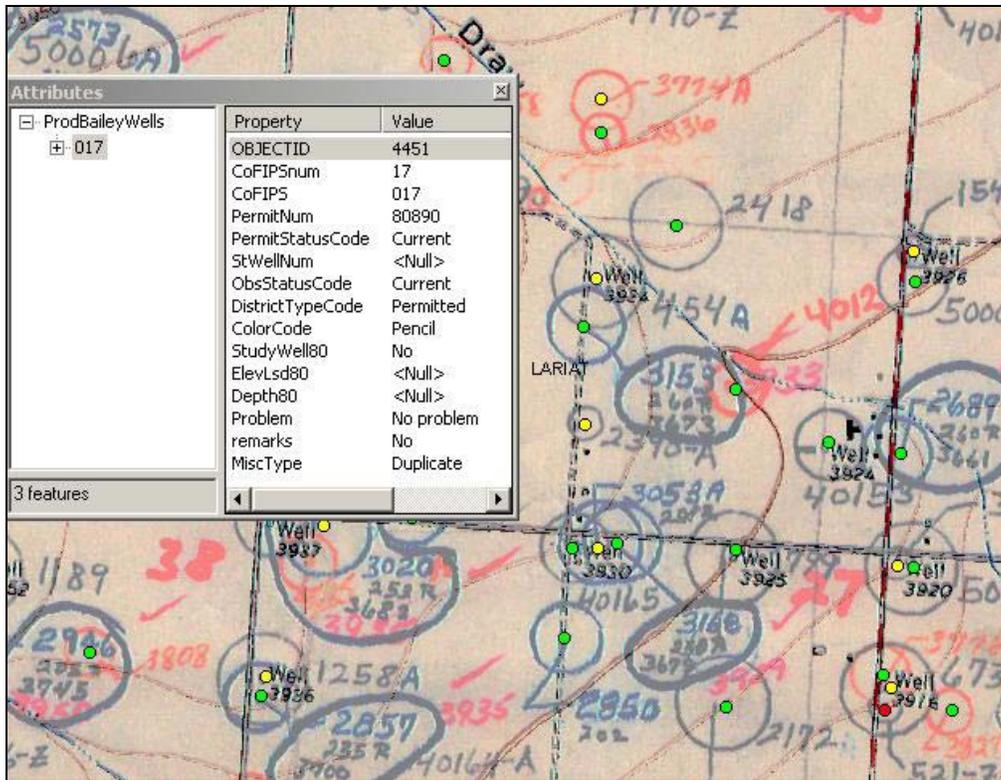


Figure 5. Capturing well data using the attributes editing tool.

Interpreting the quad maps was an art. GIS analysts invariably had questions regarding permit number and associated well locations. Communication with the district was vital for resolving these questions. To minimize attribute error an e-mail communication system was developed to track questions and answers regarding any ambiguities in map interpretation. This communication process served as a first of three levels of quality control.

During the data capture some quad maps had hundreds of wells without a permit number or a grandfathered number assigned. It became evident that the permit numbering system was more complex than originally thought and additional procedures were developed to ensure a unique permit number was assigned to each well.

In addition to the well feature class in each production personal geodatabase, a related table for permit remarks was included. The well feature class and permit remarks table were related by the permit number. The first attempt at collecting permit remarks resulted in the GIS analyst entering hundreds of remarks for each county, which significantly impacted production efficiency. Information captured in the permit remarks table included previous permit numbers, duplicate permit number information, and miscellaneous annotation such as ‘windmill’, ‘stock water’, ‘recharge well’ (Table 1). To simplify data capture additional values were added to a domain. This allowed analysts to quickly enter values for the miscellaneous annotation and input the comments that were most commonly repeated. The inclusion of these values in a domain generally resulted in fewer than one hundred permit remarks records for a county.

Value	Description
AP	Amended permit
B	Duplicate permit number
CW	City well
D	Domestic well
RC	Recharge well
S	Stock water
WM	Windmill
G	GIS assigned Permit Number

Table 1. Domain values for miscellaneous annotation

Final Database Development

Upon completion of the production database, the well feature classes were converted from the NAD27 state plane projected coordinate system to the NAD83 geographic coordinate system. Next, the latitude and longitude for each well was calculated using the Add XY function. Each county well feature class was then normalized into three feature classes and a related table. The feature classes stored three types of well data; county wells, state wells, and study wells. These feature classes were stored in a single personal geodatabase for each county.

Except for the permit number and county FIPS, the county well feature class was stripped of its attributes. The attributes were moved to a related permit table using the permit number as the primary key. These related tables were stored in a Microsoft Access database for each county. A total of nine related tables were created in the MS Access database (Table 2). These tables support various permitting attributes including permit information, permit extensions, deposit payments and refunds, ownership, legal and descriptive well location, construction information, well replacement, and pump information. In addition, fifteen look up tables were created and stored in the MS Access database for each county (Table 3).

MS Access table name	Table description
tblConstruction	Construction table
tblExtension	Extension table
tblOwner	Owner table
tblPermitRemarks	Permit Remarks table
tblPayment	Payment table
tblPermits	Permit table
tblPump	Pump Equipment table
tblReplacement	Replacement table
tblWellLocation	Well Location table

Table 2. Related tables stored in MS Access databases for each county

MS Access look up table	Look up table description
LUTAccCoords	Coordinate Accuracy table
LUTColor	Color table
LUTConstMethod	Construction table
LUTCountyFIPS	County table
LUTDistPropLine	Distance Property Line table
LUTDistrictType	District Type table
LUTExtReason	Extension Reason table
LUTYieldGPM	Maximum Yield table
LUTMiscType	Miscellaneous Type table
LUTPermitStatus	Permit Status table
LUTPropStart	Proposed Start table
LUTampm	Proposed Time table
LUTQsect	Quarter Section table
LUTRequestedBy	Requested By table
LUTWellPlottedBy	Well Plotted By table
LUTWellType	Well Type table

Table 3. Look up tables stored in MS Access databases for each county

The final deliverable included seven folders. These folders store the well and permit data, map documents, imagery, related data and documentation (Figure 6). The Data folder stores two personal geodatabases. The first of these is a county geodatabase that stores the feature classes referenced in each map document; such as roads, county boundaries and county quad indexes. The second is a district geodatabase that stores district-wide feature classes such as the HPWD boundary, county boundaries and quad indexes for the District.

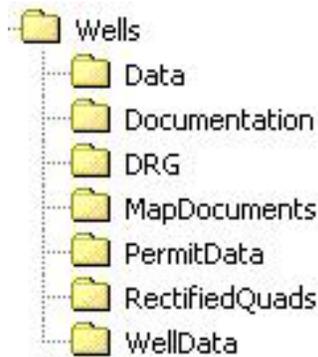


Figure 6. Final database directory structure.

Three major documents are stored in the Documentation folder. These documents include a Standard Operating Procedures and Data Dictionary, a PeMA and GIS User Manual, and a Software Manual. The DRG and RectifiedQuads folders store the image data organized by county. The rectified quads and DRG images were named using the current quad name. This provided user-friendly names to make it easier for the permit secretary or district staff to find reference data. A separate set of 12 CDs were delivered with the DOQQs for each county.

The final product included a map document created and named for each county. Each map document contained one data frame set to the NAD83 Texas State Plane Coordinate System 4202 with the display units set to yards. Twelve layers were included in each map document plus an event table (Table 4). The event table was created by geocoding the x,y well coordinates from the related well location table. Symbology was designed and assigned to each of the data layers for cartographically-appropriate viewing.

Layers

- County Wells
- State Observation Wells
- District Boundary
- County Boundary
- tblWellLocation Events
- County Quad Index
- County TxDOT Roads
- County Detailed roads
- County Legal Description
- District Counties
- District Quad Index
- All scanned quads in county
- All DRGS in county

Table 4. Listing of the layers included in each map document.

Labeling scripts were written using VBA code to display district permit numbers and state well numbers with their associated permit status such as current, abandoned, destroyed, in progress, or cancelled (Figure 7). Finally a layout was created for each map document allowing the permit secretary to print pre-made maps for stake holders as they went through the permitting process.

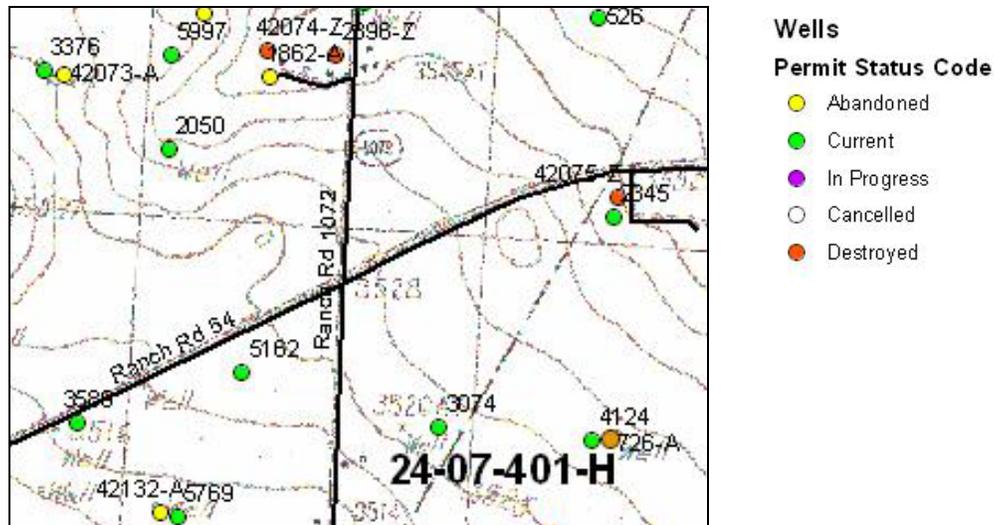


Figure 7. Sample showing District and State wells with labels.

Quality Control

The quality control (QC) for this project was performed in three phases. The first-level QC was completed by the GIS analysts during the digitizing phase of the project using the communication process established with the District. In this phase questions regarding interpretation of permit numbers, annotation or well location was communicated with screen shots between the GIS analysts and the permit secretary. As long as a record remained unresolved, it was flagged as a problem well.

The second-level QC involved a series of attribute and logical consistent checks prior to table normalization. These checks included verifying the 'county FIPS' code and checking for consistency with the permit numbering system. Other attribute and consistency checks included verifying the 'District Well Type', 'Study Wells', and correcting any remaining 'Problem Well' or 'Permit Remarks' values.

The third-level QC involved running the ArcInfo frequency command on the permit number field to check for any remaining duplicate values. In addition, visual checks of the wells on a quad and county basis were made in ArcGIS to ensure that they were located inside the county boundaries. Map documents were checked for consistency with respect to layers, symbology, annotation and labeling. The layers were all checked to make sure they were sourced to the final data directories.

Application Development

Two application design projects were developed simultaneously for GIS well location management and for permit record management. The GIS and Permit Management Application (PeMA) combines a web based data entry system with GIS data management (Figure 8). The PeMA and the GIS application work together via ODBC to allow permit data entry and management of well locations respectively.

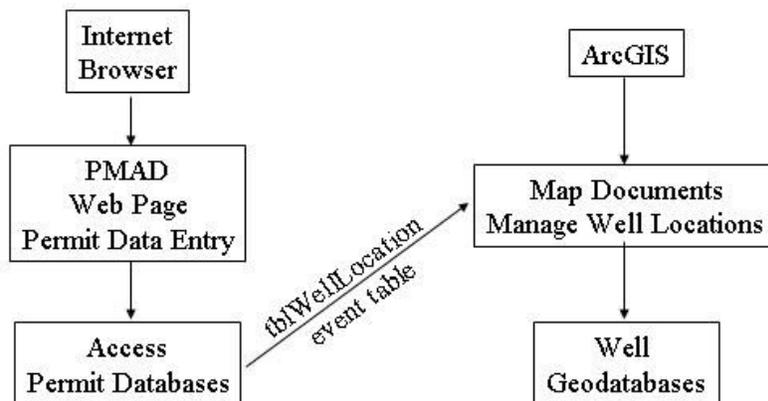


Figure 8. Application conceptual design.

The PeMA application was written in Microsoft Visual Basic 6.0 and uses .asp pages to take advantage of web functionality. Users access the PeMA through MS Internet Explorer 6.0 to enter permit record information into a Microsoft Access Database. MS Access was chosen as the database since it was supported by the HPWD. Storing the permit tables in Access allowed the PeMA to leverage the full functionality of Access without corrupting geodatabase feature class tables that would be managed by the GIS application.

The ArcGIS component works in concert with the Access PeMA. Once a permit record has been entered, the GIS application manages and updates well locations from GPS coordinates entered in each permit record in the Access well location table. The ArcGIS application is represented as a well tool bar. The well tool bar was designed for incorporation into the ArcGIS interface to allow the user to perform four functions (Figure 9).

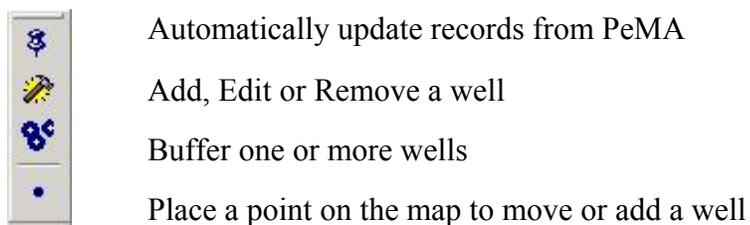


Figure 8. Well tool bar and functions.

CONCLUDING REMARKS

The GIS and PeMA applications were delivered to the HPWD in March 2004. A transition period ensued for training and to allow the District to gain experience and confidence in using the applications. During the transition period the PeMA was used to enter the permit records that were not plotted on the scanned quads during database development. Also during the transition, the HPWD fully tested the system to enter and search for permits and produce reports. After working with the GIS, the District was then able to provide additional recommendations for updating the application. Considering that the HPWD had used a manual system for over 50 years, after three months of transition the implementation was considered successful.

With the development of the well database as a framework for the GIS and PeMA applications, continued enhancement to these programs is anticipated as well as the development of new applications. Today ArcGIS enables non-GIS staff to efficiently manage well permits for compliance with district regulations. The incorporation of GIS into the District has been instrumental in policy management decisions for conserving water in the southern High Plains Aquifer.

Acknowledgements

We would like to acknowledge the exceptional support of the HPWD board, management and staff. Jim Conkwright provided the vision that made this project possible. Don McReynolds provided the institutional memory necessary to interpret the well data from maps. Scott Orr provided the technical expertise necessary to implement the PeMA application and database at the District. Gerald Crenwelge and Keith Whitworth developed and processed critical data layers and Arnold Husky provided vital information about field operations. Patty Bryant provided many useful comments and a thorough testing the application throughout the transition. In addition to the HPWD staff, we would also like to acknowledge John Underwood who supported the development of the well toolbar. Lastly, we would like to thank our students; Heath Bowlin, Matt Crawford, Ben May, Sagrario Mejia, Dana Smith and Kiran Masapari. Their diligence and enthusiasm are truly appreciated.

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