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WRRI Technical Completion Report No. 375

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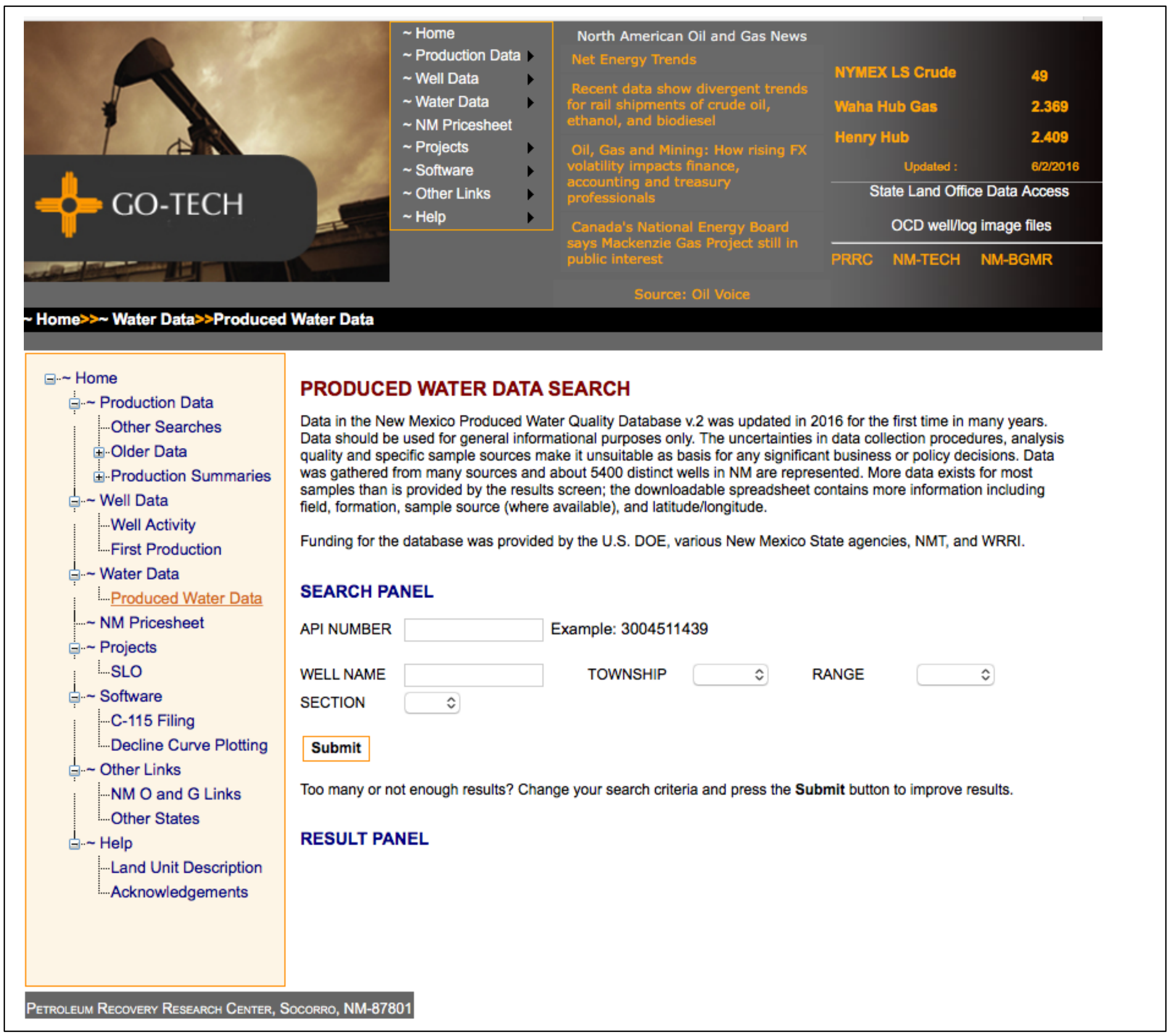

Screen shot of NM Produced Water Quality Database search page.

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Accessing Produced Water Data in New Mexico: Improving and Updating the NM Produced Water Quality Database and Web Site

By

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and

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ABSTRACT

Water produced as a byproduct of oil and gas production represents a large potential water source in southeastern New Mexico. In 2015, industry reported production of almost 900 million barrels of water. This significant volume of water is a very dispersed, largely uncharacterized, and extremely variable water source. Almost all this water is reinjected; some for pressure maintenance and improved oil recovery, but mostly as a means of disposal. A significant amount of produced water could potentially be diverted to other uses if economic, regulatory, and technological hurdles can be overcome.

In 2001, Petroleum Recovery Research Center (PRRC), a division of the New Mexico Institute of Mining and Technology (NMT), began a DOE-funded project compiling data on quality and quantity of produced water into the NM WAIDS database. The project was completed in 2004 and was maintained as a static online resource. In late 2013 the old web interface was offline at the request of NMT network administrators due to security concerns.

An update of the database and web interface was begun in 2014. The goals of the project were to improve the database quality, recode and upgrade the web site, and add new data and GIS functionality. The water quality database has been augmented, standardized, quality-checked, and published online. GIS data will be available through NM WRRI's web interface, while the database can be searched and geolocated data downloaded via PRRC's website at http://octane.nmt.edu/gotech/water/producedwater.aspx.

Keywords: produced water, water quality, NM WAIDS

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INTRODUCTION

The oil and gas industry in New Mexico generated almost 900,000,000 barrels of produced water in 2015, almost 116,000 acre-feet. This water is a byproduct of oil and gas production. It has been generally viewed as a liability in the industry for a number of reasons including lifting costs, separation and disposal costs, and issues surrounding corrosion and scale formation on infrastructure. As a result of concern over New Mexico's diminishing water resources, there is growing interest in the possibilities of reusing some of this water either within the industry or for other purposes. The resource is widely dispersed, and highly variable in quantity and quality. Knowledge of location, quality, and quantity is essential for evaluating any possible secondary use, and is also useful for the petroleum industry as an aid in reporting and compliance.

The current project objectives were to update and improve the existing produced water quality database created by the Petroleum Recovery Research Center (PRRC), a division of the New Mexico Institute of Mining and Technology (NMT), renew internet access to this database, provide GIS user-friendly functionality, and identify and attempt to fill in data gaps in newly active plays within the state, with an emphasis on southeastern New Mexico. The objectives support the work of other researchers on the overall project topic of using produced water to improve water supply sustainability in southeastern New Mexico. The following report is a description of work performed for that project.

BACKGROUND

A number of years ago, the PRRC began to compile data on quality and quantity of produced water into the New Mexico Water and Infrastructure Data System (NM WAIDS) database as part of a project funded by the U.S. Department of Energy under DOE contract DE-FC26-02NT15134. This project entailed the design and creation of a water quality database, web-based interfaces to the data including a GIS map server, and integral tools to provide operators and regulators with necessary data and useful information to help them make management and regulatory decisions regarding produced water. Detailed information about the project can be found in project annual and final reports (Cather et al., 2003, 2005)

Purposes of the original work relevant to the current project included assessments of the amount and quality of produced water to support the design of water treatment systems incorporating produced water, and also to aid producers in assessment of water quality issues such as corrosion and scale. The NM WAIDS database encompassed information on produced water quality/quantity in various producing regions of the state as well as some information on groundwater quality and depth in parts of southeastern New Mexico.

The NM WAIDS project was hosted on a large and complex website, GO-TECH, which was maintained by the Industry Service and Outreach Group at the PRRC. Work on the NM WAIDS database ceased over 10 years ago and the web-based interface and database were maintained as a static entity, with only one functional upgrade in 2007. In 2013 the entire GO-TECH site was taken offline at the request of NMT network administrators due to concerns about security of the site and its several underlying databases. Hyperlinks on data results pages provided links to produced water volume data acquired from the New Mexico Oil Conservation Division (NM OCD) via their monthly update system that was in place at the time.

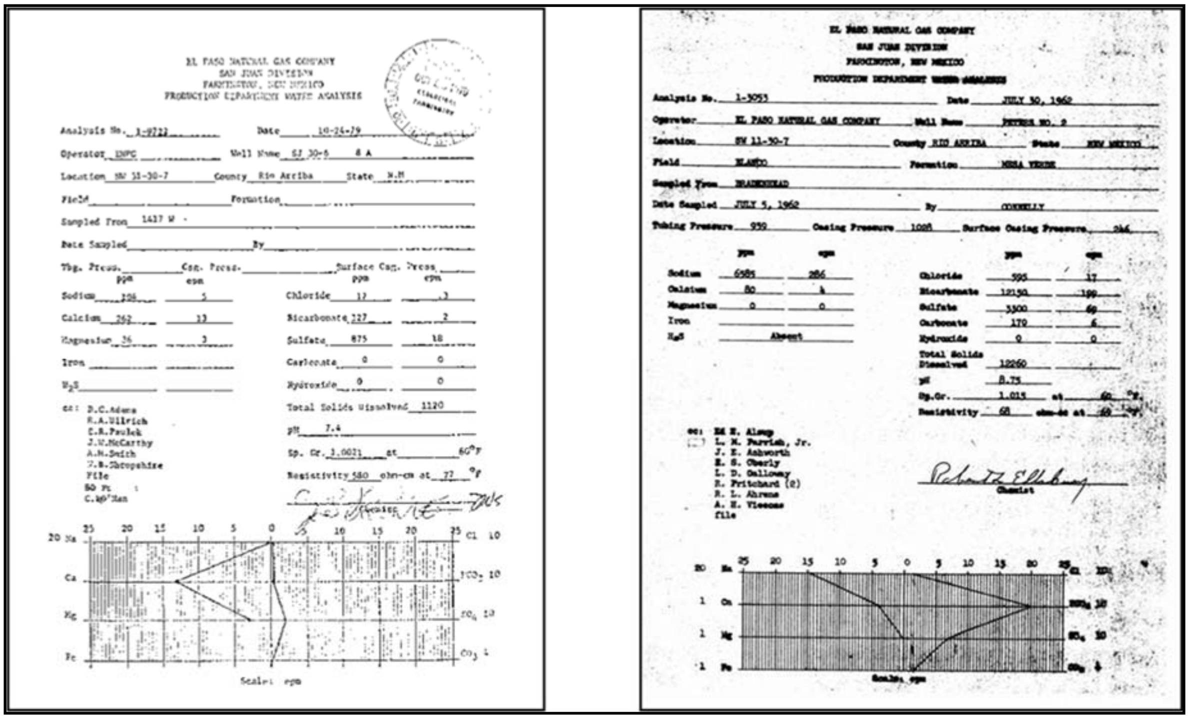
Priority in redesign and coding of GO-TECH was given to other sections of the site that had larger client bases. However, the need for the NM WAIDS data was underscored by many requests from both industry stakeholders and state agencies to redeploy the database, thus providing the incentive for the current project. Funding for an initial revision of the database was obtained from WRRI in late 2014; additional funding from the New Mexico Environment Department (NMED) was obtained in January 2016. The final update was posted in June 2016.

NM WAIDS Database Construction

A brief discussion of data collection, cleaning, and database construction processes that were used to build the original NM WAIDS database is provided here as reference documentation. Complete details can be found in the project final report (Cather et al., 2005). Creation of the database was one of the largest and most time-consuming tasks of the entire original effort. It was compiled from a large variety of source data. A number of regional oil and gas producers were solicited for water quality data, and many were very generous in sharing this information. Some of the data were provided in digital format, either as Microsoft Excel spreadsheets, Microsoft Access databases, or simple text files. Much data came from producers as paper forms supplied to them by the various companies employed to run the water analyses. Each data source had to be analyzed to determine what kind of information was available and in what format (numeric, text, semi-quantitative), so the correct fields and data definitions could be built into the database structure. Examination of the thousands of paper forms and digital files revealed that data could be divided into four main categories: general information, general sample properties, anions, and cations. A number of tables and views were used in the database construction: primary tables were the general sample information (items such as sample name, location, formation, physical parameters), anion information (CO_3, SO_4, etc.), and cation information (Ca, Na, Mg, etc). In addition to produced water quality, a large digital file of data on groundwater quality and depth in southeastern New Mexico was obtained from the Roswell office of the New Mexico State Engineer.

Researchers collected over 3000 water quality analysis forms for input into the database. There was an average of 30 fields on each form from which data had to be collected, and there were many types of forms, so the data types were not always the same from form to form. A web-based data entry system, designed to allow users to access the database remotely and securely for data entry was too time-consuming, requiring several minutes per form just to enter the data without any verification. Ultimately a process of scanning and using optical character recognition (OCR) technology was chosen. An additional advantage of the OCR process is that now a digital record of each image exists, so if there is a question about the data, the actual form image can be examined.

Many of the documents processed were poor copies of original forms that were difficult to read, and some were hand-written. Manual input was impractical for the amount of data to be entered and was also prone to significant typographical errors, but was the method used for many of the forms that could not be automatically converted to text. Figure 1 shows two typical water quality forms that could be processed automatically, with one being much easier to process than the other.



EL PASO NATURAL GAS COMPANY
SAN JUAN DIVISION
FARMINGTON, NEW MEXICO
PRODUCTION DEPARTMENT WATER ANALYSIS

Analysis No. 1-9722 Date 10-24-79
Operator EPNG Well Name SJ 30-6 8 A
Location SW 31-30-7 County Rio Arriba State N.M
Field Formation
Sampled From 1417 W
Date Sampled By
Tbg. Press. Csg. Press. Surface Csg. Press.

	ppm	epm		ppm	epm
Sodium	106	5	Chloride	17	.3
Calcium	262	13	Bicarbonate	127	2
Magnesium	36	3	Sulfate	875	18
Iron			Carbonate	0	0
H_2S			Hydroxide	0	0

Total Solids Dissolved 1120
pH 7.4
Sp. Gr. 1.0021 at 60°F
Resistivity 580 ohm-cm at 77 °F

cc: D.C.Adams
R.A.Ullrich
C.R.Paulek
J.W.McCarthy
A.M.Smith
T.B.Shropshire
File

Chemist

Scale: epm

EL PASO NATURAL GAS COMPANY
SAN JUAN DIVISION
FARMINGTON, NEW MEXICO
PRODUCTION DEPARTMENT WATER ANALYSIS

Analysis No. 1-3053 Date JULY 30, 1962
Operator EL PASO NATURAL GAS COMPANY Well Name PETERS NO. 2
Location SW 11-30-7 County RIO ARRIBA State NEW MEXICO
Field BLANCO Formation MESA VERDE
Sampled From BRADENHEAD
Date Sampled JULY 5, 1962 By CONNELLY
Tubing Pressure 959 Casing Pressure 1028 Surface Casing Pressure 246

	ppm	epm		ppm	epm
Sodium	6585	286	Chloride	595	17
Calcium	80	4	Bicarbonate	12150	199
Magnesium	0	0	Sulfate	3300	69
Iron			Carbonate	170	6
H_2S	Absent		Hydroxide	0	0

Total Solids Dissolved 12260
pH 8.75
Sp.Gr. 1.015 at 60 °F.
Resistivity 68 ohm-cm at 60 °F.

cc: Ed E. Alsup
L. M. Parrish, Jr.
J. E. Ashworth
E. S. Oberly
L. D. Galloway
R. Pritchard (2)
R. L. Ahrens
A. H. Vlecens
file

Chemist

Scale, epm

Figure 1. Two typical water data forms. These forms were both processed by OCR but the data on the left form was much easier to process. The smudges and fuzzy fonts on the right image produced more errors in processing. Data on left image was from a well drilled as part of a cathodic protection program, denoted by the "sampled from 1417 W" entry.

Once document processing was completed, a lengthy period of quality-checking ensued. Significant work in the original project went into developing automated routines for parsing and evaluating information. The original data were extremely non-standard in many respects, and two different types of data had to be evaluated: text-based data strings such as well names or miscellaneous notes, and numerical data that was written or typed on the forms. Given the large number of records, efforts were made to automate processes or use methods that could examine large amounts of data quickly.

One of the best ways to check data accuracy for the numerical water quality data was to examine the relationships in major element chemistry. Most water sample reports include data presented in two different units (Figure 1). This might be in parts per million (ppm), milligrams per liter (mg/L), milligram equivalents per liter (me/L) or equivalents per million (epm). Equivalents per million, a unit of measurement involving the number of ions, is often used in studies of chemistry of natural waters and in the interpretation of analyses. In waters of low salinity, the unit epm is numerically the same as the unit milligram equivalents per liter (me/l). For practical purposes, they can be considered identical. Concentrations expressed in units of weight as parts per million (ppm) are sometimes desired for a particular purpose and are a very common reporting unit (Wilcox and Magistad, 1943). Conversion factors for some common anions and cations are included in Table 1. The equivalent weight of chloride is 35.5; thus 5 epm of chloride is the same as 177.5 ppm and 1 ppm chloride = 0.0282 epm.

Table 1. Conversion factors for common anions and cations

Cation	Equivalent weight	Conversion Factor (1/equivalent weight)	Anion	Equivalent Weight	Conversion Factor (1/equivalent weight)
Calcium (Ca)	20	0.05	Carbonate (CO_3)	30	0.0333
Magnesium (Mg)	12.2	0.08197	Bicarbonate (HCO_3)	61	0.0164
Sodium (Na)	23	0.0435	Sulfate (SO_4)	48	0.0208
Potassium (K)	33.1	0.0302	Chloride (Cl)	35.5	0.0282
			Nitrate (NO_3)	62	0.0161
To convert epm to ppm, multiply the concentration in epm by the equivalent weight. To convert ppm to epm, divide the concentration in ppm by the equivalent weight.					

The linear relationship between epm and ppm was useful for checking accuracy of data where both measurements were reported. Figure 2 shows a graph of chloride reported in ppm vs epm for some of the scanned data. In this figure it is seen that most reported data points lie on or very close to a line whose slope corresponds to the conversion values determined by ppm/epm. The human eye can quickly pick out several data points that vary greatly from expected, and also see that in general the data entry appeared to be good. A spreadsheet or programming method was also used. If the reported value was less than ½ or greater than two times the calculated value based on the conversion factor of 1ppm = 0.0282 epm for chloride, the data was considered suspect and values were checked against the scanned images of the data forms. In approximately half the cases, the error was found to be in the conversion of the image to text. The most common conversion error occurred in cases where the OCR program could not distinguish between a comma and a decimal point. In the other half of the cases checked, the OCR conversion was correct, and the problem lies in the actual data itself. A decision was made to keep the data in the database and leave the decision to use the data to the individual database user. An error flag was used to indicate these records.

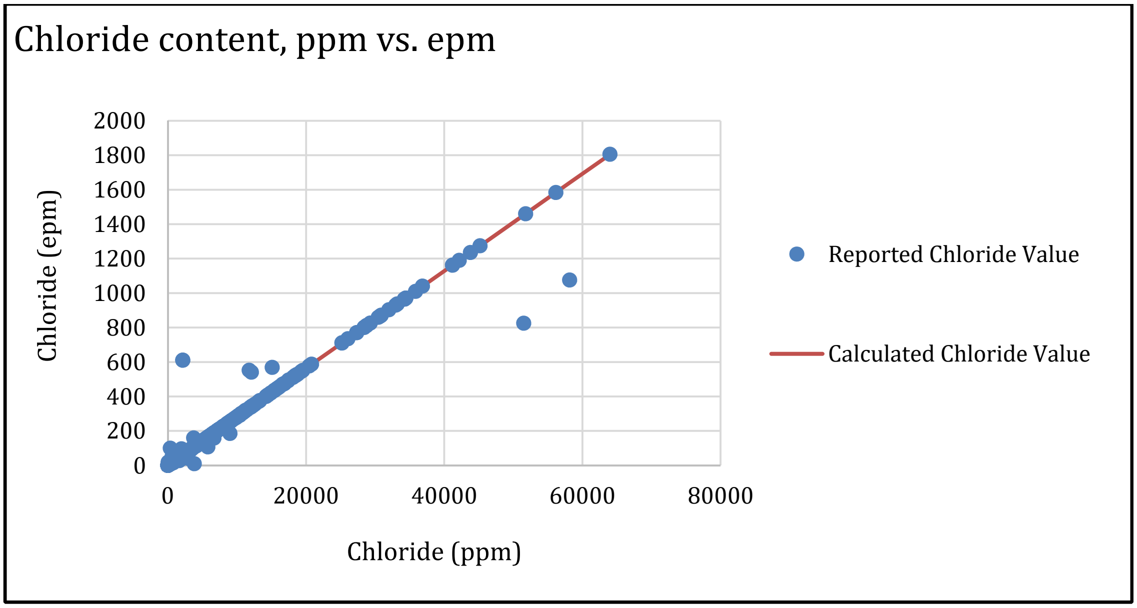


Figure 2. Reported and calculated values of chloride in ppm and epm units. Such comparisons were used for quality control of scanned and hand-entered data.

Apart from checking the quality of the numerical data, a tremendous amount of effort went into correctly identifying and locating wells (Wei et al., 2006). Once the database schema was constructed, the various sets of digital or scanned and converted data were imported into the database. Elimination of duplicate data was a complex and iterative process (Wei et al., 2005) required after addition of each new data set. Later versions of the database were restructured to improve online performance but these changes did not include any changes or improvements to the content. The only data reduction was elimination of duplicate and clearly incorrect data.

NM WAIDS Web Site

The original NM WAIDS web site was a useful tool for oil and gas operators and stakeholders in the state, and was also a valuable resource for researchers. The site provided access to a database comprised of two main datasets: Produced Water, with several thousand records of water quality from oil and gas wells throughout the state, and Groundwater, with very basic information but over 25,000 records, for southeast New Mexico only. Data vintage ranged from the1920's to 1998 for groundwater, and the 1930's to 2002 for produced water. There was an online manual of information concerning oilfield corrosion and scale identification, and a toolkit that would allow users to calculate water compositions based on mixes of different types of waters and also probability and composition of any resulting precipitate (Figs 3-5). NM WAIDS received several hundred thousand visits a year at a time when the overall GO-TECH site was receiving a few million visits per year.

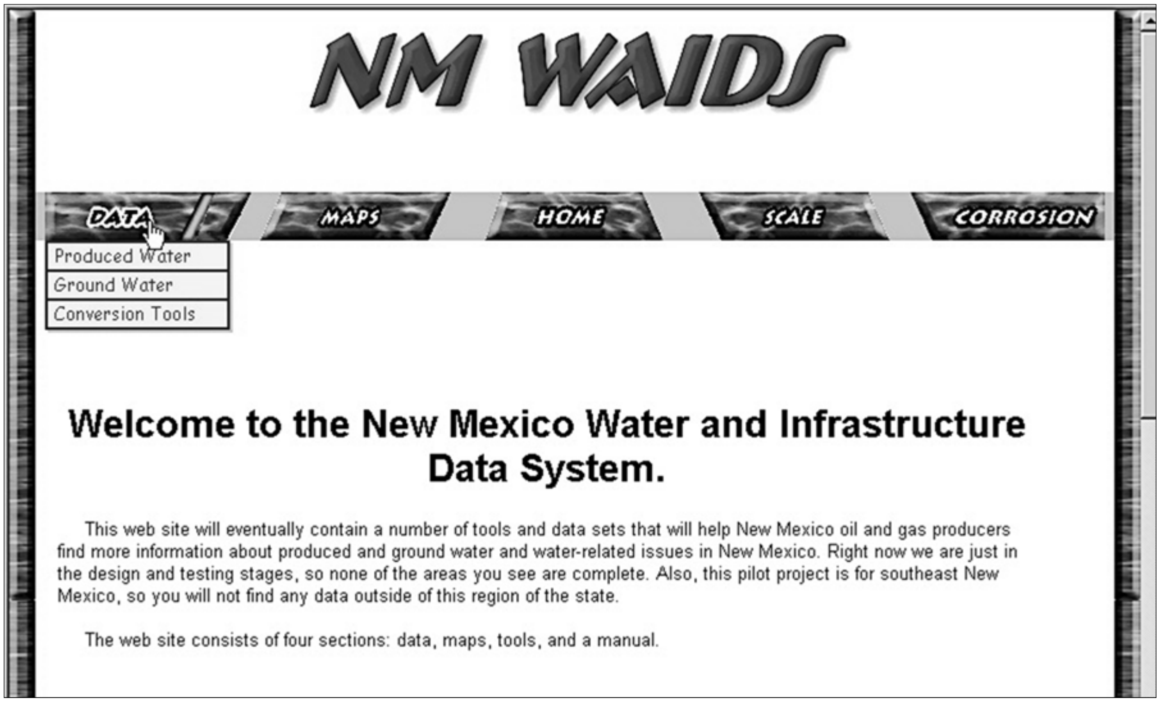


Figure 3. Home page for original NM WAIDS web site. Interface included links to produced and groundwater databases and query pages, a GIS map server, various tools for predicting corrosion and scale, an online corrosion manual, and reference materials.

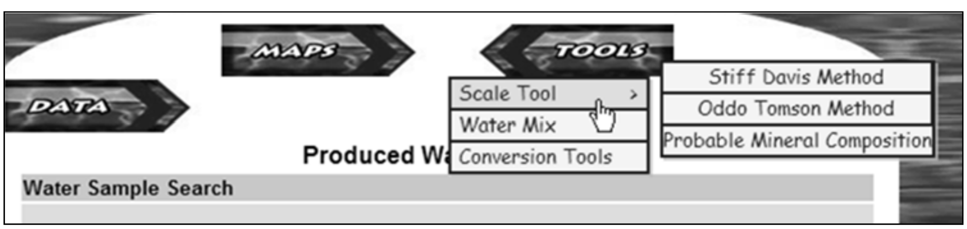


Figure 4. Tools included two scale calculation tools, a mineral composition tool, one to determine the composition of mixing of two waters, and unit conversion calculators.

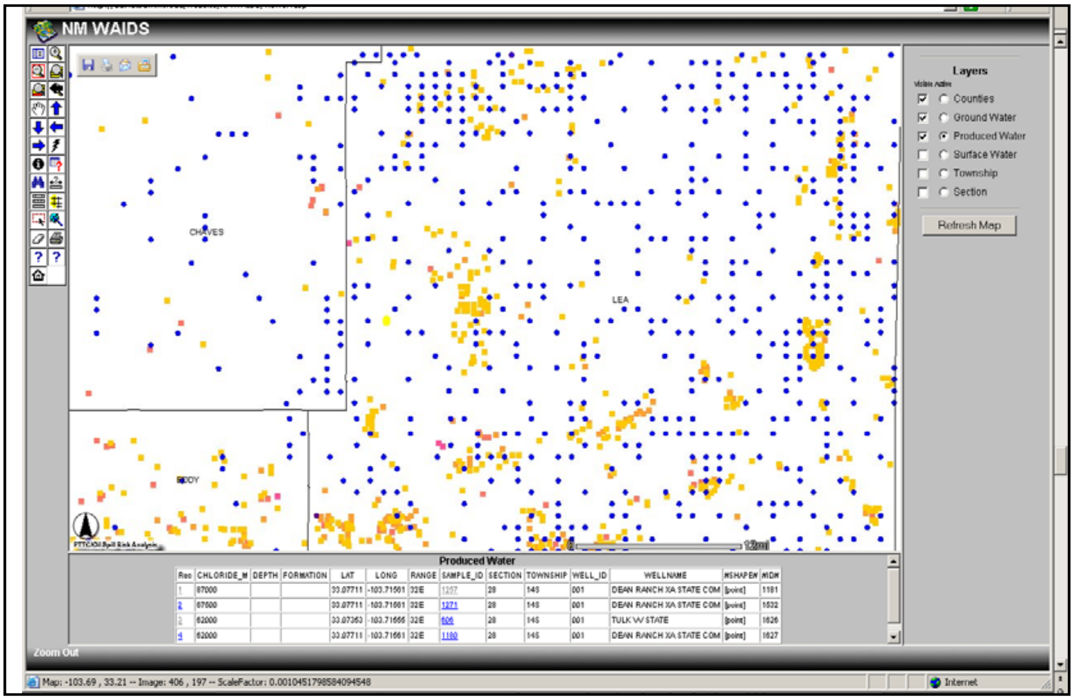


Figure 5. The original NM WAIDS site had an online GIS map server, here zoomed to Lea County. Produced and groundwater data shown as lighter and darker gray symbols, respectively.

In the years elapsed since the database was first put online, cyber security has become an increasingly important consideration. The last functional upgrade to the NM WAIDS web site was completed in 2006-2007. With passing time this interface and the coding behind it had become vulnerable to hacking. In 2013, the GO-TECH server (octane.nmt.edu) was identified as compromised and deemed a security risk by federal agencies so the server was taken out of service by NMT. As a result of this, the entire GO-TECH website, including NM WAIDS, was subjected to a series of web application tests to identify vulnerabilities with the site. Testing was conducted by CAaNES LLC (now RiskSense, Inc.), a company devoted to Internet threat and vulnerability management. Testing identified and validated 1028 security vulnerabilities that were classified by risk posed by each vulnerability to the organization. Out of the total 1028 vulnerabilities, 439 belonged to a high threat class, 23 belonged to a medium threat class and 566 were of low threat. The vast majority of threats were due to either cross-site scripting or injection. Cross-site scripting can allow malicious content to be delivered to a web application user, while injection (in particular SQL injection) can allow malicious content or code to infect the server database system.

All of the hardware and software components of the system required updating; and much of the old code simply would not work well with the updated programs and systems. This upgrade was labor intensive and required significant resources; work order was prioritized by relative importance to our client base. Two parts of GO-TECH were deemed highest priority: the section containing New Mexico Production Data access pages, and the section devoted to access to NM State Land Office data. Because of the scarcity of funding and other resources, and the perceived lower priority given the water databases, upgrades to NM WAIDS of any type would have been very unlikely without the additional project funding provided by NM WRRI.

METHODOLOGY

Database Inspection, Cleaning, and Expansion

As a first step in the current project, the existing NM WAIDS database was evaluated for structure and content. There were multiple tables that contained the same information – careful examination allowed deletion of four tables. The remaining information was reorganized into tables containing location information, sample information, water quality data, and water injection and production volumes. See Appendix A for more information on database tables. During this process it became apparent that some of the information was still suspect; in particular duplicate data still existed because of the difficulties in well identification during the initial data collection period. Some wells still lacked proper identification or location information, and some numerical data were obviously wrong as compared with the overall data cohort. These issues were addressed during the process of data cleaning, described below.

Data Coverage

The existing data were also examined for gaps that might be filled in the course of the project. Data were plotted using ArcGIS to determine where there might be gaps in the spatial distribution of data in the original database. As expected, the major gap was the age of the data – much dated from the 1950s to 1999, and little new data were entered after original database deployment in 2004. The other significant gap was a lack of data that sampled wells drilled during the recent increase in horizontal drilling of oil wells in the Permian Basin, and to a lesser extent, the San Juan Basin. Figure 6 shows some of the general geologic provinces of the Permian Basin and distribution of some recently active oil-producing formations. Other oil and gas plays have been more important in past decades and this is reflected in the data. Figures 7-9 show stratigraphic charts depicting the major producing oil and gas plays of the Permian and San Juan basins in New Mexico. In the Permian Basin, the formations of the Delaware Mountain Group, the Bone Spring, and the Wolfcamp plays have become the principal targest of current interest and drilling activity since the completion of the 2004 reservoir study. In the San Juan Basin, the Mancos shale oil play is the main focus of more recent drilling activity. Most of the basin is more gas-prone and with the relatively low economic value of gas vs. oil, it has seen reduced activity for several years.

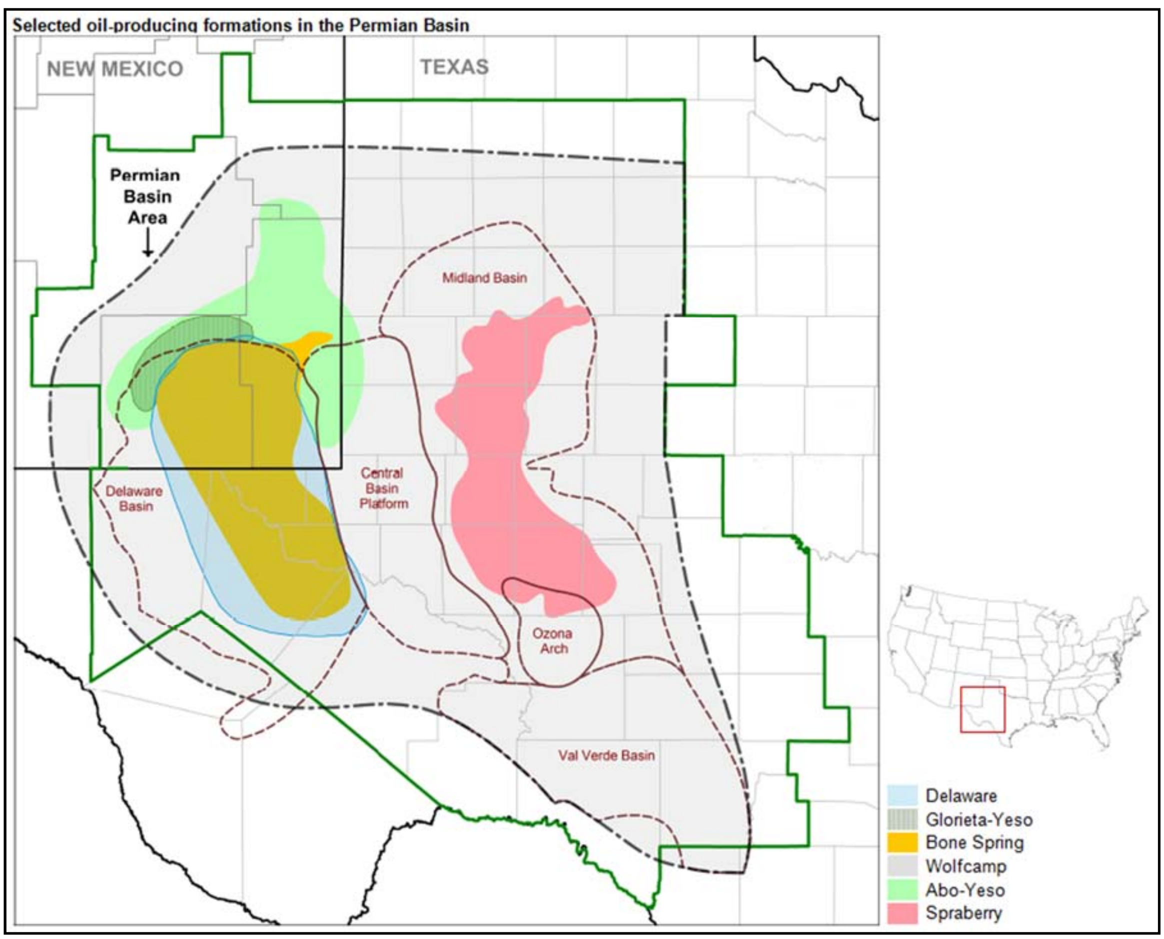


Figure 6. Geologic provinces and significant oil producing formations in the Permian Basin (from U.S. Energy Information Agency, 2014). Note: Wolfcamp is found throughout the entire region so is not shown.

Northwest Shelf, Central Basin Platform Oil and Gas Plays				
Age		**Strata**		**Oil or Gas Play**
Triassic		Chinle		
		Santa Rosa		
Permian	Ochoan	Dewey Lake Rustler Salado		
	Guadalupian	Artesia Group	Tansill	Artesia Platform Sandstones (132)
			Yates	
			Seven Rivers	
			Queen	Upper San Andres and Grayburg Plays
			Grayburg	Northwest Shelf Platform (120) Central Basin Platform (124) Artesia Vacuum Trend (125)
		San Andres		
	Leonardian	Glorieta		Leonard Restricted Platform Carbonate (117)
		Yeso	Paddock	
			Blinebry	
			Tubb	
			Drinkard	
	Wolfcampian	Abo		Abo Platform Carbonate (116)
		Hueco (Wolfcamp)		Wolfcamp Platform Carbonate (114)
Pennsylvanian	Virgilian	Cisco		Northwest Shelf Upper Pennsylvanian Carbonate (110)
	Missourian	Canyon		
	Des Moinesian	Strawn		Northwest Shelf Strawn Patch Reef (109)
	Atokan	Atoka		Atoka-Morrow Gas Play (202)
	Morrowan	Morrow		Morrow Gas Play (203)
Miss.		Mississippian Undivided		Mississippian Gas Play (208)
Devonian	Upper	Woodford		Woodford Shale
	Middle			
	Lower	Thirtyone		Devonian Thirtyone Deep Chert (106)
Silurian	Upper	Wristen		Wristen Buildups and Platform Carbonates (105)
	Middle			
	Lower	Fusselman		Fusselman Platform Carbonates (104)
Ordovician	Upper	Montoya		
	Middle	Simpson		Simpson Cratonic Sandstone (103)
	Lower	Ellenburger		Ellenburger karst-modified ramp carbonate (102)
Cambrian		Bliss		
Precambrian		Igneous, metamorphic, volcanic rocks		

Figure 7. Oil and Gas plays of the Northwest Shelf and Central Basin Platform in southeastern New Mexico (after Broadhead et al., 2004). Plays that are present on the Northwest Shelf and Central Basin Platform are listed next to their appropriate stratigraphic units. Numbers in parentheses represent the play identification number as defined in the study. Yellow colors indicate gas plays not discussed in the 2004 study. In this case, numbers refer to those used in Engler and Cather (2014). Units in blue colors lack significant oil or gas production in New Mexico.

Delaware Basin Oil and Gas Plays				
Age		Strata		Oil or Gas Play
Triassic		Chinle		
		Santa Rosa		
Permian	Ochoan	Dewey Lake		
		Rustler		
		Salado		
		Castile		
	Guadalupian	Delaware Mountain Group	Bell Canyon	Delaware Mountain Group Basinal Sandstone (130)
			Cherry Canyon	
	Leonardian		Brushy Canyon	Bone Spring Basinal Sandstone and Carbonate (118)
		Bone Spring		
	Wolfcampian	Hueco (Wolfcamp)		Wolfcamp Slope/Basin Play (115)
Pennsylvanian	Virgilian	Cisco		
	Missourian	Canyon		
	Des Moinesian	Strawn		
	Atokan	Atoka		Atoka-Morrow Gas Play (202)
	Morrowan	Morrow		Morrow Gas Play (203)
Miss.		Mississippian Undivided		Mississippian Gas Play (208)
Devonian	Upper	Woodford		Woodford Shale (207)
	Middle			
	Lower	Thirtyone		Devonian Thirtyone Deep Chert (106)
Silurian	Upper	Wristen		Wristen Buildups and Platform Carbonates (105)
	Middle			
	Lower	Fusselman		
Ordovician	Upper	Montoya		
	Middle	Simpson		
	Lower	Ellenburger		
Cambrian		Bilss		
Precambrian		Igneous, metamorphic, volcanic rocks		

Figure 8. Oil and Gas plays of the Delaware Basin in southeastern New Mexico (after Broadhead et al., 2004). Plays that are present on the Northwest Shelf and Central Basin Platform are listed next to their appropriate stratigraphic units. Numbers in parentheses represent the play identification number as defined in the study. Yellow colors indicate gas plays not discussed in the 2004 study. In this case numbers refer to those used in Engler and Cather, 2014. Units in blue colors lack significant oil or gas production in New Mexico.

ERA	SYSTEM	SERIES	LITHOLOGIC UNIT	THICKNESS (ft)	
CENOZOIC	Quaternary	Recent & Pleistocene	Alluvium in valleys	0 -100' +	
CENOZOIC	Quaternary	Pleistocene	Terrace gravel & gravelly stream channel alluvium in the upper parts of some valleys	0- 100' +/-	
CENOZOIC	Quaternary or Tertiary	Pleistocene or Plicoene	Gravel capping high terraces	0- 100' +/-	
CENOZOIC	Tertiary	Miocene (?)	Lamprophyre dikes		
CENOZOIC	Tertiary	Eocene	San Jose Formation	200' +/- 1800'	
CENOZOIC	Tertiary	Paleocene	Nacimiento Formation	< 537' - 1,750'	
CENOZOIC	Tertiary	Paleocene	Ojo Alamo Sandstone	70' - 200'	
MESOZOIC	Cretaceous	Upper Cretaceous	Kirtland Shale and Kirtland Form. Undivided	100' +/- 450'	*
MESOZOIC	Cretaceous	Upper Cretaceous	Pictured Cliffs Sandstone	0 - 235'	*
MESOZOIC	Cretaceous	Upper Cretaceous	Lewis Shale	500' - 1,900'	
MESOZOIC	Cretaceous	Upper Cretaceous	Mesaverde Group: La Ventana Tongue of Cliff House Sandstone	37' - 1,250' (Total 560' - 1,825' +/-)	*
MESOZOIC	Cretaceous	Upper Cretaceous	Mesaverde Group: Menefee Formation	345' - 375'	*
MESOZOIC	Cretaceous	Upper Cretaceous	Mesaverde Group: Point Lookout Sandstone	110' - 200' +/-	*
MESOZOIC	Cretaceous	Upper Cretaceous	Mancos Shale	2,300' - 2,500'	*
MESOZOIC	Cretaceous	Upper & Lower Cretaceous	Dakota Sandstone	150' - 200'	*
MESOZOIC	Jurassic	Upper Jurassic	Morrison Formation	350' - 600'	
MESOZOIC	Jurassic	Upper Jurassic	Tocito Formation	60' -125'	
MESOZOIC	Jurassic	Upper Jurassic	Entrada Sandstone	< 227'	*
MESOZOIC	Triassic	Upper Triassic	Chinle Formation	1,050' +/-	
PALEOZOIC	Permian		Cutler Formation	500' - 950'	
PALEOZOIC	Carboniferous: Pennsylvanian	Upper & Middle Pennsylvanian	Magdalena Group: Madera Limestone	0 - 800' +/-	
PALEOZOIC	Carboniferous: Pennsylvanian	Upper & Middle Pennsylvanian; Lower Pennsylvanian	Magdalena Group: Sandia Formation (upper clastic member of Sandia Formation of Wood & Northrop, 1946)	0 - 200'	
PALEOZOIC	Carboniferous: Mississippian	Upper Mississippian	Arroyo Penasco Formation (lower limestone member of Sandia Formation of Wood & Northrop, 1946)	0 -158'	
PRECAMBRIAN			Granitic and Metamorphic Rocks		

Figure 9. Stratigraphic chart of the eastern part of the San Juan Basin in New Mexico. Symbols indicate oil and gas producing formations in the region (after Baltz, 1967, p. 11).

One of our industry partners in the current project was instrumental in providing more recent data that helped fill some of the data gaps in the Permian Basin. Additional data were also obtained from old sources including previously unscanned forms of USGS water quality data which did not appear to already exist within their own database (Nathan Myers, USGS, personal communication, 2015), and data obtained from other producers that had been acquired after the initial database was created that had been too difficult to identify at the time it was received. The current interest in drilling in the southeastern part of the state dictated our efforts at obtaining data focused on this area. If additional funding is made available, efforts should be made to gather more recent data from the Mancos and Gallup plays in the San Juan Basin, as well as sample data from coalbed methane produced waters in the Raton Basin.

Data Cleaning

In the course of evaluating the content of the NM WAIDS database several areas of work were identified. These included correcting wrong and incomplete well identification and location information, eliminating data transcription errors, and duplicate data, and standardization of field and formation names. Although the processes for correcting these problems will not be related in detail, a brief discussion is in order. Duplicate records were identified by the process of looking not only at well names and APIs, but by comparing actual data values. Values for commonly-populated fields such as total dissolved solids (TDS), chloride, pH, and specific gravity were commonly used in combination as unique identifiers to search for duplicates. This step was performed after all new data were added ensuring the process only need be repeated once.

Following duplicate elimination, crosschecks of remaining data were made with the current well database maintained by the NM Oil Conservation Division (NM OCD). If well name and API were consistent between sources, no further action was necessary, but several hundred wells had inconsistencies that required more research. In the great majority of cases, well names and/or ID numbers were changed from the name given in the original information. However, a few hundred wells had problems with names, API numbers, and locations, including correct identification of county and state.

Fortunately, both the NM OCD and the Colorado Oil and Gas Conservation Commission (COGCC) now have extensive online resources including images of well files, hearing cases, administrative order documents and searchable databases of well information. By using these resources and the ability of Google to search millions of documents for specific words almost every single well was correctly identified. Only three wells out of over 5500 remain unidentified. For all other wells, the API number, well name and well ID number were corrected to reflect the most current information. The publicly available NM OCD database (called ONGARD) does not include well names for those wells that were out of production prior to the advent of the ONGARD database. Wells plugged prior to about 1992 are simply listed as “PreOngard Well” both in the database and on the various web pages that access ONGARD and or other NM OCD databases. Fortunately, the PRRC has maintained a copy of the NM OCD data for many years and one feature of our own database is that we do include the last known well name and could supply that information for those wells. It was also discovered that a number of wells that were not correctly identified in the NM WAIDS database were actually wells in southwestern Colorado; corrected information was added for these wells.

Although a significant amount of quality control had been done on the numerical water quality data when the database was first deployed in 2004, we revisited data in the course of review for the new iteration of the database. One issue was found with resistivity data – some were reported in ohm×m and some in ohm×cm on the original forms, and sometimes the unit listed on the original form was not correct, as was obvious from the magnitude of the reported value. All data in the current database were standardized to ohm×cm and unusual values checked against original data where available. Values of other data were checked in some cases where they stood out because of unusually high or low values, and generally were found to be consistent with what was originally reported on the form.

One interesting finding was made when old forms were reviewed. Over 100 samples from the San Juan Basin included some variation of the abbreviation CPS, often followed by a numeric designation, in the “sampled from” blank on the form or simply written at the top of the form, or an entry such as seen in Figure 1a, where there was a number followed by the letter “W”. A search of OCD online image files enabled us to determine that these samples were not actually from water produced by an oil or gas well, but were samples of water taken from deep groundbed cathodic protection wells that were drilled by operators to prevent electrolytic corrosion of subsurface infrastructure associated with the oil and gas wells in the area. While the water quality information is therefore less useful for evaluating produced water, it is still helpful information concerning water quality and depth in that region and was retained in the database with the notation that the data was from CPS wells and should be considered groundwater data.

One other important question was raised when examining the data; this concerns the actual samples themselves. It was not always clear whether the analyzed fluid was actually water from the producing formation, fluid from the wellbore representing a mix of formations, or even from tank batteries from more than one well. Reported sample depth was often the total depth of the well, thus not a reliable indicator. Finally, sample quality might have been poor to begin with – sample dates and analysis dates reveal time gaps that could alter water chemistry due to atmospheric exposure (Patzke, 1989). Some samples were collected during major waterflood activities and likely reflect significantly altered water chemistry, while others were collected because the producer was having a problem with scaling or corrosion. In most cases, particularly in older wells, water quality was not evaluated routinely so the information may be skewed towards more problematic water quality (Hiss et al, 1969). None of these issues were controllable in our work, but are worth mentioning so users are aware of potential problems with data.

Data Standardization

Standardization of field name and formation data improves the ability of a user to search the database by a pool or a formation, and this type of information is often requested by operators in the area. Field name and formation data entered in the earliest version of the NM WAIDS database were derived directly from the forms or operator records and resulted in considerable variability. Both field and formation were described using a variety of abbreviations and names. Subsequent work on unrelated projects has provided us with a standardized list of pool names, formation names, and a GIS layer of pool boundaries for New Mexico. Figure 10 is an example of this work, showing the pools that comprise the Leonardian play in the Central Basin Platform (CBP) and Northwest Shelf (NWS). Pools are categorized by producing formation, and play boundaries by potential for further development. Standardized field and formation names were incorporated into the newest version of the database. In addition to formation, samples were also grouped into plays following the work of Broadhead and others (2004), Engler and Cather (2014), and Engler and others (2015).

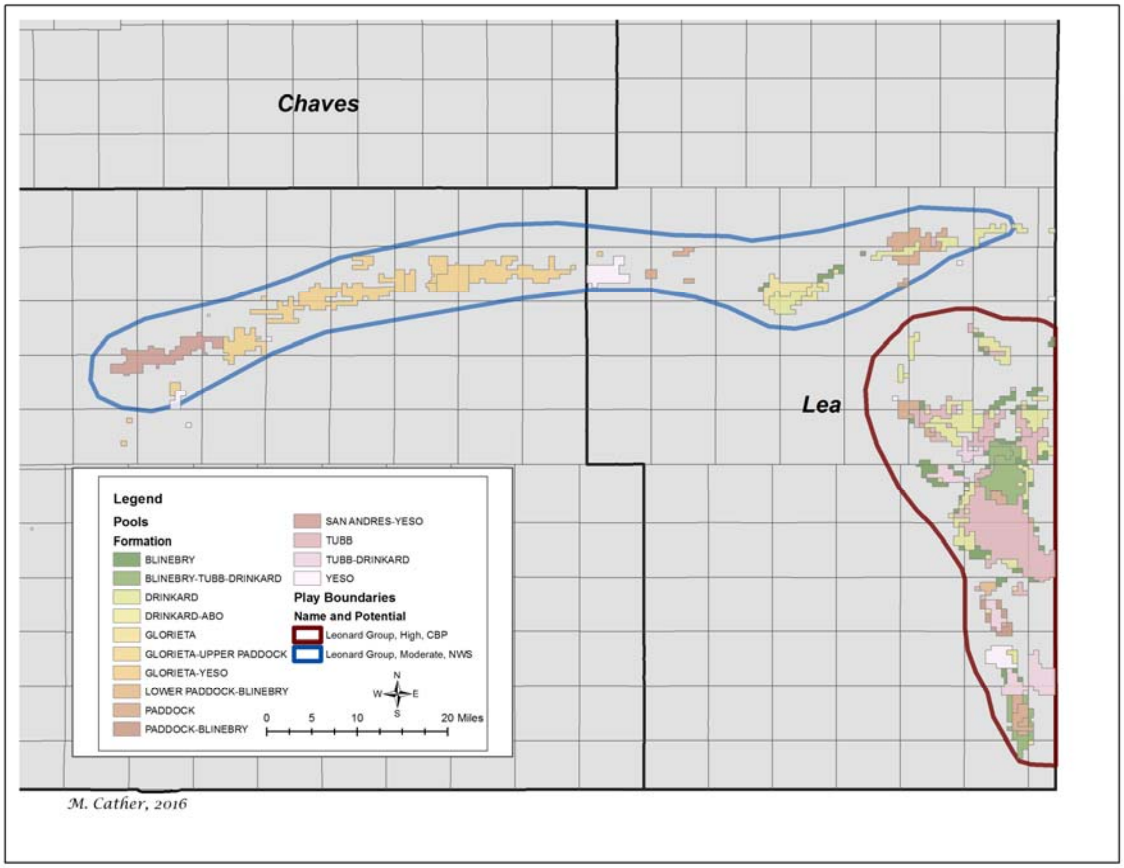


Figure 10. Pool and play boundaries for the two major Leonardian plays in southeastern NM.

Website Redevelopment

The original NM WAIDS project was created using the Integrated Development Environment (IDE) Microsoft Visual Studios, using C# as a programming language. The project utilized ASPX pages for the user interface. Much of the old code had security flaws that could be exploited to hack servers, change data, or even infect client computers with malware. Improvements to the graphical user interface were necessary in order to be integrated with the new look developed for the GO-TECH main site.

Several steps were necessary to achieve the objective of getting the Produced Water Quality Database and NM WAIDS web site back online. These steps included:

- Review all existing code that pertained to the NM WAIDS web site, including client and server side as well as any database procedures that would be relevant
- Document functionality of all code

- Identify security issues, poor coding practice, inconsistencies, and broken links or procedures, and determine appropriate fixes
- Identify an optimum IDE and programming language
- Convert all code and procedures to updated platforms and languages
- Configure server to handle different operating environments that are needed by various components of the web site including a legacy system requested by one of our state agency clients
- Run security testing on web site
- Beta-test revised web site and make needed changes
- Publish new version of web site

RESULTS AND DISCUSSION

Data Analysis and Identification of Data Gaps

Data from at least four sources were combined to create the newest version of the NM Produced Water Quality Database (NM PWQD). The bulk of the data were from the older NM WAIDS database. However, over 2700 new samples were added. These come primarily from operator-contributed databases, with minor amounts of data obtained from previously unknown sources found warehoused either in physical or online repositories. Figure 11 shows a map comparing the areal distribution of newly added data as compared with what was previously in the database in the Permian Basin. Many of the additions covered the central part of the Delaware Basin, where the majority of new completions in the New Mexico part of the Permian Basin have been in the past 5-6 years. No new data has been added for the San Juan Basin. Table 2 describes the current geographic distribution of data in the NM PWQD.

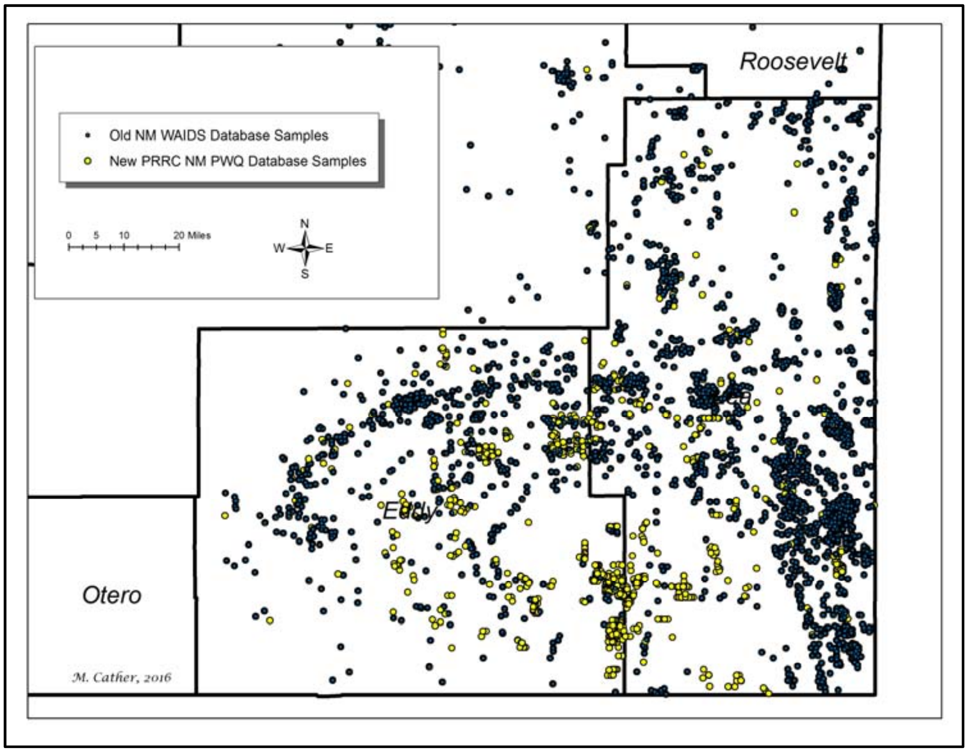


Figure 11. Comparison of locations of old data vs. newly acquired data.

Table 2. Sample count by region.

State	Region	Number of samples
NM total		9341
	San Juan Basin	2928
	Permian Basin	6379
	Other Area	34
CO		79
TX		72

Sample Vintage

Samples show a wide spread in age of the data. Table 2 and Figures 12 and 13 show distribution of samples by vintage of data using the year the sample was taken or analyzed as a criterion. Although much of the data is older, it is still relevant. About 60% of the 6376 samples in the database from the Permian Basin are from wells that are still not listed as plugged by the NM OCD, and that number rises to about 80% for the San Juan Basin.

Table 3. Sample vintage.

Sample Vintage	Current San Juan Basin	Current Permian Basin	Total, Current Producing Areas*	NM WAIDS (older database)
Unkown	577	2457	3034	3170
Pre-1950	3	34	37	37
1950-1959	111	437	548	778
1960-1969	372	304	676	533
1970-979	613	298	911	641
1980-1989	637	174	811	150
1990-1999	594	812	1406	904
2000-2009	120	387	507	502
2010-2016	0	1473	1473	0
Total	2450	6376	9403	6715

*Total of 9413 samples in database include samples in other states and outside major producing areas in NM.

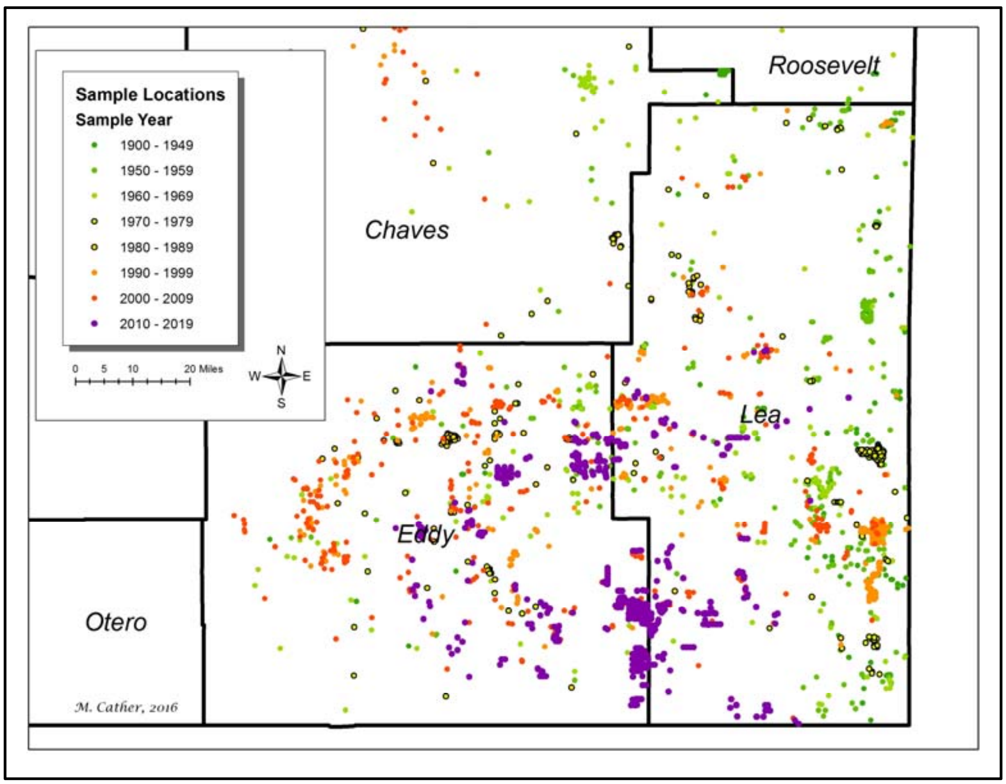


Figure 12. Distribution of Permian Basin samples with respect to date sample was taken or analyzed.

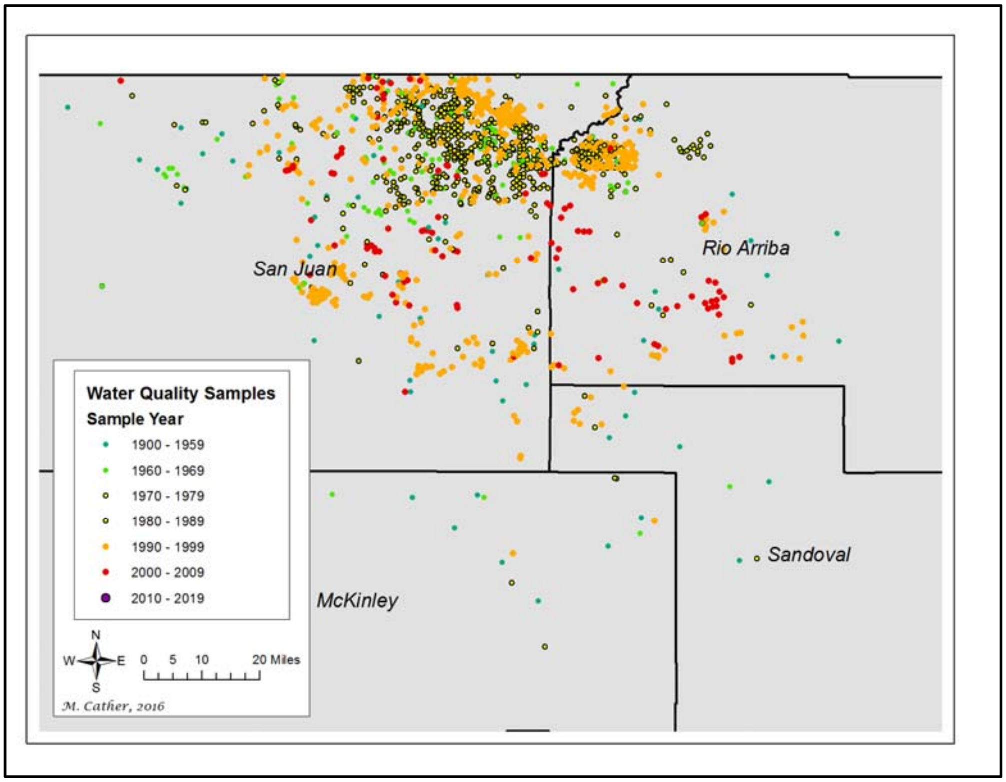


Figure 13. Distribution of San Juan Basin water samples with respect to date sample was taken or analyzed.

Areal Distribution

Approximately 67% of the total 9493 samples in the database are in the Permian Basin of New Mexico. Visual assessment of areal distribution of the Permian Basin data (Figure 14) illustrates that sample locations are fairly dispersed and widespread, consistent with the distribution of oil and gas wells. A comparison of sampled wells to all well locations shows that sampling coverage reflects the general distribution of wells, particularly with respect to more recent well activity (Figure 15). Aggregating sample location by township does show some areas are over-represented, with very few wells but each well having more than one sample, or under-represented with no samples. Out of 490 townships in southeastern New Mexico, 406 had at least one sample, but 317 of those townships had a sample rate of 5% or less. Figure 16 shows sample rates by township in the area, recent well activity, and indicates regions that, based on low sample numbers and high activity, would benefit by additional sampling.

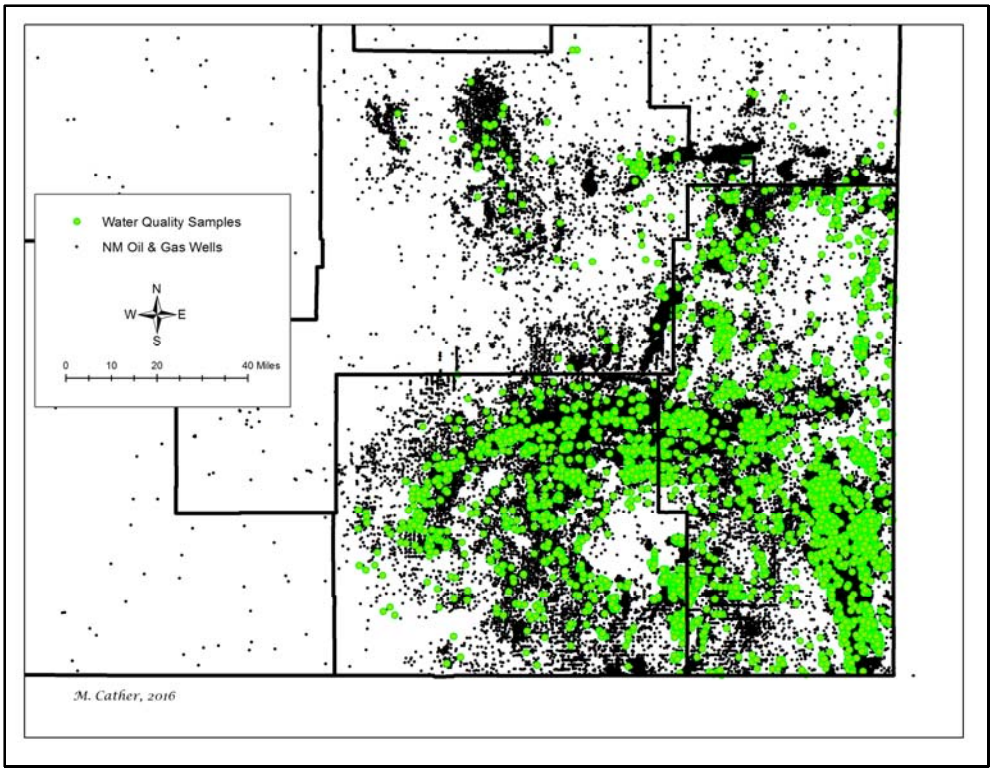


Figure 14. Distribution of samples as compared with overall distribution of oil and gas wells in southeastern New Mexico.

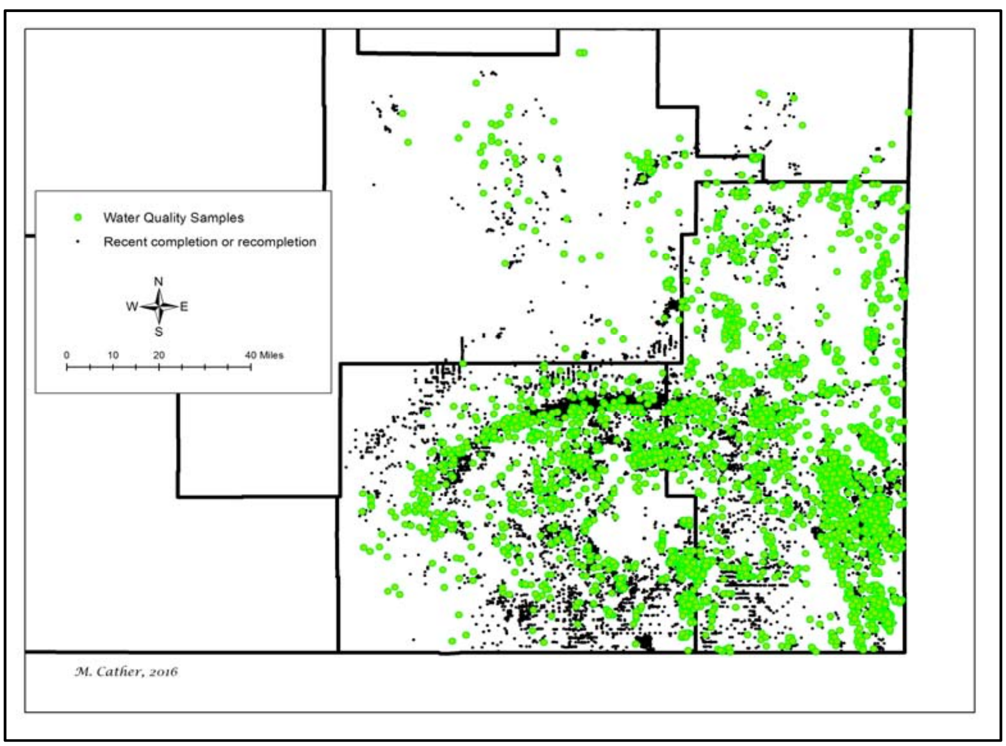


Figure 15. Distribution of samples as compared with recent well activity (completion or recompletion after 2010) in southeastern New Mexico.

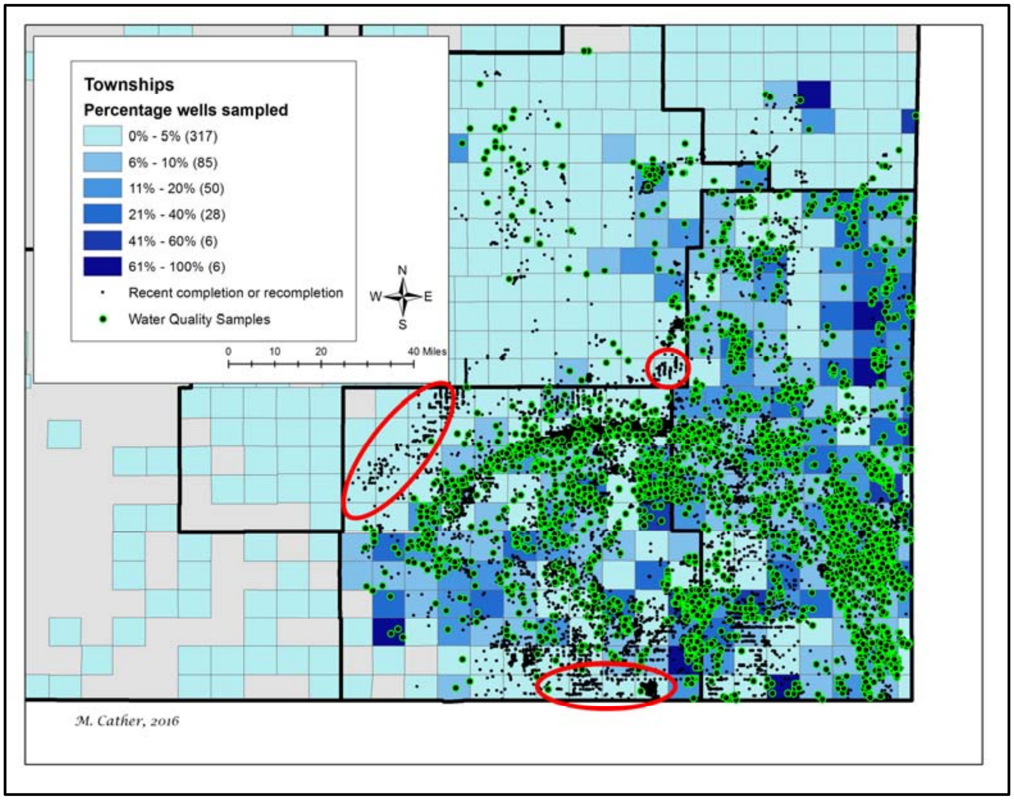


Figure 16. Map comparing relative density of sampling by township with current activity and with all sample locations. Darker colored townships indicate a higher percentage of total wells in the township have been sampled. Red ellipses are areas that would benefit from additional sampling efforts.

Similar information is shown in Figures 17 and 18 for the San Juan Basin. Figure 17 shows water quality sample locations superimposed on all well locations in the basin, as well as recent completions or recompletions since 2010. Figure 18 shows sample density by township, along with recent activity and sample locations. It is clear that sample density in certain parts of Rio Arriba and Sandoval Counties is low compared to the amount of activity that has recently been occurring in these areas. High activity in these areas is because of recent successful horizontal oil well completions in the Mancos shale. The red ellipses in Figure 18 show areas where future produced water sampling efforts should be focused.

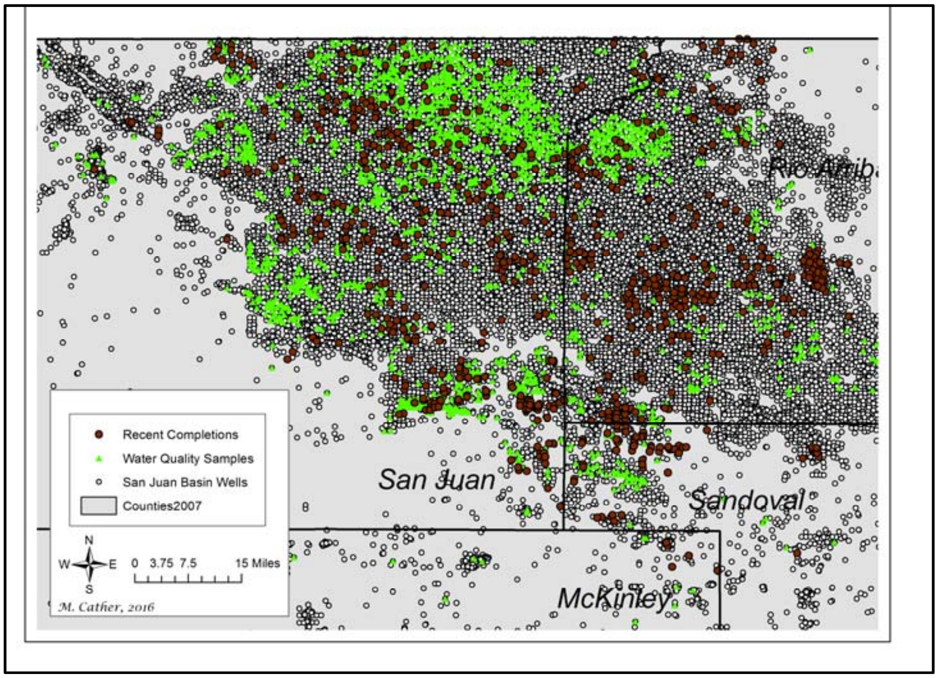


Figure 17. Distribution of water samples as compared with the overall distribution of wells in the San Juan Basin, and recent well activity (completion or recompletion after 2010).

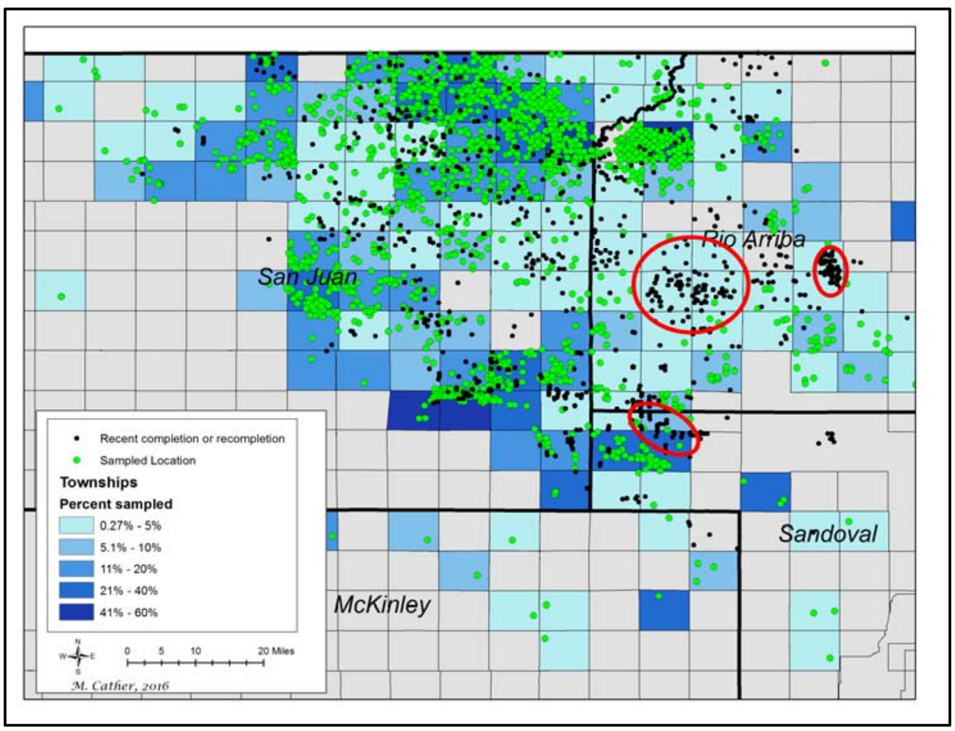


Figure 18. Map comparing relative density of sampling by township with current activity and with all sample locations. Darker colored townships indicate a higher percentage of total wells in the township have been sampled. Red ellipses are areas that would benefit from additional sampling efforts.

Distribution by Play

Figure 19 shows the sample set classified by the plays identified in southeastern New Mexico and Figure 20 shows a similar map with recent well activity, noted as completions or recompletions since January 2011. It appears from these maps that the Bone Spring Formation and Delaware Mountain Group Basinal sandstones, primarily the Brushy Canyon sandstone, are still under-represented with respect to their importance to producers. Likewise, wells producing from Artesia platform sandstones are overrepresented as compared with recent completion activity. These Artesia Group wells were heavily sampled during the 1950s and 1960s when the play was active in both primary and waterflood-enhanced production. Many of these wells are still operational although at a reduced production level.

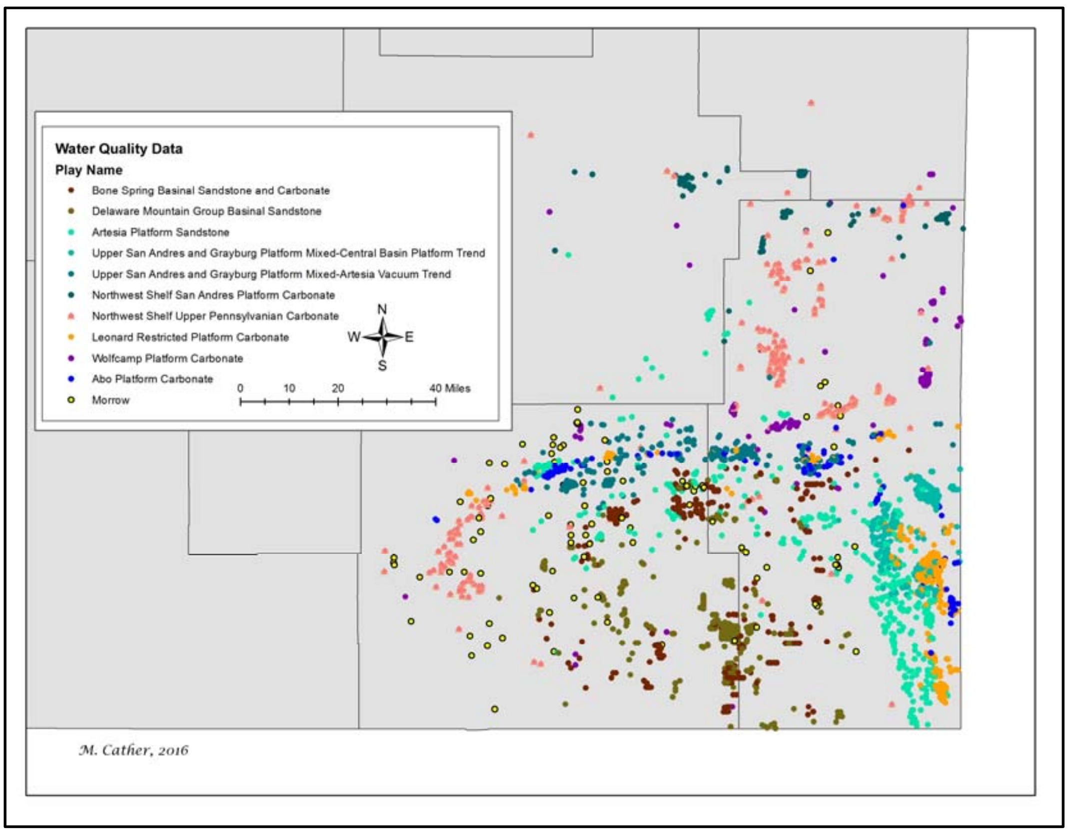


Figure 19. Water quality data by play in southeastern New Mexico. Not all samples have enough information to assign to a play.

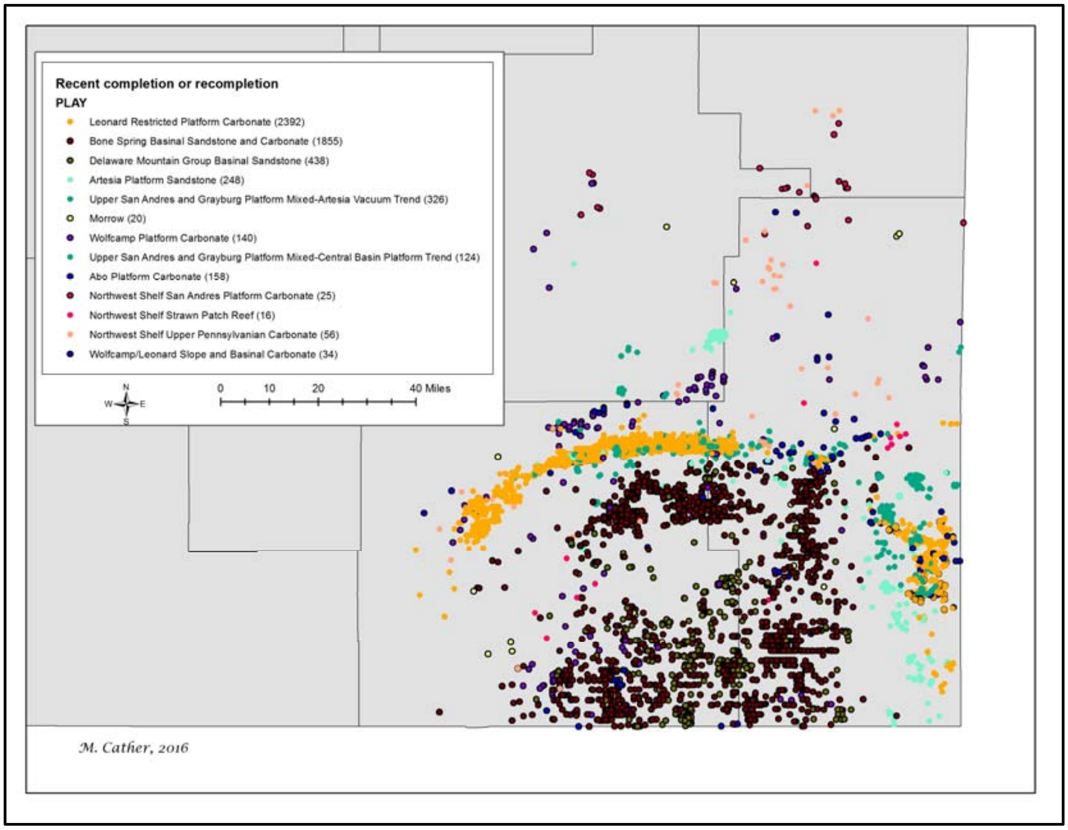


Figure 20. Map showing recent drilling activity in southeastern New Mexico, defined as completion or re-completion recorded since 1/1/2011, wells grouped by play.

Plays in the San Juan Basin are less well defined. However, samples can be grouped according to the producing formation where pool data is available for the sampled well. Figure 21 shows produced water samples by formation. One feature of interest in this figure is the cluster of CPS wells located in northern San Juan County. These data, as previously discussed, are not from produced water but water from wells drilled as part of a cathodic protection program. Most samples are from groundwater and range in depth from a few tens to a few hundreds of feet. Figure 22 shows recent well activity by play. Most of the clusters of recent activity have been due to the interest in the Mancos shale play in southern Rio Arriba and Sandoval Counties, and recent recompletions in the Gavilan Pictured Cliffs Pool in Rio Arriba County. The NM PWQD is lacking in samples from the Mancos and Pictured Cliffs in these areas of recent activity.

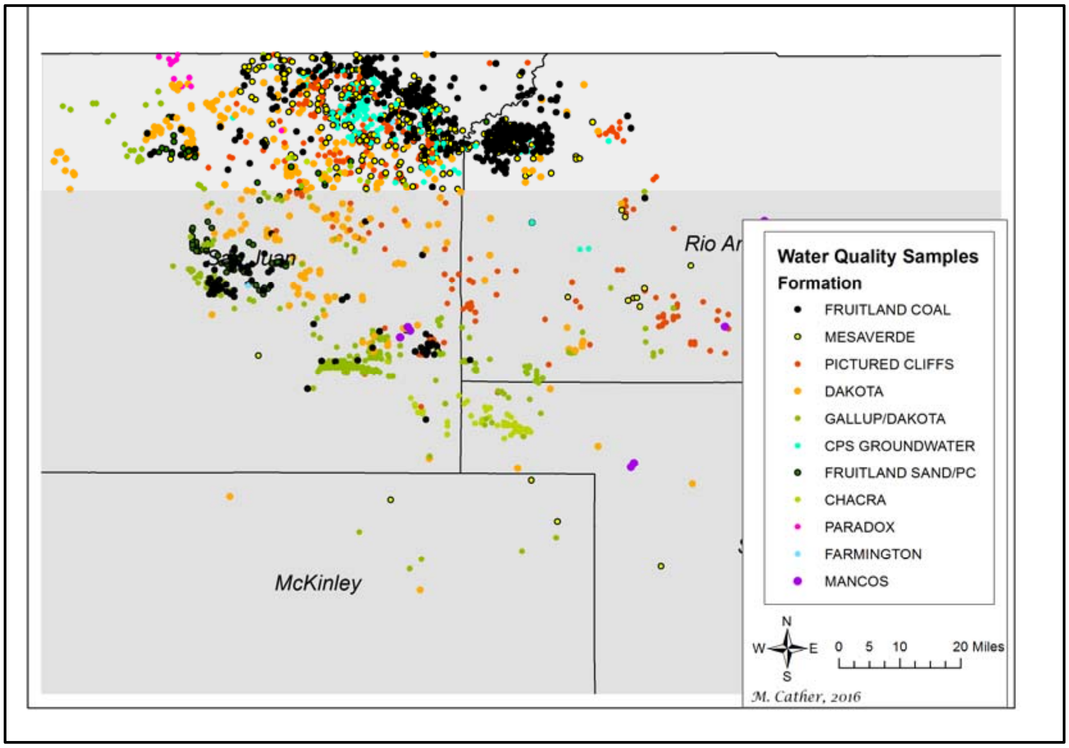


Figure 21. Water quality data by formation in the San Juan Basin. Not all samples have enough information to assign to a play.

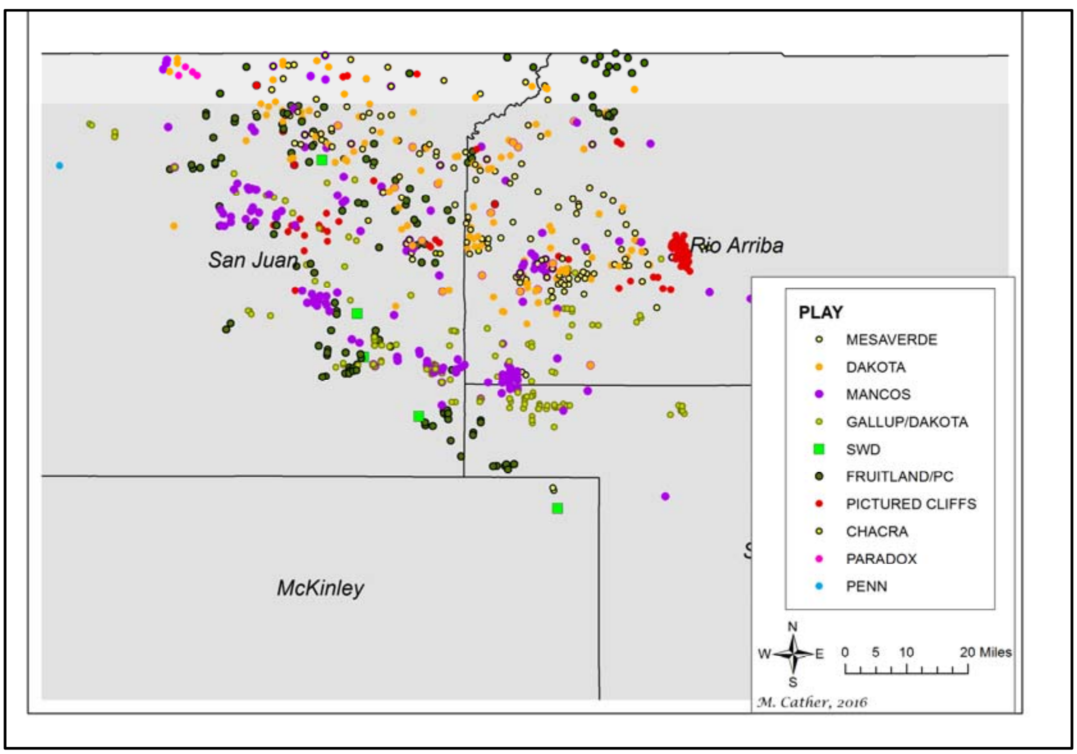


Figure 22. Map of recent completions in the San Juan Basin, wells grouped by play. Salt Water Disposal (SWD) wells shown for reference.

Water Volume Analysis

In addition to understanding variation in water quality, it is important to know where and how much water is being produced, where high volumes are available, and information about sustainability of production. Any type of reuse scenario would probably have to consider locating in an area where a significant volume of water of "acceptable for need" quality is currently being produced. Producers report volumes of oil, gas, and water production to the NM OCD on a monthly basis. The information is entered into the ONGARD database, and monthly updates to the public are provided via ftp server as an enterprise-scale database. PRRC has been automatically downloading, processing, and archiving that data in our own production database since 1996. This data is available at http://octane.nmt.edu/gotech. The water volume data reported by operators, particularly in years prior to about 2000 were considered somewhat unreliable (Jane Prouty, NM OCD, personal communication, 2005) but are the best data available. For wells in some areas, water is both injected and produced as part of pressure maintenance and waterflood operations, so not all the volume of produced water is necessarily available for reuse. Reported production volumes may not accurately reflect what the reservoir would produce without those operations. Information about recycling of this nature is difficult to obtain in the public databases.

Production data can be looked at on a per-well basis, or aggregated by township. All liquid production is reported in barrels (42 gallons). One acre-foot of water is about 7758 barrels. Figures 23 and 24 depict cumulative production from individual wells that have reported water production in the past three years, for the Permian and San Juan basins. For simplification of the figure, wells that produced under about 400,000 barrels of water, or about 50 acre feet, for their lifetime of production were omitted. There are relatively few wells that produce a very large volume of water and it would be worth investigating these wells further.

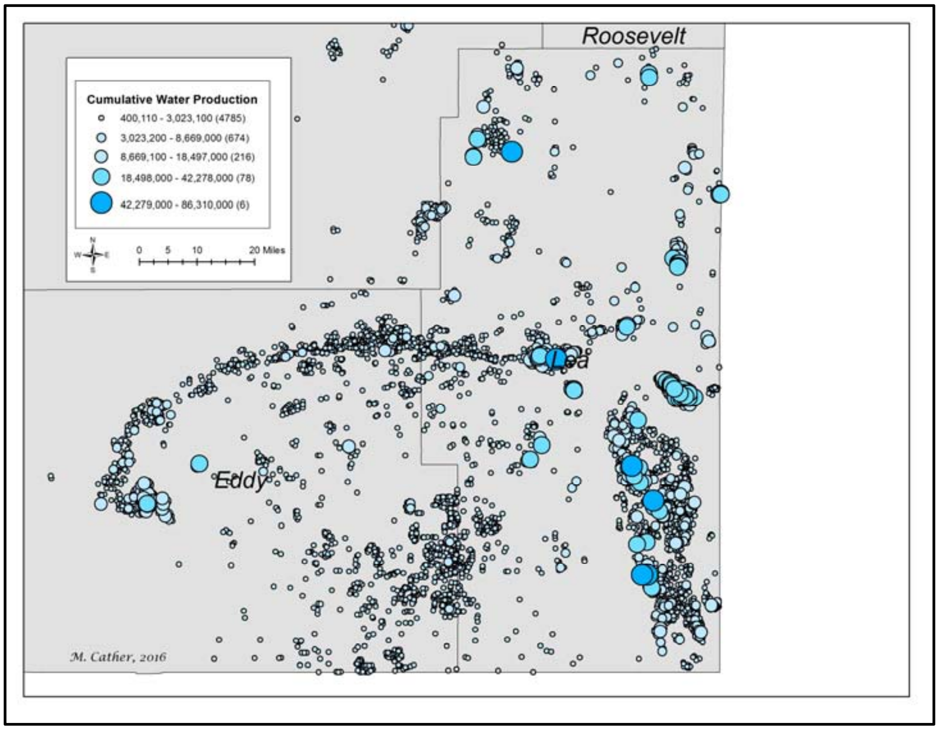


Figure 23. Cumulative production of water for Permian Basin wells producing over 60 acre-feet of water. All wells in this figure reported water production in 2014 or 2015. 1 barrel of water is about 42 gallons; 1 acre-foot is equivalent to 7738 barrels.

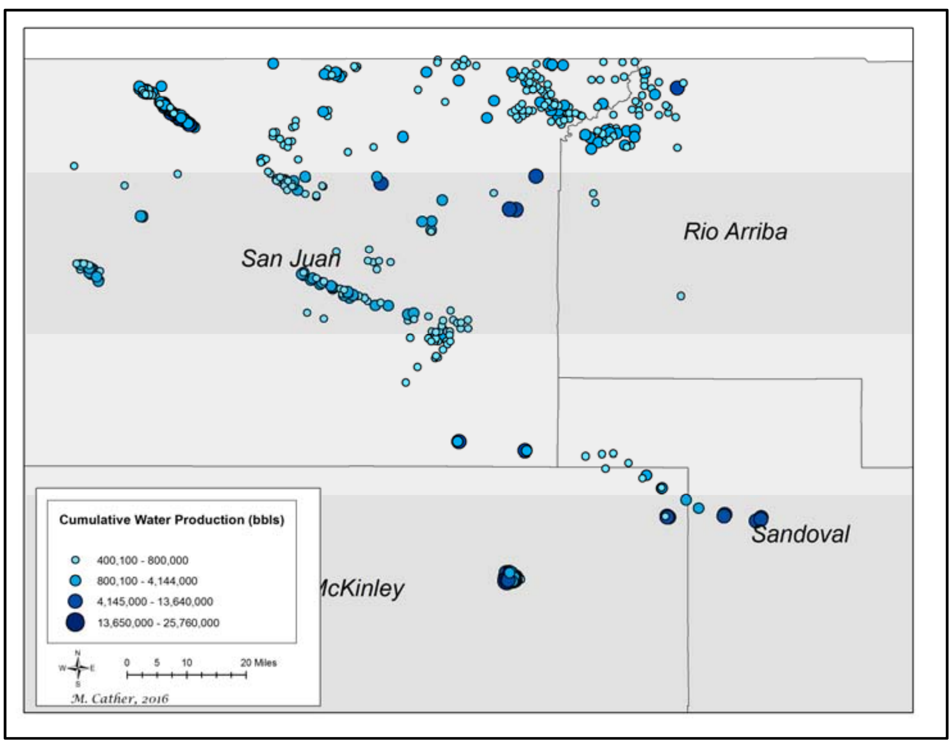


Figure 24. Cumulative production of water for San Juan Basin wells producing over 60 acre-feet of water.

Figures 25-30 provide an aggregated view of water production by township in New Mexico, looking first at total water production and second only at annual production for 2015 for the Permian and San Juan Basins, respectively. Comparing Figures 25 and 26 for the Permian Basin, a similar pattern of production exists in the two maps, but there is an increase in water production in recent time in the deeper parts of the Delaware Basin towards the southern border of the state. Unfortunately, this water is often found to be highly saline and would be costly to use for any purpose that required relatively low salinity water. Figure 27 does highlight one area in eastern Lea County that has both low TDS waters reported, and high production volumes. This area might be a target for further investigation into water reuse. In the San Juan Basin (Figures 28-29), the pattern of water production appears the same for both lifetime cumulative and 2015 total water production by township, with minor exceptions in McKinley County (lower contribution to 2015 production), and southern San Juan County (higher production in a few townships). Water salinities appear to be much more variable across the basin. There is a trend for Fruitland coalbed methane waters to be less saline in the northern part of the basin (EPA, 2004) and north of the New Mexico border salinities may be < 10,000 mg/L.

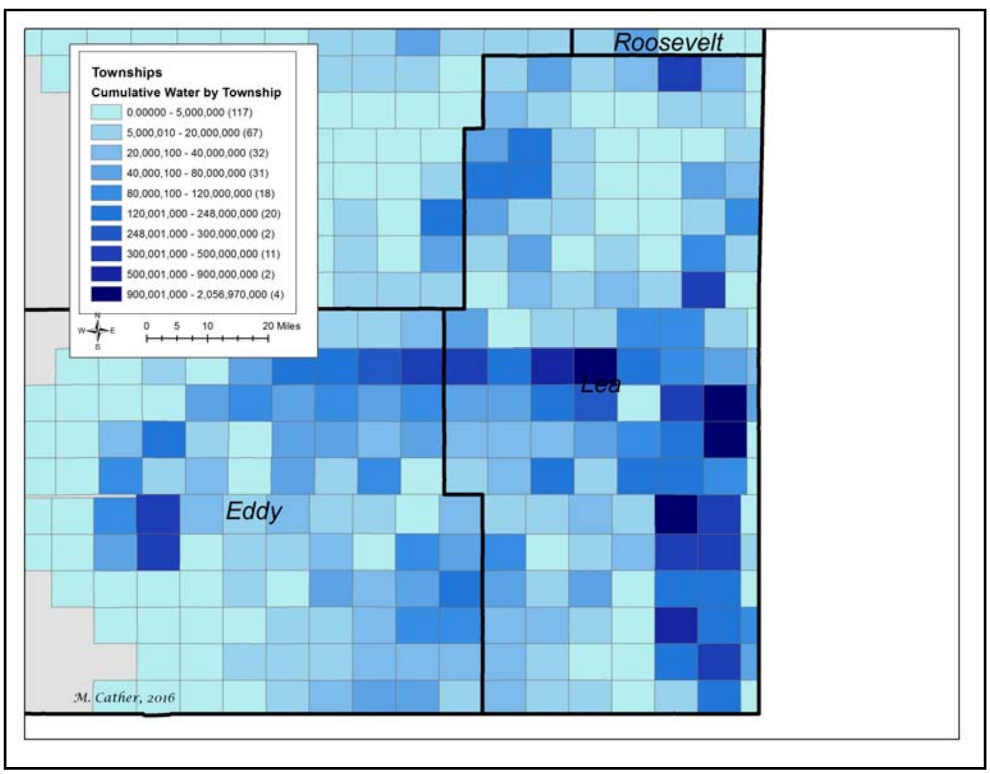


Figure 25. Cumulative water production by township, Permian Basin, reported in barrels (bbls).

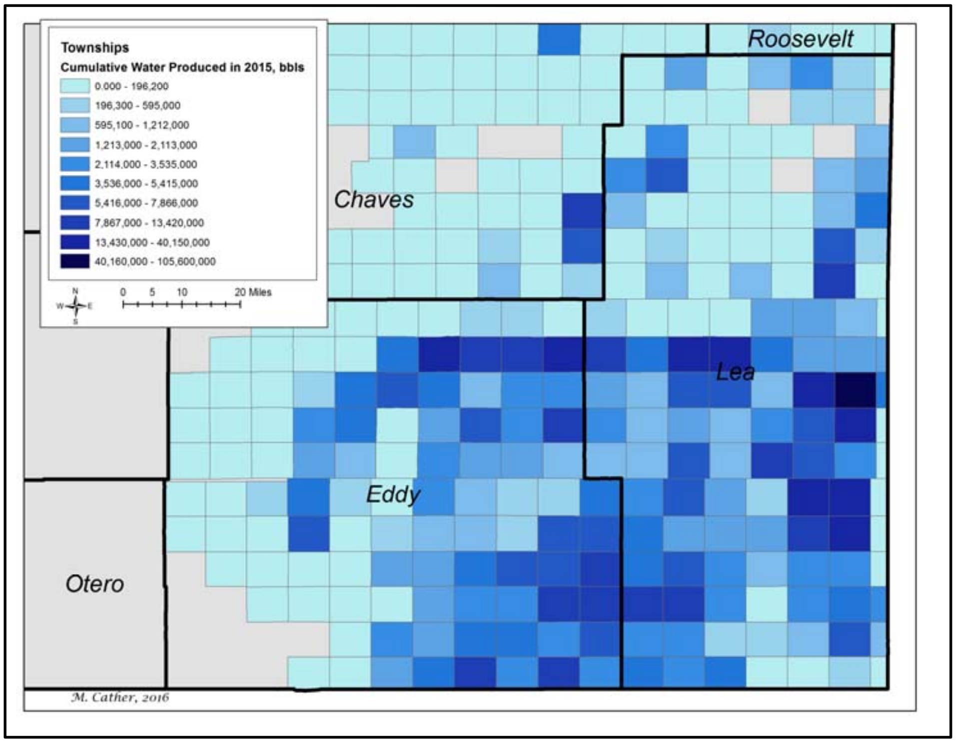


Figure 26. Production of water by township in 2015, Permian Basin.

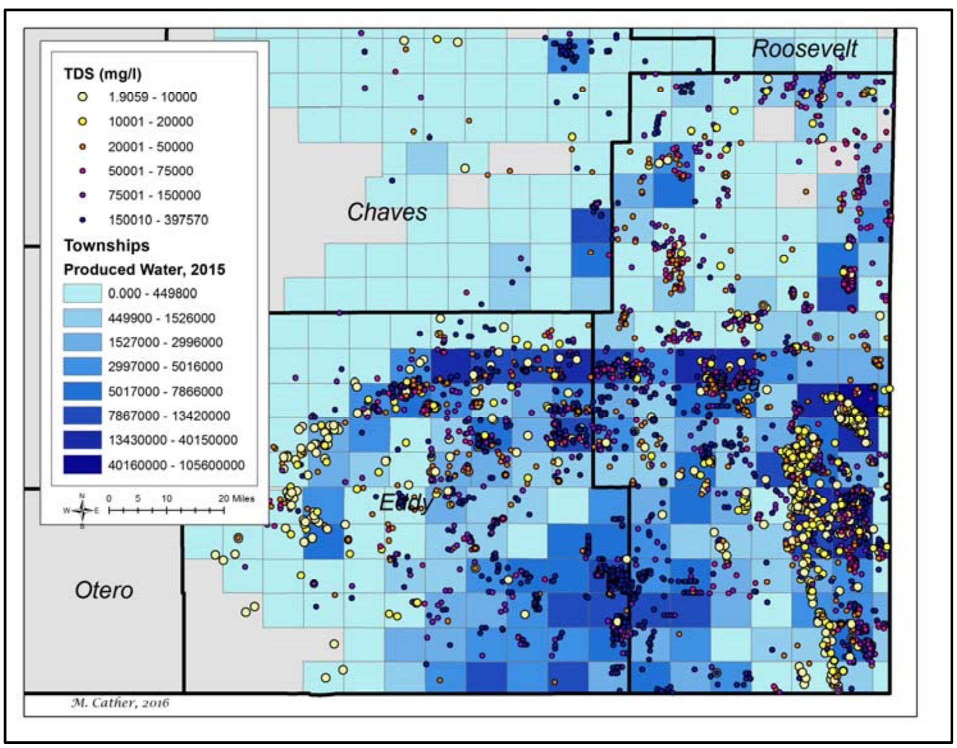


Figure 27. Water production in 2015 compared with TDS of samples, Permian Basin. Samples with lower TDS values (yellow circles) show clusters in eastern Lea County where there is also relatively high water production.

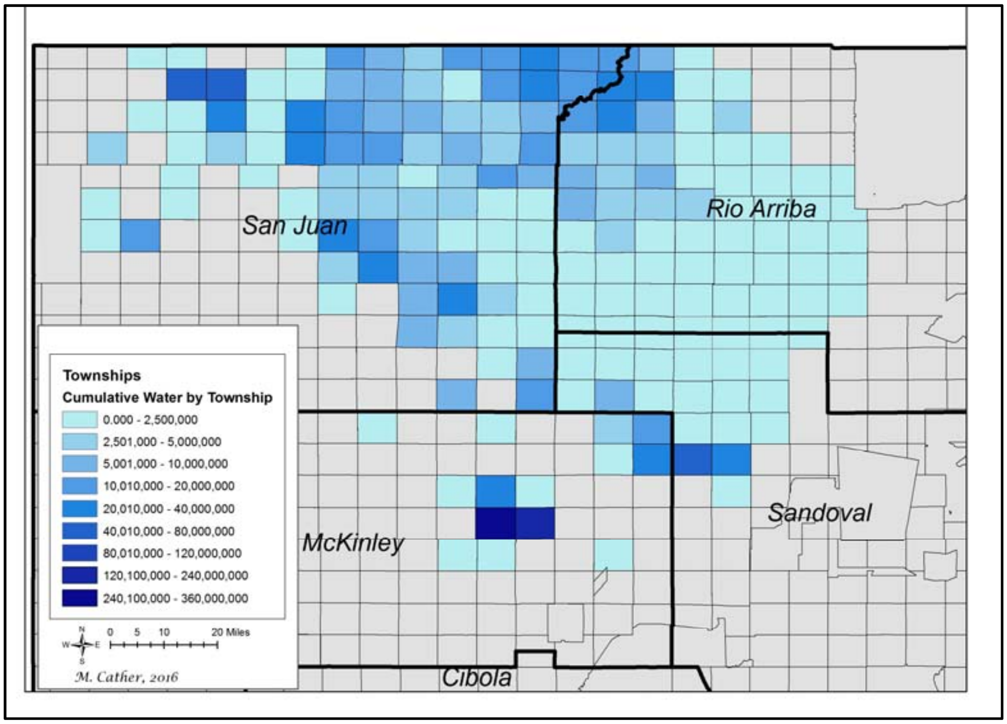


Figure 28. Cumulative water production by township, San Juan Basin, reported in barrels (bbls).

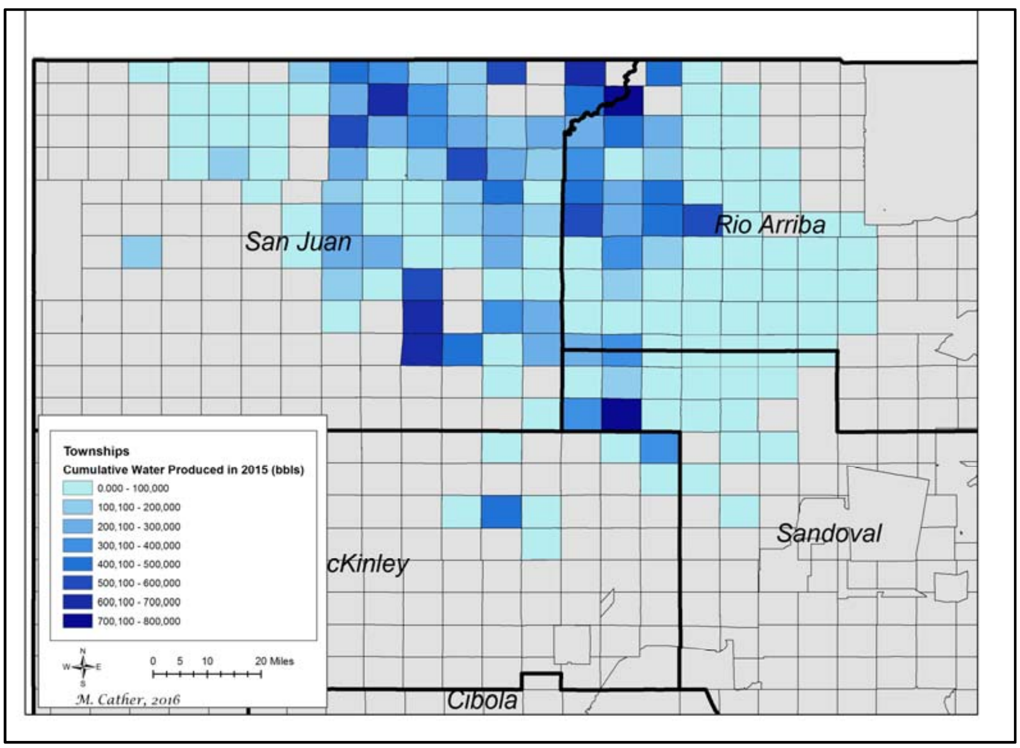


Figure 29. Production of water by township in 2015, San Juan Basin.

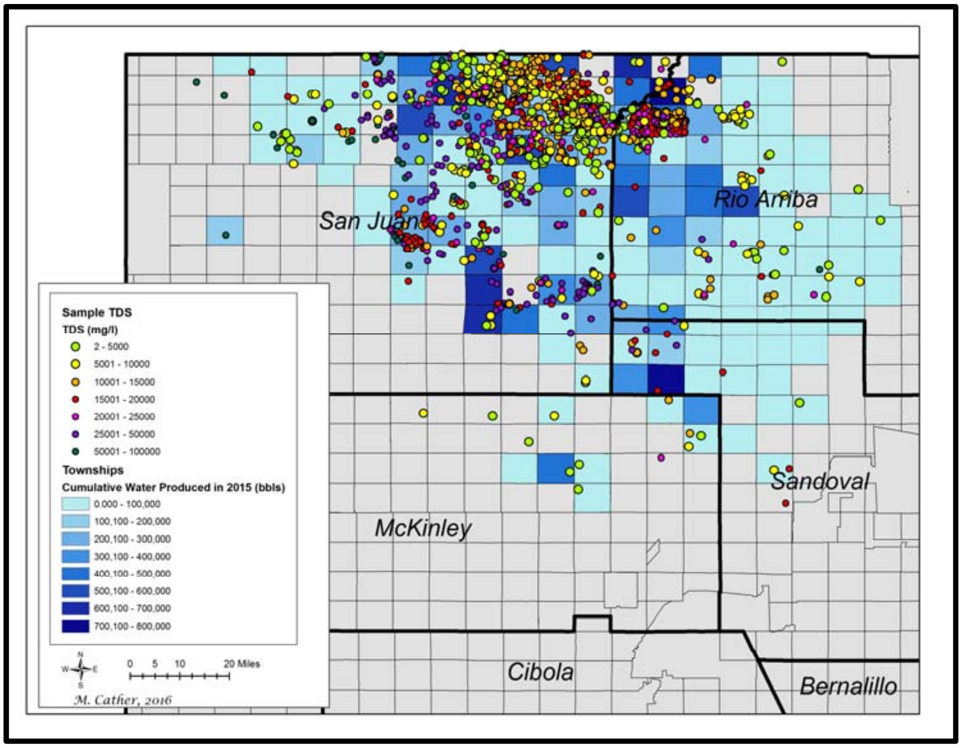


Figure 30. Water production in 2015 compared with TDS of samples in the San Juan Basin

Data Deployment

Several challenges arose during the process of redesigning and recoding the NM WAIDS. NM WAIDS was part of a larger web site (GO-TECH) that has provided access to a variety of data since 1996, and we wanted to create an entire site that, with the exception of the NM State Land Office data pages, all had the same theme, look and feel. This was made difficult for a variety of reasons. Each section of the old web site used different programing languages and Internet Development Environments (IDE). The underlying database servers resided on several machines with different vintages of operating systems and database servers. In order to comply with NMT security requirements, all components of all sections of the web site had to be upgraded to the most recent versions available. Each component was subjected to a variety of security tests prior to publication. Finally, we were requested to put the new web site on a virtual machine that would be operated by the campus computer services department and this introduced another layer of complexity and the longest time delays of all.

The following has been completed to date: PRRC has moved all database services to a single machine, created a new project based on a different IDE and language, structured the project to have a Model View Controller (MVC) layout, converted ASPX files to Thymeleaf .html files, recycled and reformatted old Javascript code, and connected and tested the various database connections with more secure coding. Most of the web tools, with the exception of the GIS mapping capabilities, have been recoded. Data download functions have been recoded and enabled. The revised design layout for the entire site, including NM WAIDS is complete at this point. Internal beta testing is underway. The Produced Water Quality Database has been updated on our server, so that any query accesses the most recent version of the database.

Because of delays in deployment of the new website we have added water quality database search functionality to our existing GO-TECH website, which was also recoded and has undergone extensive security testing. The search is available from the URL http://octane.nmt.edu/gotech/water/producedwater.aspx -and will be easily found from links in the menus at the left or top of any page (Figure 31). Figure 32 is a screen shot showing the results of a search on the well name “State J”. Searches use a “like” configuration so the user does not have to know an entire name. Searches can use a combination of location criteria (township, range, section), or can use a specific API. Experience has shown that these are the most common sorts of searches the typical user will use. The result panel is simple, showing the well identification, location, and TDS and chloride data. Each column is sortable, and the results can be paged through if there are more than 10 results. The user is also advised that more data are available, and they can create and download the Excel spreadsheet created for their search query by pressing the appropriate button. This spreadsheet (Figure 33) contains the full set of data available for the results, and includes water quality information, field and formation, and latitude and longitude.

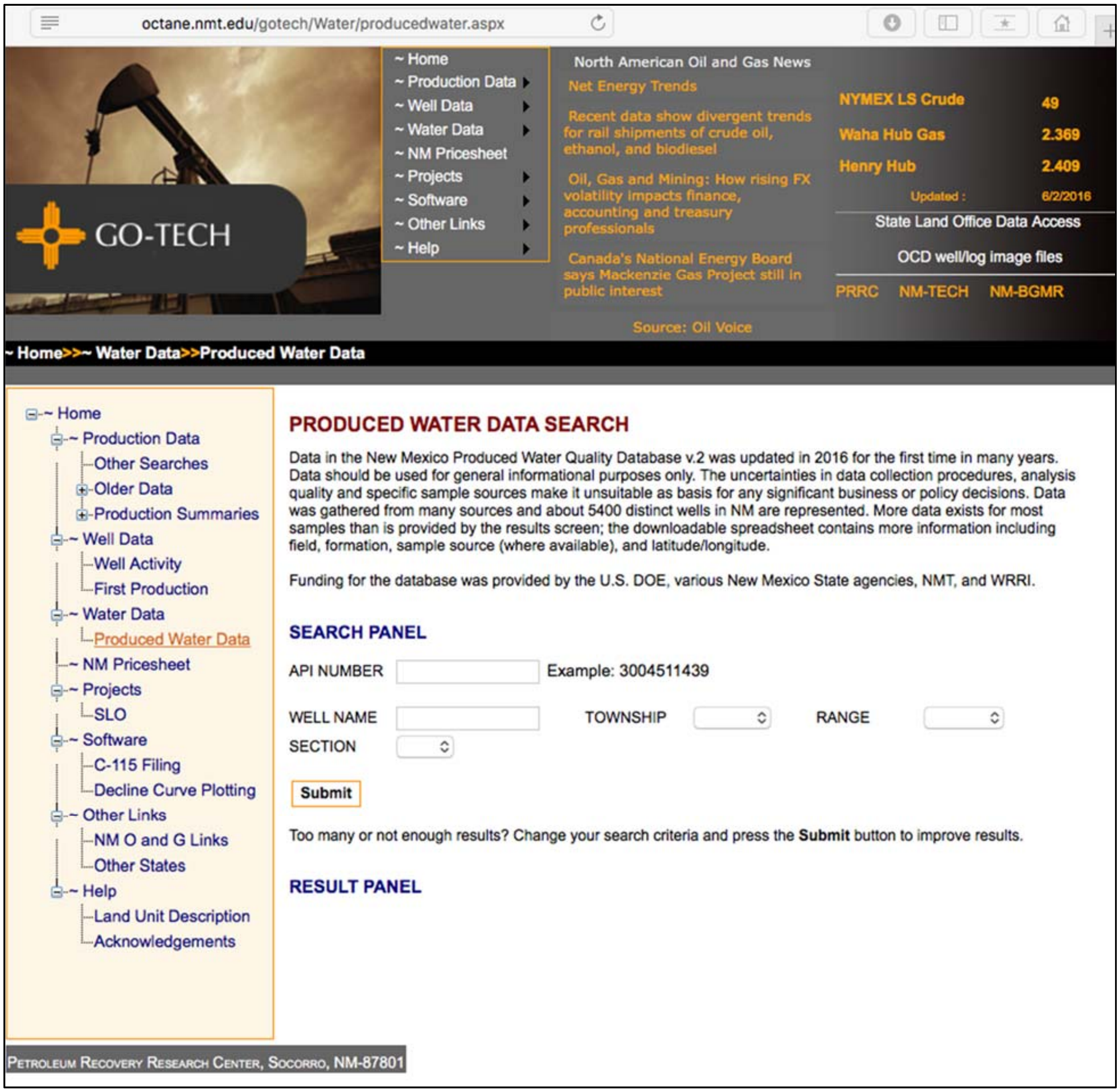


Figure 31. Screen shot of Produced Water Database search page. Links on left-hand and top menus both provide access from the GO-TECH home page http://octane.nmt.edu/gotech/

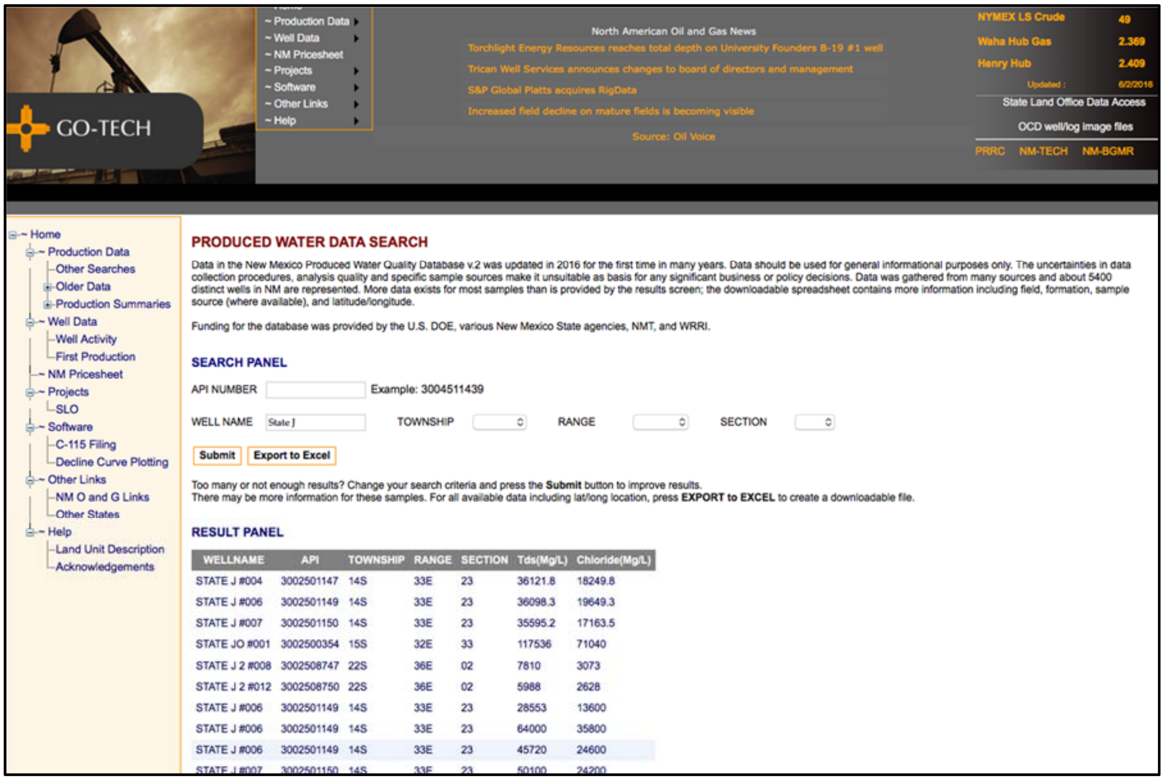
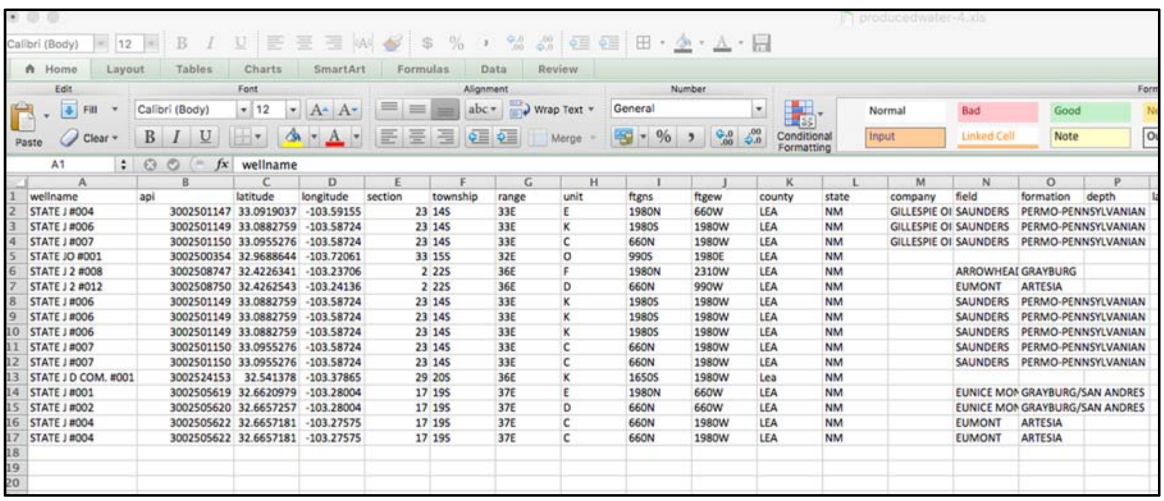


Figure 32. Screen shot of the main search and result panel for the NM PWQD on the GO-TECH web site at http://octane.nmt.edu/gotech/water/producedwater.aspx.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	wellname	api	latitude	longitude	section	township	range	unit	ftgns	ftgew	county	state	company	field	formation	depth
2	STATE J #004	3002501147	33.0919037	-103.59155	23	14S	33E	E	1980N	660W	LEA	NM	GILLESPIE OI	SAUNDERS	PERMO-PENNSYLVANIAN	
3	STATE J #006	3002501149	33.0882759	-103.58724	23	14S	33E	K	1980S	1980W	LEA	NM	GILLESPIE OI	SAUNDERS	PERMO-PENNSYLVANIAN	
4	STATE J #007	3002501150	33.0955276	-103.58724	23	14S	33E	C	660N	1980W	LEA	NM	GILLESPIE OI	SAUNDERS	PERMO-PENNSYLVANIAN	
5	STATE JO #001	3002500354	32.9688644	-103.72061	33	15S	32E	O	990S	1980E	LEA	NM				
6	STATE J 2 #008	3002508747	32.4226341	-103.23706	2	22S	36E	F	1980N	2310W	LEA	NM		ARROWHEAI	GRAYBURG	
7	STATE J 2 #012	3002508750	32.4262543	-103.24136	2	22S	36E	D	660N	990W	LEA	NM		EUMONT	ARTESIA	
8	STATE J #006	3002501149	33.0882759	-103.58724	23	14S	33E	K	1980S	1980W	LEA	NM		SAUNDERS	PERMO-PENNSYLVANIAN	
9	STATE J #006	3002501149	33.0882759	-103.58724	23	14S	33E	K	1980S	1980W	LEA	NM		SAUNDERS	PERMO-PENNSYLVANIAN	
10	STATE J #006	3002501149	33.0882759	-103.58724	23	14S	33E	K	1980S	1980W	LEA	NM		SAUNDERS	PERMO-PENNSYLVANIAN	
11	STATE J #007	3002501150	33.0955276	-103.58724	23	14S	33E	C	660N	1980W	LEA	NM		SAUNDERS	PERMO-PENNSYLVANIAN	
12	STATE J #007	3002501150	33.0955276	-103.58724	23	14S	33E	C	660N	1980W	LEA	NM		SAUNDERS	PERMO-PENNSYLVANIAN	
13	STATE J D COM. #001	3002524153	32.541378	-103.37865	29	20S	36E	K	1650S	1980W	Lea	NM				
14	STATE J #001	3002505619	32.6620979	-103.28004	17	19S	37E	E	1980N	660W	LEA	NM		EUNICE MON	GRAYBURG/SAN ANDRES	
15	STATE J #002	3002505620	32.6657257	-103.28004	17	19S	37E	D	660N	660W	LEA	NM		EUNICE MON	GRAYBURG/SAN ANDRES	
16	STATE J #004	3002505622	32.6657181	-103.27575	17	19S	37E	C	660N	1980W	LEA	NM		EUMONT	ARTESIA	
17	STATE J #004	3002505622	32.6657181	-103.27575	17	19S	37E	C	660N	1980W	LEA	NM		EUMONT	ARTESIA	

Figure 33. Screen shot of a portion of the downloaded spreadsheet obtained for the wells returned in the search request depicted in Figure 32.

Redeployment of the online GIS mapping service to both oil and gas production wells and produced water sample data was explored. Initial work using one particular software solution did not work well on the large production well dataset, so efforts were focused on using Google Maps as a programming interface. A beta product was created but would require significant modification before it can be useful to a general audience. This effort was considered of lower priority; geospatial data has been provided to NM WRRI for inclusion in the general GIS web service that they are compiling for this study. As mentioned previously, latitude and longitude information are available the downloaded results spreadsheets from the GO-TECH web site. This allows users to create their own maps, which in our experience is often the most requested type of service.

RECOMMENDATION FOR ADDITIONAL WORK

While this project provides access to an upgraded and expanded version of the produced waters database for New Mexico, there are still a few areas that require additional efforts:

1) Web-site testing, maintenance, and upgrades: Although the preliminary web site is complete, it is expected that the early weeks of use will bring requests and comments from users. Responding to some of these will certainly improve functionality; what our developers find to be best for information display and download may not correspond to what the client audience prefers.

2) Database updates and enhancements: The water quality database is relatively static. Although a significant amount of data was added in this latest version, we have not investigated the updated versions of public datasets such as those compiled by the USGS and other agencies that should be incorporated into the database (USGS, 2016). Because of challenges involved in duplicate record elimination and the short time frame for the current project, we chose not to add these resources at this time. In particular, other available datasets should be analyzed to see if they contain different and newer data from the areas identified in this study as under-represented.

3) Inclusion of reference materials developed for and derived from previous NM WAIDS work. An online manual of corrosion information was developed for the NM WAIDS project, and at least two student theses were written based on the water data collected for the produced and groundwater databases (Davidson, 2003; Haley, 2004). This information still has value,

particularly the Davidson thesis, which discusses water quality variability in southeastern New Mexico and should be included as a resource in the redesigned web site.

4) Closer integration of the water quality database with produced water volume information. The GO-TECH web site has production and injection volumes for oil and gas wells in New Mexico as reported by the NM Oil Conservation Division, and users can easily find the information. All this information is updated every month on the GO-TECH web site. A static version of some of the water volume data has been included in the latest copy of the NM PWQD database. This includes water production and injection volumes for 2014 and 2015, as well as cumulative total volumes. An improvement would be integration of volume and quality information so that no additional search from the user is needed, and keeping this information up-to-date.

SUMMARY

Work completed during the past two years has completely upgraded and revised the New Mexico Produced Water Quality database and web site. These data and the web site, originally compiled as part of a DOE-funded project that terminated in 2005, were taken offline because of cybersecurity vulnerabilities identified in 2013, and since that time there has been no public access to the thousands of water quality records for produced and groundwater data that were contained in the databases. The new web site has much of the functionality of the old site.

Work has included improvement, augmentation, and analysis of data in southeastern New Mexico. Over 2700 new records have been added, and all data have undergone a significant amount of verification and correction. Analysis of data by geographic distribution, vintage, and producing plays shows the database is fairly consistent with production trends in the Permian Basin, where there is more emphasis now on oil plays and in plays that are producing from the Bone Spring and Delaware Mountain Group formations. There is a lack of more recent information from the San Juan Basin. Current interest in the Mancos shale oil play is not seen in the distribution of samples in the database. Maps of water volumes and water quality highlight certain areas in eastern Lea County, and northern San Juan County that may warrant closer investigation as potential sources of abundant produced water of relatively low salinity as compared to some other regions. However, almost all produced water in New Mexico is high salinity and would be expensive and difficult to treat to any kind of drinking water standard. This would indicate the primary usages for recycling of treated produced water would be in construction, agriculture, or industry including the potential reuse of the treated water for well completion (e.g., fracking) operations.

Data Disclaimer

Data in the New Mexico Produced Water Quality Database should be used for general informational purposes only. The uncertainties in data collection procedures, analysis quality and specific sample sources make it unsuitable as a basis for any significant business or policy decisions. Information should be independently verified prior to use in any administrative or legal application.

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APPENDIX A - PRODUCED WATER DATA DESCRIPTION

There are seven tables in the Produced Water Quality Database. Relationships between the tables are shown in Figure A1. The relationships are discussed in the following paragraph. Individual tables are described more completely in subsequent paragraphs and attributes and attribute descriptions shown in subsequent figures and tables.

Table Relationships

PRRC_PWQ_SampleInfo is the master table for the water quality part of the database. This table contains the unique sample ID for each record. Sample ID relates one-to-one to the Sample ID in the **PRRC_PWQ_Sample_Quality** table. **PRRC_PWQ_SampleInfo** contains well identification and location information along with information about formations and pools for individual samples. **PRRC_PWQ_Sample_Quality** contains the actual numerical data. The table **PRRC_PWQ_SampleInfo** does not have a one-to-one relationship with the **NM_Well_Locations** table. The API number does relate in both tables, but both tables have records in them that are mutually exclusive to the table. NM_ **PRRC_PWQ_SampleInfo** does have some data from the adjacent states of Colorado and Texas, and a few samples that do not have API numbers. **NM_Well_Locations** contains location information for all the wells in New Mexico that are currently recorded in the NM OCD ONGARD database. Location information is derived from either the NM OCD, or through a location-calculation routine based on the footage and section/township/range description. **NM_Water_Volumes** contains information about volumes of produced and injected waters including cumulative totals and annual totals for 2014 and 2015, the last complete years for reported water volumes. This information is derived from the ONGARD database using volume data reported by month and year. **Last_Water_Inj** and **Last_Water_Prod** contain the last year that a volume was reported for a given combination of API and pool. This information would be necessary in identifying potential areas for water reuse projects. Two additional tables are provided for reference. **Pool_Codes** contains a list of OCD pool IDs, their official name and a cleaned and standardized version of that name for pools found in the database. Not all New Mexico pool codes are included in this list. **Well_Location_Codes** contains a listing and descriptions of various codes used in several attribute fields in **NM_Well_Locations** and is a lookup table.

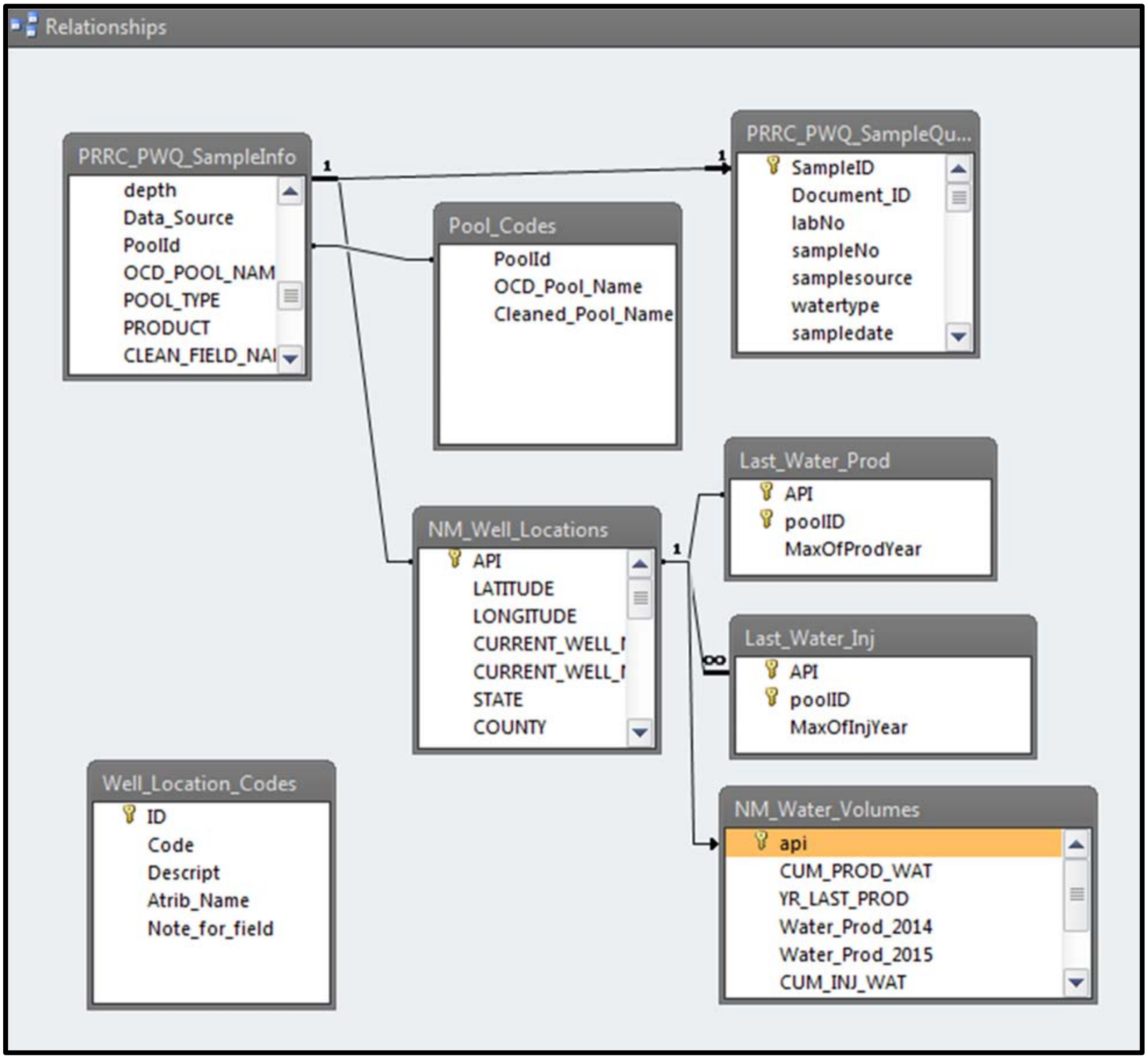


Figure A1. Relationship diagram for tables in database.

All wells in the **Last_Water_Inj**, **Last_Water_Prod**, and **NM_Water_Volumes** tables are found in the **NM_Well_Locations** table, and relate to sample information via the API, and, where available, the Pool ID. Not all wells can be assigned a pool identification number. If a well does not produce (dry hole, shut in, etc.) or is not in an area defined as a regulatory pool there may insufficient information to assign pool, formation, or play information.

Table Descriptions

Table A1 shows attribute descriptions and table property for the PRRC_PWQ_SampleInfo table. Table A2 shows the same information for PRRC_PWQ_SampleQuality. They are related through SampleID. Table A3 shows the number of non-zero records for various water quality parameters.

Table A1. Attributes and description of PRRC_PWQ_SampleInfo table.

Field Name	Data Type	Description
SampleID	Number	ID Number
Well_Name	Text	Current well name
WellId	Text	Current well ID number, usually 3-digit, sometimes followed by alpha-numeric, variable in Colorado
api	Text	10-digit API number assigned by NM OCD
Document_ID	Text	name of document data is from, if available
latitude	Number	latitude, most derived from NM OCD UTM NAD83 well file
longitude	Number	longitude, most derived from NM OCD UTM NAD83 well file
section	Text	section designation (1-36)
township	Text	Township number
township_dir	Text	Township direction, N or S
range	Text	Range number
range_dir	Text	Range direction, N or S
ftgns	Text	Footage call - feet from north or south section line
ftgns_dir	Text	Direction of footage from section line - N would mean X number of feet from the north section line, S means from the south line
ftgew	Text	Footage call - feet from east or west section line
ftgew_dir	Text	Direction of footage from section line - E would mean X number of feet from the east section line, W means from the west line
unit	Text	Unit or smallest parcel of land, Usually A-P unless the unit is in an irregularly-sized parcel of land, then has a number designation
County	Text	County of surface location
state	Text	State of surface location
company	Text	Company, if reported, in original database
field	Text	Cleaned version of NM OCD field name
formation	Text	Cleaned version of NM OCD production formation name
depth	Text	depth of sample, where provided
Data_Source	Text	What source for data was. NMWAIDS = old version of database

PoolID	Number	Official NM OCD Pool Code. Efforts were made to use pool that well was producing from in the year the sample was collected if possible and info otherwise not available
OCD_POOL_NAME	Text	Official NM OCD Pool Name, from which information in other fields is derived
POOL_TYPE	Number	OCD classification of pool
PRODUCT	Text	OCD classification of product
CLEAN_FIELD_NAME	Text	Field name, cleaned of misspellings, odd comments, punctuation, etc.
CLEAN_FM_NAME_SHORT	Text	Formation name, cleaned of misspellings, weird abbreviations, odd punctuation, etc.
CLEAN_FM_NAME_FULL	Text	Same as above but all formation names spelled out
Play_Name	Text	Useful for grouping data - derived from work performed for U.S. BLM Carlsbad and Farmington Field Offices RFD Documents
ALT_NAME1	Text	Something useful in mapping
SWD_WC_ETC	Text	Use this to designate SWD or Wildcat wells - Wildcat wells don't belong to a regular pool even though they produce from named formations
MAP_LABELS	Text	Useful for mapping purposes if trying to categorize by pool or formation
Sample_Year	Text	year of sample analysis or collection, if available. 1900 means we don't know when but not recent
Last_H2O_Prod	Text	Last year water production was reported for the well and pool
Last_H2O_Inj	Text	Last year water injection was reported for the well and pool
PLSS_ID	Text	Corresponds to PLSS ID in township shape files from CADNSDI v.2 - may need modification for some joins to work. Useful for aggregation in mapping or statistical work.

Table A2. Attributes, descriptions, and table properties for PRRC_PWQ_SampleQuality.

Field Name	Data Type	Description
SampleID	Number	ID Number
Document_ID	Text	name of document data is from, if available
labNo	Text	lab number, as on some source forms
sampleNo	Text	sample number, as on some source forms
samplesource	Text	source of sample, if available, uusually a descriptor of part of well or facility sampled
watertype	Text	type of water (produced or other) if available
sampledate	Date/Time	Date sampled

analysisdate	Date/Time	Date analyzed
ph	Number	pH
ph_temp_F	Number	temperature pH measured
specificgravity	Number	specific gravity
specificgravity_temp_F	Number	temperature specific gravity measured
tds_mgL	Number	Total Dissolved Solids in milligrams/liter. Some measurements were converted from epm or ppm
tds_mgL_180C	Number	Total Dissolved Solids in milligrams/liter, measured at 180 C
alkalinity_as_caco3_mgL	Number	alkalinity
hardness_as_caco3_mgL	Number	hardness
hardness_mgL	Number	hardness, milligrams/liter
resistivity_ohm_cm	Number	resistivity, all measurements converted to ohm cm
resistivity_ohm_cm_temp_F	Number	temperature resistivity was measured at
conductivity	Number	inverse of resistivity (almost never given in this dataset)
conductivity_temp_F	Number	temperature conductivity was measured at
sodium_mgL	Number	Sodium, given in milligrams/liter
calcium_mgL	Number	Calcium, given in milligrams/liter
iron_mgL	Number	Iron, given in milligrams/liter. Sometimes iron is given as a descriptor in the anions or general remarks field.
barium_mgL	Number	Barium, given in milligrams/liter
magnesium_mgL	Number	Magnesium, given in milligrams/liter
potassium_mgL	Number	Potassium, given in milligrams/liter
strontium_mgL	Number	Strontium, given in milligrams/liter
manganese_mgL	Number	Manganese, given in milligrams/liter
chloride_mgL	Number	Chloride, given in milligrams/liter
carbonate_mgL	Number	Carbonate, given in milligrams/liter
bicarbonate_mgL	Number	Bicarbonate, given in milligrams/liter
sulfate_mgL	Number	Sulfate, given in milligrams/liter
hydroxide_mgL	Number	Hydroxide, given in milligrams/liter
h2s_mgL	Number	Hydrogen Sulfide, given in milligrams/liter. Sometimes H2S is given as a descriptor in the anions or general remarks field.
co2_mgL	Number	Carbon dioxide, given in milligrams/liter

o2_mgL	Number	Oxygen, given in milligrams/liter
anionremarks	Text	non-numerical comments about sample composition
generalinforemarks	Memo	non-numerical comments about sample
Data_Source	Text	Source dataset

Table A3. Number of non-zero records, out of 9493 total records.

Field Name	Number Records >0	Field Name	Number Records >0
SampleID	9493	conductivity_temp_F	187
samplesource	4830	sodium_mgL	4846
watertype	698	calcium_mgL	5338
sampledate	6850	iron_mgL	2874
analysisdate	2062	barium_mgL	698
ph	6478	magnesium_mgL	5235
ph_temp_F	186	potassium_mgL	998
specificgravity	3175	strontium_mgL	694
specificgravity_temp_F	1649	manganese_mgL	1558
tds_mgL	8297	chloride_mgL	8680
tds_mgL_180C	25	carbonate_mgL	553
alkalinity_as_caco3_mgL	78	bicarbonate_mgL	8346
hardness_as_caco3_mgL	75	sulfate_mgL	7330
hardness_mgL	686	hydroxide_mgL	73
resistivity_ohm_cm	1979	h2s_mgL	578
resistivity_ohm_cm_temp, F	1453	co2_mgL	1795
conductivity	194	o2_mgL	88

The table **Last_Water_Prod** (Figure A2) contains the last year that water production was reported for a particular well. This does not necessarily mean the well is plugged or not producing, only that the operator didn't report water production. Data are reported by API and PoolID, so must be aggregated for all information about a given well. Some wells (APIs) have reported production from multiple pools through the years. Figure A3 shows **Last_Water_Inj** which contains similar information for injection of water. **NM_Water_Volumes** (Figure A4) contains summary information for water production and injection. Data includes cumulative production/injection for the well at the API level, and annual production/injection for 2014 and 2015. **NM_Well_Locations** (Figure A5) contains locations for all wells in New Mexico. Attributes include latitude/longitude data from the NM OCD, as well as the unit letter, section, township, and range information, symbology derived from the NM OCD, and an attribute entitled PLSS_ID useful for aggregation of data at the township level. PLSS_ID is an alphanumeric description of the township for a given location that corresponds to that same PLSS_ID in the Cadastral National Spatial Data Infrastructure (NSDI) CADNSDI publication data set for rectangular and non-rectangular Public Land Survey System (PLSS), version 2, available from the New Mexico Resource Graphic Information System (RGIS) at http://rgis.nmt.edu. The data in this attribute may need to be modified somewhat to match other versions of the PLSS. Figure A6 shows the **Pool_Codes** table, and Figure A7 shows the **Well_Location_Codes** table. This table is slightly different in that it contains reference codes for several different attribute fields in the **NM_Well_Locations** table. It is to be used as a data dictionary type of table for looking up codes; thus no single field in this table relates directly to any single field in the locations table.

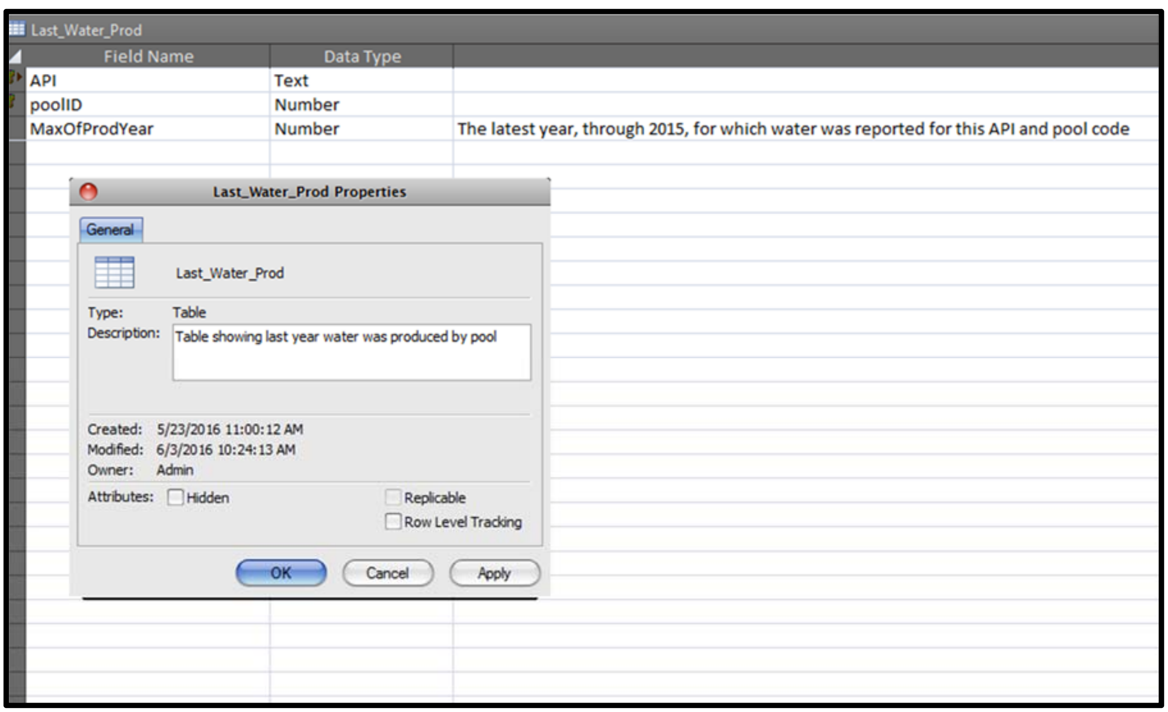


Figure A2. Last_Water_Prod table attributes.

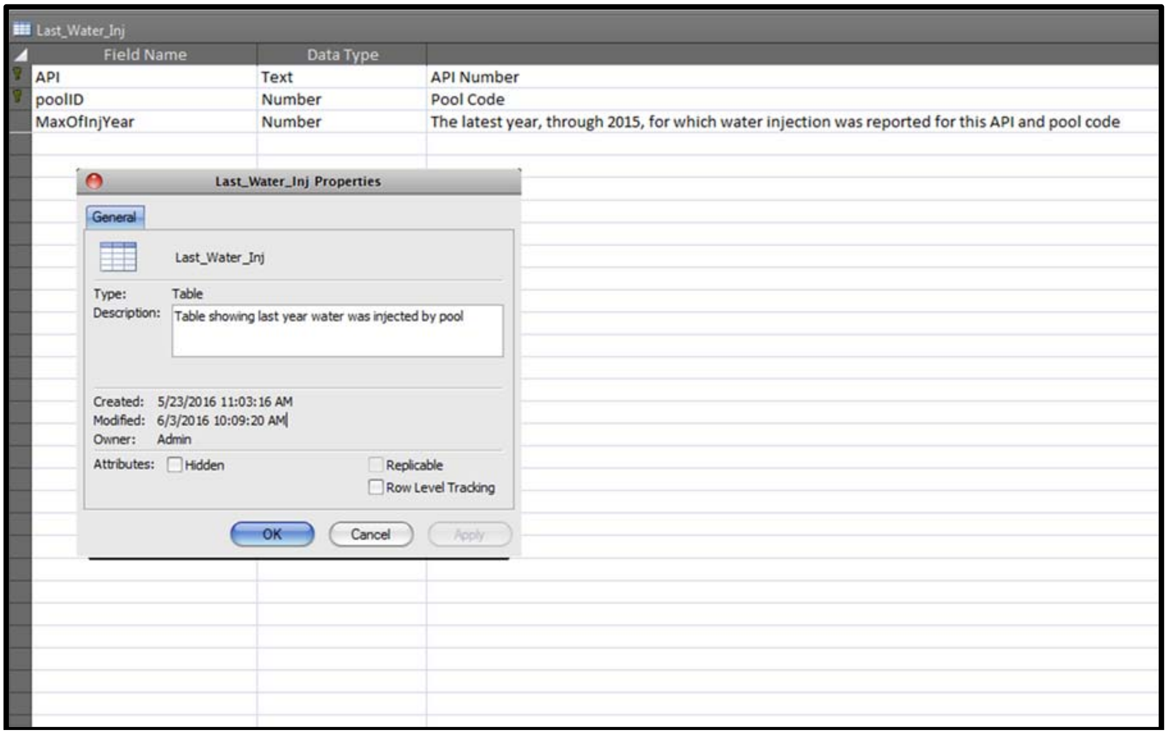


Figure A3. Last_Water_Inj table attributes.

NM_Water_Volumes

Field Name	Data Type	
api	Text	10-digit API number
CUM_PROD_WAT	Number	total reported volume of produced water over lifetime of well, bbls
YR_LAST_PROD	Number	last year of reporting - did not exclude zero-volume years
Water_Prod_2014	Number	total volume of produced water, 2014, bbls
Water_Prod_2015	Number	total volume of produced water, 2015, bbls
CUM_INJ_WAT	Number	total reported volume of injected water over lifetime of well, bbls
YR_LAST_INJ	Number	last year of reporting - did not exclude zero-volume years
Water_Inj_2014	Number	total volume of injected water, 2014, bbls
Water_Inj_2015	Number	total volume of injected water, 2015, bbls

NM_Water_Volumes Properties

General

NM_Water_Volumes

Type: Table

Description: Table describing production and injection volumes

Created: 5/17/2016 2:23:36 PM

Modified: 6/2/2016 10:32:49 PM

Owner: Admin

Attributes: Hidden; Replicable; Row Level Tracking

OK | Cancel | Apply

Figure A4. NM_Water_Volumes table containing summary information about production and injection volumes.

NM_Well_Locations

Field Name	Data Type	Description
API	Text	10 DIGIT API
LATITUDE	Number	Derived from NM OCD (NAD83) shape files
LONGITUDE	Number	Derived from NM OCD (NAD83) shape files
CURRENT_WELL_NAME	Text	FROM NM OCD EXCEPT THAT PRE-ONGARD DESIGNATION IS NOT USED - LAST KNOWN WELL NAME FROM NM OCD WELL FILE 'NOTES' COLUMN IS USED
CURRENT_WELL_NUMBER	Text	FROM NM OCD EXCEPT THAT PRE-ONGARD DESIGNATION IS NOT USED - LAST KNOWN WELL NUMBER FROM NM OCD WELL FILE 'NOTES' COLUMN IS USED
STATE	Text	STATE WHERE WELL OR FACILITY IS LOCATED
COUNTY	Text	STATE WHERE WELL OR FACILITY IS LOCATED
TOWNSHIP_DES	Number	NUMERIC DESIGNATION FOR TOWNSHIP
TOWNSHIP_DIR	Text	NORTH OR SOUTH
RANGE_DES	Number	NUMERIC DESIGNATION FOR RANGE
RANGE_DIR	Text	EAST OR WEST
SECTION	Number	SECTION DESIGNATION
UNIT_LETTER	Text	UNIT LETTER OR NUMBER
FTGNS	Number	FOOTAGE FROM NORTH OR SOUTH SECTION LINE
NSCODE	Text	DIRECTION FOR FOOTAGE
FTGEW	Number	FOOTAGE FROM EAST OR WEST SECTION LINE
EWCODE	Text	DIRECTION FOR FOOTAGE
Status_1	Text	Derived from NM OCD (NAD83) shape files
Status_2	Text	Derived from NM OCD (NAD83) shape files
well_type	Text	Derived from NM OCD (NAD83) shape files
Symbology	Text	Derived from NM OCD (NAD83) shape files
TOWNSHIP_ALL	Text	ALPHANUMERIC DESIGNATION FOR TOWNSHIP
RANGE_ALL	Text	ALPHANUMERIC DESIGNATION FOR RANGE
PLSS_ID	Text	DESIGNATION TO MAKE GROUPING BY TOWNSHIP AND RANGE - SHOULD CORRESPOND TO PLSS ID IN Cadastral PLSS Standardized Data - PLSS Township - Version 2

NM_Well_Locations Properties

General

NM_Well_Locations

Type: Table

Description: Table with locations of all wells in NM. Locations & symbology from NMOCD.

Created: 6/2/2016 10:39:49 PM

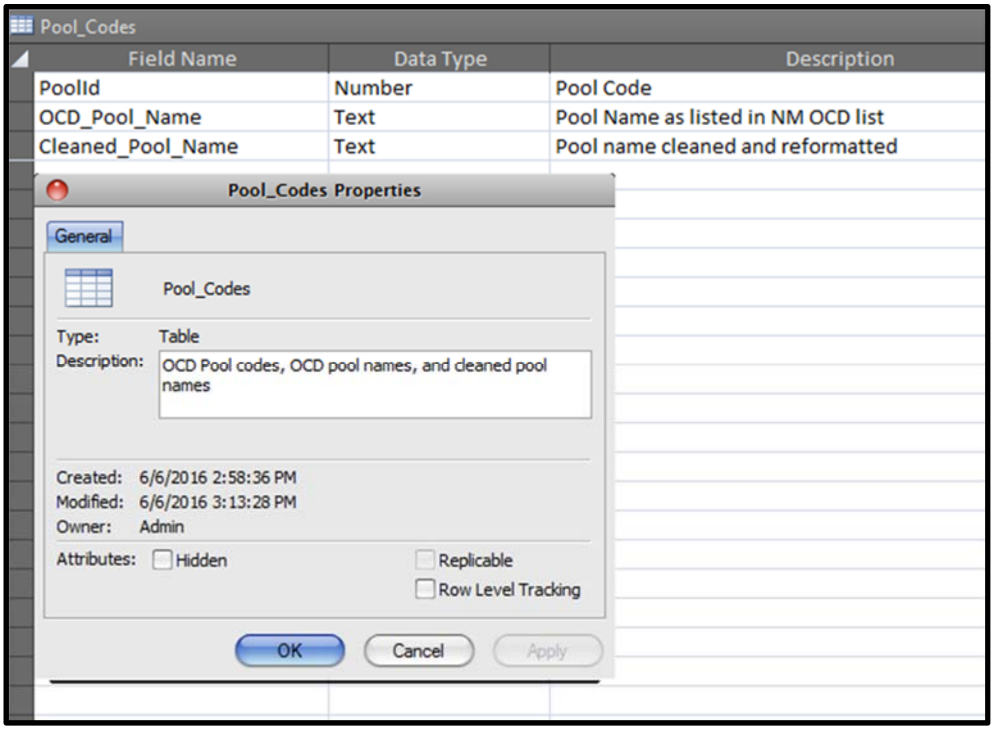
Modified: 6/3/2016 10:09:20 AM

Owner: Admin

Attributes: Hidden; Replicable; Row Level Tracking

OK | Cancel | Apply

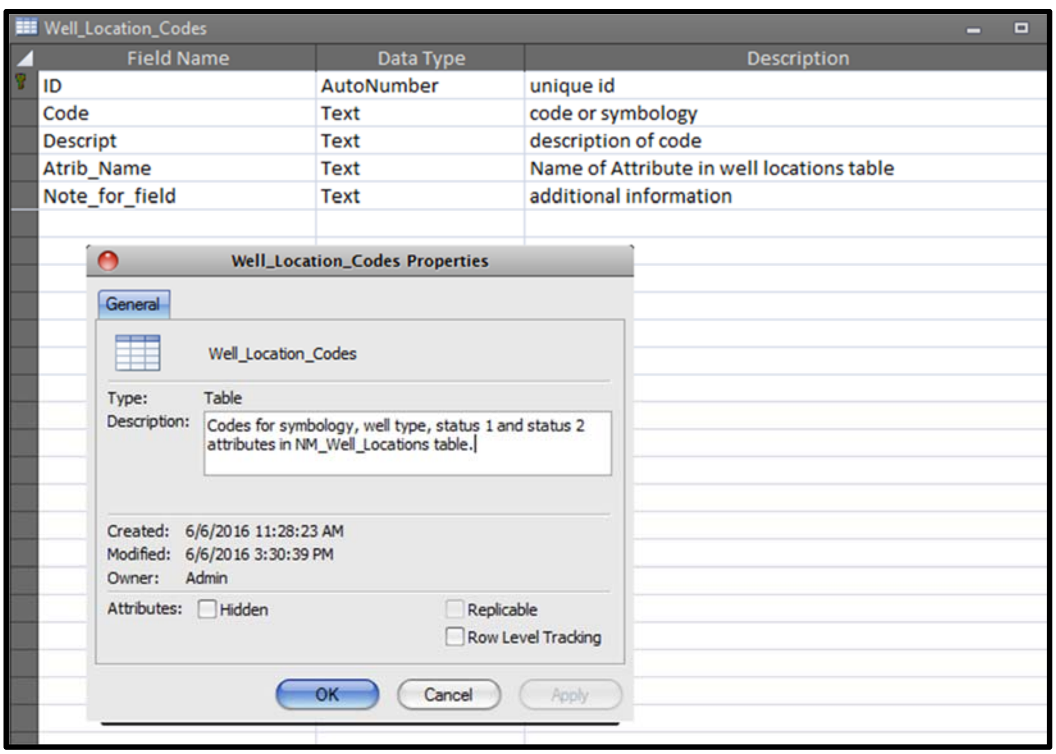
Figure A5. NM_Well_Locations table attributes.



Pool_Codes

Field Name	Data Type	Description
PoolId	Number	Pool Code
OCD_Pool_Name	Text	Pool Name as listed in NM OCD list
Cleaned_Pool_Name	Text	Pool name cleaned and reformatted

Figure A6. Pool_Codes table attributes.



Well_Location_Codes

Field Name	Data Type	Description
ID	AutoNumber	unique id
Code	Text	code or symbology
Descript	Text	description of code
Atrib_Name	Text	Name of Attribute in well locations table
Note_for_field	Text	additional information

Figure A7. Well_Locations_Codes table and attributes. This is a data dictionary table. The "Code" field contains codes from several different fields in the NM_Well_Locations table, and the field "Atrib_Name specifies the field in NM_Well_Locations that particular record applies to.