Creating a Well Database and Web Mapping Application: Using Geographic Information Systems to Manage and Monitor Groundwater Resources in Sonoma County, California

by

Heather Kelley

A Thesis Prospectus Presented to the
Faculty of the USC Graduate School
University of Southern California
In Partial Fulfillment of the
Requirements for the Degree
Master of Science
(Geographic Information Science and Technology)

December 2016

Dedication

I dedicate this work to my friend Megan Gosch, I truly could not have done this without your friendship and support for the last 20 years. And to my amazing and patient husband David, you never lost faith in me, even when I did. Thank you for your unwavering friendship and support.

Acknowledgements

I would like to thank my family and many friends for their continued support throughout my graduate coursework and thesis writing. You all put up with me through every exhausted weekend and every foul mood. I thank you. John and Wanda, you both supported me through many anxious weekends when I thought I was failing, you assured me that I was not.

Thank you to all my teachers at USC, but especially Dr. Elisabeth (Lisa) Sedano my thesis chair, and my committee members Dr. Jennifer Swift and Dr. Yao-Yi Chiang. You made this process much easier with your continued support and guidance. To my Supervisor at the Water Agency who has provided me with constant support, Courtney Ellerbush. To James (Jay) Jasperse and the entire Water Resource Planning team who have provided me with information, data and guidance as I learned about the often confusing and difficult groundwater legislative process.

To my editors and helpers, Tara Sandau and Sherry Barbic, you have read and re-read this thesis looking for passive language and errors. Thank you both! To Tim McGee who provided technical assistance with the CMV and hydrograph development, your help is much appreciated.

And to Ed Nelson and Kathy Pons, and to all volunteers everywhere who selflessly spend their own personal time away from their families to educate themselves, collect data, monitor natural processes and resources, and share their information with scientists and graduate students. Your efforts are constantly improving the world. Thank you!

Table of Contents

List of Figures

List of Tables

List of Abbreviations

AGOL	ArcGIS Online
API	Application Program Interface
CASGEM	California Statewide Groundwater Elevation Monitoring
CMV	Configurable Map Viewer
CSV	Comma Separated Values
COS	City of Sonoma
DMS	Data Management System
DWR	Department of Water Resources
GIC	Groundwater Information Center
GICMA	Groundwater Information Center Interactive Map Application
GIS	Geographic Information System
GPS	Global Positioning System
GMP	Groundwater Management Plan
GSA	Groundwater Sustainability Agency
GSP	Groundwater Sustainability Plan
MXD	ArcMap document file
NASA	National Aeronautics and Space Administration
NGWA	National Ground Water Association
OSM	Open Street Map
REST	Representational State Transfer
SGMA	Sustainable Groundwater Management Act
SGM	Sustainable Groundwater Management Program

SQL	Structured Query Language
SSMS	SQL Server Management Studio
SWRCB	State Water Resources Control Board
URL	Uniform Resource Locators
USC	University of Southern California
USGS	United States Geologic Survey
VGI	Volunteered Geographic Information
VOMWD	Valley of the Moon Water District
WRP	Water Resource Planning Section

Abstract

Citizen scientists and governments are managing resources and collaborating at a level unimaginable before the era of Web 2.0. The opportunities that currently exist for these collaborations are as exciting as they are manifold. These opportunities are only out-paced by the numerous challenges that scientists and citizens face. This thesis presents web mapping applications and associated databases developed for collecting, storing and depicting groundwater well data. These Geographic Information Systems (GIS) tools were developed to support the collaboration between citizen scientists and a local water agency, monitoring groundwater resources in two basins in Sonoma County, California: Santa Rosa Plain and the Sonoma Valley Groundwater Basin. The government-supplied data provided by the Sonoma County Water Agency and volunteer gathered data provided by volunteers from Sonoma Valley ensured the continued success of groundwater resource monitoring. While these volunteers were not trained professionals, the data and information that they provide is unique and invaluable. Their efforts, coupled with the local government agency have made resource management plans for groundwater successful. This thesis was successful in improving the previous methods of data management, communication and data-sharing while also providing opportunities for future improvement.

Chapter 1 Introduction

The democratization of spatial data and analysis is changing the world (Goodchild, 2007). Geographic Information System (GIS) technology is continually evolving with tools allowing professional users to create, analyze, and manipulate spatial data and output for further use and examination. GIS transformed to accommodate the professional and nonprofessional user, allowing both to work with and share spatial data. Novices use GIS and tools such as recreation grade Global Positioning System (GPS) units to create and share spatial data. The evolution in spatial data-sharing creates opportunities for people who are not professional geographers but have knowledge of important spatial phenomena to catalog and share their knowledge. However, without having professional standards and methods to guide them, various issues such as data inaccuracy may arise.

Professional geographers understand that it is important to follow standards when creating spatial data, so that other users understand how the data was created, the accuracy that the data was captured or created at, the intended use of the data, and if the data is confidential or can be shared with other people. Nonprofessional GIS users may not be aware that data standards exist and as a result, the data may be shared or used inappropriately.

This thesis project used GIS tools, specifically geodatabases and web mapping applications, to collect and depict well-water data in two groundwater basins in Sonoma County, California: Santa Rosa Plain and the Sonoma Valley. The well-water data is a combination of volunteered public data and data managed by a local water agency, the Sonoma County Water Agency (Water Agency). This project used GIS and volunteered geographic information (VGI) to facilitate an existing partnership between the volunteers in the Sonoma Valley groundwater basin and the Water Agency in Sonoma County, California.

Developing an enterprise geodatabase and two accompanying web mapping applications to store, analyze and report on groundwater well data was the primary product of this thesis. An additional goal was to help the collaborating partners in Sonoma County, including the Water Agency and the well-monitoring-volunteers, share groundwater well data easily and efficiently. The well volunteers use the web mapping application to enter water level data into the enterprise database; increasing efficiency in the project by reducing one step in the data-entering process. The web applications also provides the well volunteers immediate feedback on the water levels for the wells they monitor.

The Water Agency along with other local entities is working with the state Department of Water Resources (DWR) to manage local groundwater resources. In 2014, California passed the Sustainable Groundwater Management Act (SGMA), a law that mandates the coordinated management of groundwater resources between the state and local governments. To provide context for this project and the basis for the Water Agency's role in monitoring groundwater in Sonoma County, it is necessary to review the legal framework of groundwater law in California.

This chapter discusses the creation of and functions of the Water Agency as it pertains to the management of water resources, including groundwater in Sonoma County. This chapter also examines the development of groundwater legislation in California that led to SGMA, how SGMA is applied in Sonoma County, and how SGMA created the opportunity for this thesis project.

1.1 Formation and Mission of the Water Agency

The Water Agency, founded in 1949, originally was known as the Sonoma County Flood Control and Water Conservation District. The Water Agency is a special district created by the State Legislature. The Sonoma County Board of Supervisors acts as the Water Agency's Board of Directors. This legal authority grants the Water Agency power to produce and supply surface water for beneficial use, to control and manage flood waters, to generate electricity, and to provide recreational amenities in connection with the Water Agency's facilities (Sonoma County Water Agency, 2007).

The primary role of the Water Agency is a wholesale distributor of potable water. The surface water that is used by the citizens of Sonoma and Marin County originates in Mendocino County. The Water Agency is organized into several divisions to manage the various projects and programs it maintains. Groundwater projects are managed by the Water Agency Water Resource Planning Division (WRP) in the Engineering and Resources Planning Division (Sonoma County Water Agency, 2007). The Water Agency is the lead local government agency responsible for managing groundwater resources in Sonoma County.

1.2 Groundwater Legislation in California

Groundwater is a property right in California. California follows the Correlative Right Doctrine, which defines water rights as correlative between all land owners owning property over a groundwater source, with the share of water based on the amount of land acreage that is over the groundwater (Joshi 2005). In the case of an overdraft, the correlative rights rule sets limits on the amount of water that can be pumped so no groundwater owner is harmed by another (Joshi 2005). Correlative right creates the opportunity to set limits on water-use and manage groundwater resources to prevent damage to property owners.

California was the last western state to establish a regulatory system for groundwater management (Governing 2014). The state requires monitoring for groundwater pollution and contamination, and water quality monitoring of public supply wells, but has not officially required the monitoring of groundwater use through any statewide legislative process until 2014. California has not historically monitored groundwater use through the legislature due to the way groundwater is regarded (as private property) in the state.

DWR is a state agency, part of the California Natural Resources Agency and is responsible for the State's management and regulation of surface water use. While not historically required to monitor groundwater use in California, DWR is the state agency responsible for managing surface water use and groundwater resources.

DWR, in conjunction with the State Water Resources Control Board (SWRCB), determines the quality of all available water resources in the state and reports to the state legislature and the SWRCB any sources of pollution and steps that need to be taken to improve polluted water resources (California Department of Water Resources 2003). The SWRCB regulates the quantity, location of diversion, time of diversion, place of use, and purpose of use for surface water diverters. This includes groundwater quality reporting.

DWR provides information to other state government agencies, local government agencies, and the public through various methods including technical bulletins. The Technical Bulletin 118 (Bulletin 118) series provides information about the groundwater resources of the state. Prior to the Bulletin 118 series, the first statewide groundwater report published in 1952 by the predecessor of DWR was "Water Quality Investigations Report No. 3, *Ground Water Basins in California* (Report No. 3)" (California Department of Water Resources 2003).

Report No. 3 is important because it refers to the mandate in Section 229 of the state California Water Code requiring the predecessor of DWR to investigate and report on water quality in all state waters. In order to monitor groundwater quality, it is essential to know the location of all groundwater basins providing water supply in the state. Report No. 3 identified and mapped all "important" groundwater basins at the time. In 1952, 223 groundwater basins were identified and mapped.

Bulletin 118-75, published in 1975, was a significant update in the Bulletin 118 series regarding the mapping of groundwater basins and avoiding groundwater overdraft where possible. Bulletin 118-75 stated that the identification of groundwater basins should be based on geologic and hydrologic conditions while considering political boundaries. Another consideration of the Bulletin 118-75 update was that DWR should identify basins that are subject to overdraft. These groundwater basins are those that DWR recognizes as important for management. In 2003, 515 groundwater basins had been identified and mapped as depicted in Bulletin 118-2003, and all of these basins would benefit from monitoring.

Given that legally California views groundwater as a property right, and that water use has not been monitored by any state agency, in order to mandate groundwater use monitoring, the state had to pass legislation. There have been several laws passed by the state providing the legal infrastructure to monitor groundwater use. All of these laws have set the stage for the current laws which seek to monitor groundwater use in California and in Sonoma County.

1.2.1. Assembly Bill 3030 (AB 3030) and Senate Bill 1938 (SB 1938)

The Groundwater Management Planning Act (AB 3030) was passed in 1992. AB 3030 revised sections 10750-10756 of the California Water Code to provide a "systematic procedure for an existing local agency to develop a groundwater management plan (GMP)" (California

Department of Water Resources 1992, California Legislative Information 1992). This section of code allows a local agency with “the powers of a water replenishment district to raise revenue to pay for facilities to manage the basin (extraction, recharge, conveyance, quality)” (California Department of Water Resources 1992). These GMPs can be developed for groundwater basins identified in the Bulletin 118 series.

AB 3030 does not require local agencies to establish GMPs, and no new government agency will be formed to oversee the GMPs. However, if a local agency decides to establish a GMP, public hearings and the adoption of a resolution by public agencies to develop the GMP is required. Also, no GMP can be adopted for an adjudicated groundwater basin or in a basin that is managed under other sections of the California Water Code.

Under AB 3030, there are twelve technical components that may be included in a GMP. The inclusion of these technical components are highly encouraged and the requirements include factors such as the control of saline water intrusion, regulating contaminated groundwater and monitoring groundwater levels and mitigating “conditions of overdraft” (California Department of Water Resources 1992). While AB 3030 does not require the creation of the GMPs, it was an initial step towards developing formal plans to manage groundwater use and to inform the public of the development of these plans. This is a comprehensive initial step in the formal monitoring of groundwater levels in California.

In 2002, Senate Bill 1938 (SB 1938) enhanced AB 3030. SB 1938 requires local agencies to make available to the public a written statement regarding the opportunities for public involvement in GMPs, include certain objectives in GMPs, adopt monitoring protocols and use scientific practices to manage groundwater in areas where there is no identified Bulletin 118 basin (California Department of Water Resources 2002, California Legislative Information 2002).

Additional important elements for SB 1938 require the agencies creating the GMP to submit a digital copy of the GMP to DWR and DWR will make the GMPs available to the public. Funds are made available to local agencies to be used for the development of GMPs. Also, there are required components of a GMP, introduced in SB 1938 and defined in the California Water Code 10753.7 as:

1. Basin Management Objectives: these objectives relate to monitoring and management of groundwater levels
2. Agency cooperation: the local lead agency shall cooperate with other local agencies to work cooperatively and collaboratively
3. Mapping:, the local agency must prepare a map that details the area of the groundwater basins as defined in Bulletin 118
4. Monitoring Protocols: the local agency must adopt monitoring protocols to detect changes in groundwater levels, quality, "inelastic surface subsidence," flow and quality of surface water that directly affect the groundwater levels or quality created by groundwater pumping
5. Any area that is located outside of a Bulletin 118 groundwater basin must have scientific "geologic and hydrologic" principles applied to those areas (California Department of Water Resources 2002)

SB 1938 is a comprehensive bill created to provide a legal method for monitoring groundwater, informing the public of monitoring plans, and preserving groundwater levels while not officially mandating groundwater monitoring. AB 3030 and SB 1938 set the stage for more comprehensive laws state laws by creating the legal framework to manage groundwater use in California.

1.2.2. California Statewide Groundwater Elevation Monitoring

The California Statewide Groundwater Elevation Monitoring (CASGEM) program was authorized by Senate Bill X7 6 (SB X7 6) and enacted in November 2009 (California Department of Water Resources 2016a). This Senate bill “mandates a statewide groundwater elevation monitoring program to track seasonal and long-term trends in groundwater elevations in California's groundwater basins” (California Department of Water Resources 2016a). CASGEM is significant because it acknowledges the need to monitor groundwater elevation. To achieve that goal, the amendment requires collaboration between local monitoring entities and DWR to collect groundwater elevation data (California Department of Water Resources 2016a).

DWR developed the CASGEM Program to identify and protect groundwater basins from significant subsidence. The CASGEM Program established a permanent, locally-managed program of regular and systematic monitoring in all of California's alluvial groundwater basins (California Department of Water Resources 2016a). DWR coordinates the CASGEM Program and is required to report to the Governor and the Legislature every five years regarding program findings (California Department of Water Resources 2012).

The CASGEM Program does not track groundwater use, it monitors subsidence and groundwater elevation. One component of the CASGEM program prioritized all Bulletin 118 basins as high, medium or low priority for subsidence.

It took over 20 years for the state government of California to react to the pressures of climate change, population growth, historic groundwater declines, and the current drought to develop SGMA. However, given the current state of groundwater in California, these are not surprising developments.

1.2.3. Sustainable Groundwater Management Act (SGMA)

In 2014, California passed the Sustainable Groundwater Management Act. SGMA is comprised of Assembly Bill 1739 (AB 1739), (Dickinson), Senate Bill 1168 (SB 1168) (Pavley), and Senate Bill 1319 (SB 1319) (Pavley) (California Legislative Information 2013-2014a, 2013-2014b, 2013-2014c). For the first time, SGMA requires local agencies to manage and monitor groundwater resources. With this law, California has mandated that local water agencies and public entities form Groundwater Sustainability Agencies (GSAs). Local entities must form GSAs by June 30, 2017. Once formed, a GSA to is required to adopt and implement a Groundwater Sustainability Plan (GSP). The deadline for GSP adoption is 2022 (California Department of Water Resources March 2016d).

These GSPs are far more comprehensive and detailed than the GMPs described by AB 3030/SB 1938, and these are mandated, whereas the GMPs were not. SGMA only applies to Bulletin 118 basins prioritized as medium or high priority by CASGEM (California Department of Water Resources 2016c). The purpose of the GSPs is to provide the current status for groundwater basins around the state and provide management strategies to improve groundwater quality and water levels. The GSPs will be comprehensive with the best available information. The GSPs will be available to the public to provide transparent management for the basins.

SGMA provides for groundwater management by local agencies that have responsibility for water supply, water management, or land use. DWR’s role in SGMA is to develop regulations, best management practices and provide technical support. The SWRCB provides regulatory oversight and enforcement of all laws regarding water quality violations. Surface water is regulated by the SWRCB through a legal system established by the California Water Code. Local GSAs will be the planning and implementation entities (California Department of Water Resources 2016c). DWR and SWRCB will work with local GSAs to make sure that SGMA is successfully managing groundwater in the state, or more drastic measures will be taken. If local agencies are not able to work together and form GSAs and comply with other requirements of SGMA, the SWRCB may assume management responsibilities for the groundwater basin (California Department of Water Resources 2016b).

The GSPs provide new tools, such as local regulations and mandated monitoring of groundwater levels that water agencies will use to manage groundwater resources locally. These plans allow water agencies to actively monitor and manage groundwater resources but require transparency with the public and DWR. Local entities must provide feedback to the state and the public about the ongoing status of local groundwater basin supplies and quality. Additionally, the GSPs will allow the local water agencies to develop GSAs to require monitoring of groundwater if the current efforts to improve groundwater quality and amounts do not succeed.

1.3 Groundwater Programs in Sonoma County

There are 14 groundwater basins located in Sonoma County. Four of these groundwater basins have been the subject of studies conducted by the United States Geologic Survey (USGS): the Alexander Valley, the Petaluma Valley, the Santa Rosa Plain, and Sonoma Valley. Figure 1 on the following page locates these groundwater basins. These studies supported the creation of the existing GMPs and showed the current status of the groundwater resources of these basins.

The scientific data that the USGS has collected and presented in these reports will also provide information for the GSPs. In addition to these reports, local entities monitor groundwater elevation for these basins under the CASGEM Program, and SGMA implementation is underway.

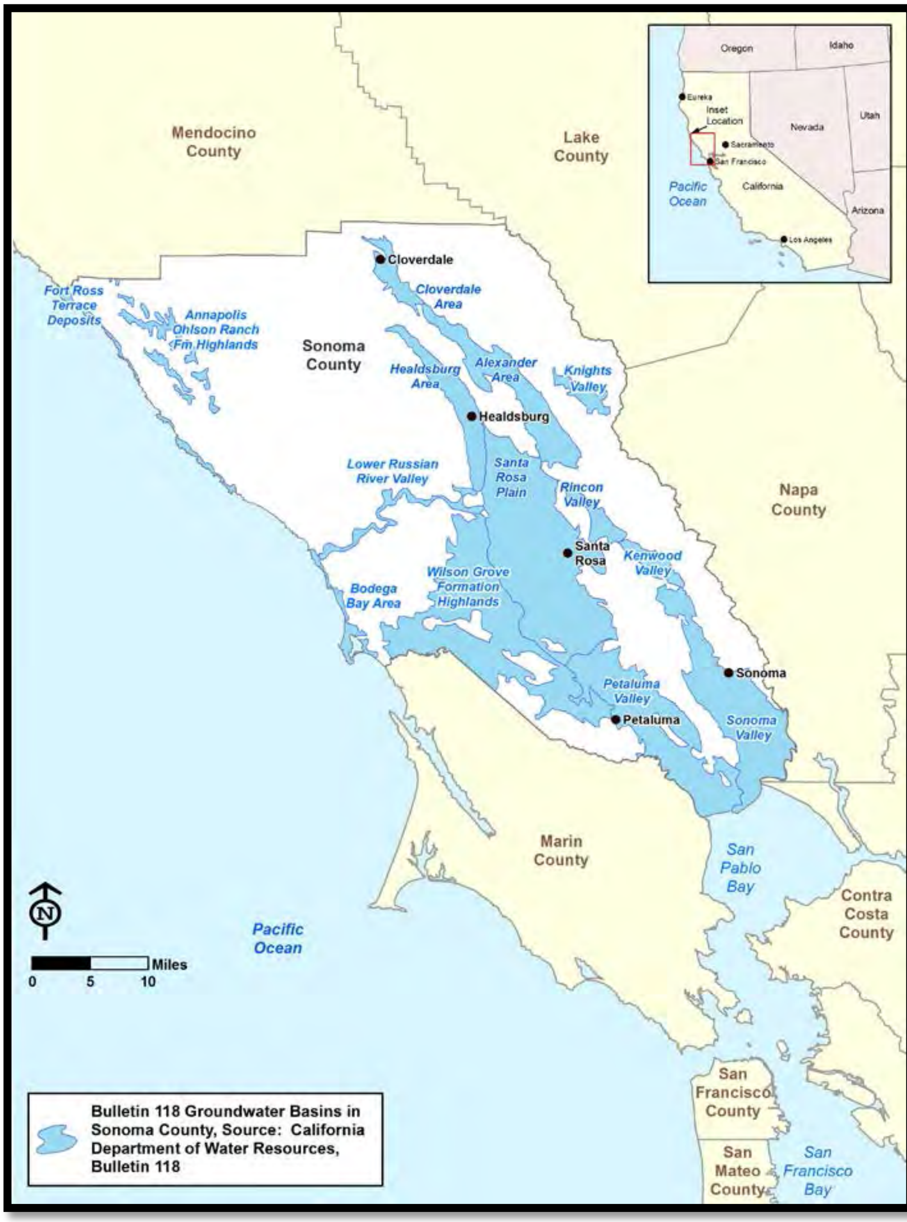


Figure 1 Bulletin 118 Groundwater Basins in Sonoma County. *Source*: Heather Kelley 2016

1.3.1. United States Geologic Survey Groundwater Studies in Sonoma

In 2000 the Water Agency Board of Directors directed the Water Agency to develop and implement a county-wide groundwater program to "enhance knowledge and local management" of the four larger and most developed groundwater basins in Sonoma County (Brown and Caldwell 2015). To meet the requirements of this program, scientific basin-wide studies of the Alexander Valley, Petaluma Valley, Santa Rosa Plain and Sonoma Valley groundwater basins were conducted with the USGS. These studies form the basis for the development of the GMPs for the basins.

The Water Agency was the lead in the development of the two existing GMPs in Sonoma County: Sonoma Valley and Santa Rosa Plain (Brown and Caldwell 2015). These GMPs provide foundational information on groundwater conditions, existing and proposed monitoring programs and recommend strategies for improving groundwater quality and levels. Along with the USGS and the Water Agency, these studies were conducted with input from other public and private stakeholders.

All parties attended meetings to determine the existing conditions of the groundwater basins, potential threats, current usage and best management practices for the groundwater resources of Sonoma Country. Much of the information in the USGS studies will support the GSAs in the future. The USGS studies were important to understand the basic operation and current conditions of the groundwater basins in Sonoma County.

The first of these studies for Sonoma Valley was completed in 2006, and the GMP has existed since 2007. The Alexander Valley study was completed in 2006, but no GMP currently exists for this basin, as it is not a medium priority basin in the CASGEM program. The status of Alexander Valley may change in the future as new criteria are developed based on environmental resources. The Santa Rosa Plain study was completed in 2014, and there has been a plan in place since that time. The Petaluma Valley study was initiated in 2014, and the plan is scheduled for completion in 2017 (Brown and Caldwell 2015).

1.3.2. CASGEM in Sonoma County

The CASGEM program is implemented in Sonoma County with the Water Agency, the County of Sonoma and the City of Petaluma designated as Monitoring Entities by DWR for the groundwater basins and sub-basins in Sonoma County. Figure 2 on the following page shows the entities and their assigned basins for monitoring under CASGEM. The City of Petaluma is designated as the Monitoring Entity for the Petaluma Valley Groundwater Basin.

The Water Agency is designated as the lead Monitoring Entity for the Kenwood Valley Groundwater Basin and the Sonoma Valley Groundwater Sub-basin; the Water Agency serves as the lead agency for the Sonoma Valley Groundwater Management Program which encompasses these two basins (Brown and Caldwell 2015). The County is responsible for the remaining basins in the County. As Santa Rosa Plain and Sonoma Valley are designated as a medium priority under CASGEM, and they are subject to SGMA.

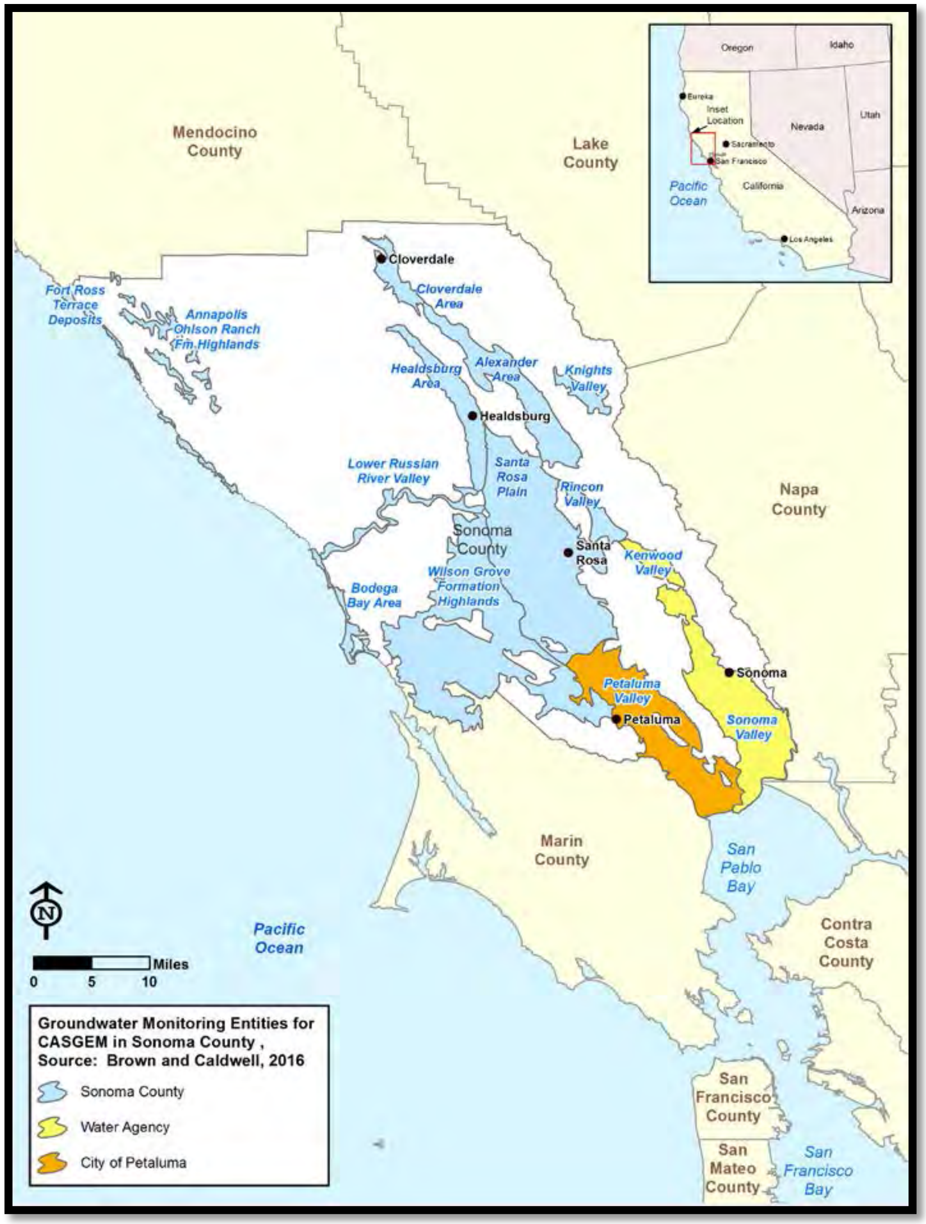


Figure 2 Groundwater Monitoring Entities for CASGEM in Sonoma County. *Source*: Heather Kelley 2016

Of the 14 basins in Sonoma County identified by Bulletin 118 two are subject to SGMA based on their CASGEM prioritization, as shown in Figure 3.

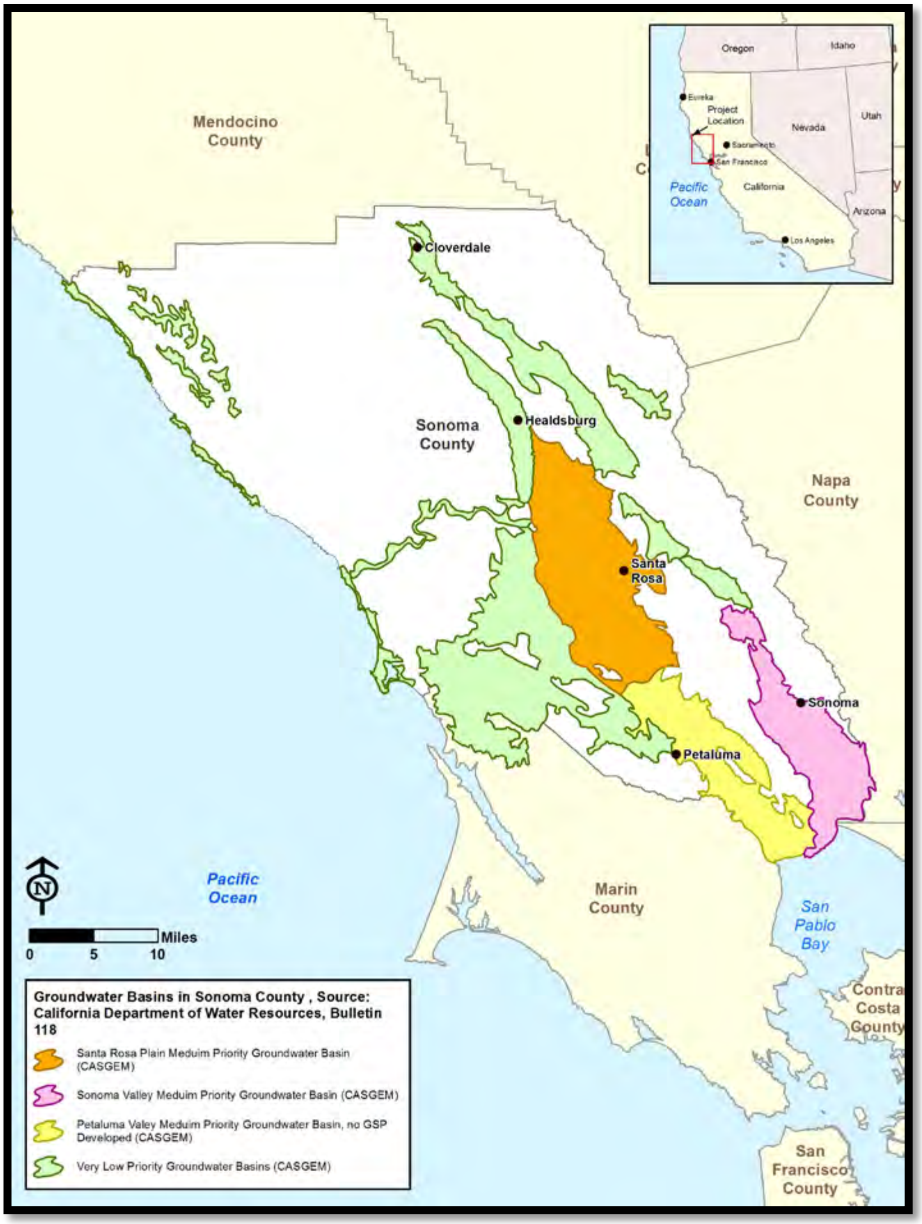


Figure 3 CASGEM Prioritization of Groundwater Basins in Sonoma County. Source: Heather Kelley 2016

1.3.3. SGMA in Sonoma County

The implementation of SGMA is underway in Sonoma County. In April of 2015, Sonoma County and the Water Agency hired the Consensus Building Institute to hold stakeholder meetings to assess GSA formation for all three of the medium-priority basins in Sonoma County. The purpose of these meetings was to determine the structure of the GSAs for the basins and how to manage SGMA in the county. A final report was released to the public in September 2015.

One result of these meetings determined that each basin will have a separate GSA for that basin, with each basin coordinating activities and sharing information. Subarticle 4 of the revised California Water Code, for the proposed GSP regulations, discusses the creation of Monitoring Networks. The Monitoring Networks will be a tool to collect and analyze groundwater data in the basins. The Monitoring Network can be one network shared between the basins, and is an example of the three GSAs sharing resources and information and working together.

SGMA mandates local water agencies and public entities form Groundwater Sustainability Agencies (GSAs). The Water Agency is one of 12 local entities working together to form GSAs for the three medium priority CASGEM groundwater basins in Sonoma County: Petaluma Valley, Sonoma Valley, and Santa Rosa Plain. These local entities are shown in Table 1. Local entities must form GSAs by June 30, 2017. The GSA is required to prepare a GSP by 2022 (California Department of Water Resources March 2016d).

Table 1 GSA Agencies in Sonoma County

Santa Rosa Plain Basin	**Petaluma Valley Basin**	**Sonoma Valley Basin**
City of Cotati	City of Petaluma	City of Sonoma
City of Rohnert Park	North Bay Water District	North Bay Water District
City of Santa Rosa	Sonoma County	Valley of the Moon Water District
City of Sebastopol	Sonoma County Water Agency	Sonoma County
Town of Windsor	Sonoma Resource Conservation District	Sonoma County Water Agency
Sonoma County		Sonoma Resource Conservation District
Sonoma County Water Agency		
Sonoma Resource Conservation District		

Staff from the GSA-eligible entities are working together to determine how to implement SGMA and what the requirements of SGMA will mean for groundwater-users in Sonoma County. This is a critical time in Sonoma County as public-outreach continues, and the Basin Advisory Panels (created by the GMPs for Santa Rosa Plain and Sonoma Valley) work together to determine best implementation strategies for SGMA. The formation of the GSAs and development of the official GSPs for each basin is forthcoming, and must be completed by June of 2017. In the summer of 2016 public meetings were ongoing, sharing results of the stakeholder meetings conducted in 2015, and requirements regarding the formation of the GSAs.

SGMA draft regulations require the development and implementation of a coordinated Data Management System (DMS) to store and coordinate data between the GSA entities. As the Water Agency is the lead agency in the implementation of SGMA in Sonoma County, the Water Agency has begun the process of establishing a DMS. An enterprise database and web applications are a good first step towards the development of establishing a DMS. A component of the DMS is monitoring groundwater levels with existing data and other groundwater data as it becomes available.

This thesis project used existing well data from volunteers, the Water Agency and other monitoring entities to depict well location and water level information in Santa Rosa Plain and Sonoma Valley. In order for the Water Agency along with other local partners to become a GSA for these two basins, it is necessary to develop a DMS to help monitor and share the groundwater data in this local area. This thesis project helped WRP organize the groundwater data for these two groundwater basins in an enterprise database and prepare for the development and implementation of a coordinated DMS.

In addition to the GSPs for the Santa Rosa Plain and Sonoma Valley groundwater basins, ample data exists for the management and monitoring of the wells: well location, water level data for each well, and spatial data depicting the location and extent of these two groundwater basins. These existing data created an opportunity to manage these basins with GIS. The volunteer program has been in existence since the 1950's. In addition, the Water Agency has collected water level data via submersible pressure transducers on certain wells since 2004. Adding well data to the findings of the GSPs provides detailed information regarding the current water level conditions in the basins.

1.4 Research Objective

There were several objectives for this thesis project: to prepare the spatial and nonspatial data WRP manages for inclusion into the DMS; to improve communication between the well monitors in Sonoma Valley and WRP staff; to improve efficiency for WRP by creating hydrographs dynamically in web applications; and to present WRP with options utilizing GIS in new ways .

The products of this thesis were two enterprise databases and four web mapping applications: three web applications for Sonoma Valley and one for Santa Rosa Plain groundwater basin. The project developed a view-only web application for Santa Rosa Plain and Sonoma Valley as well as two editable web applications for Sonoma Valley.

The editable web applications allow the members of the public currently volunteering water level data to the Water Agency to update this data online via the web application. WRP uses the view-only web applications to view more layers than appear in the editable web applications. WRP updates water level data received from other Monitoring Entities in the county for these basins and the submersible pressure transducers via the enterprise databases.

To support the editable web applications, an enterprise database was created. The use of an enterprise database system, such as SQL (Structured Query Language) Server Management Studio (SSMS), allows the display of data in web mapping applications and online editing (Esri 2016a). The addition of new water level data by the volunteers via the web mapping applications are the online edits performed in this project. The enterprise database helps support groundwater monitoring and modeling internally by WRP. WRP actively works and models the Sonoma Valley and Santa Rosa Plain basins. The volume of data generated by the submersible pressure transducers is extensive. Currently, WRP uses Microsoft Access (Access) as their primary database software. The volume of data managed by WRP from the submersible pressure transducers is challenging for WRP staff to maintain using Access. Another goal of this thesis was to improve WRP's ability to work with and analyze well water data and increase their efficiency and data management capability.

It is important to support the implementation of SGMA for the well volunteers through an editable web application. This thesis assumed that the private citizens who already willingly provide their water level data via email would prefer to add their information directly to the web mapping application. Additionally, these volunteers benefit by viewing their data in tables and hydrographs displayed on the web mapping applications. The presentation of well information to the volunteers via web applications may also be an attractive feature to other members of the public who are interested in volunteering their water level data but have so far have not been inclined to do so.

One intention of the web applications was to generate enthusiasm for existing volunteers and for the volunteers to share this enthusiasm with their neighbors who are not volunteering data. In the world of Web 2.0 and VGI, increasing the number of volunteers without mandating monitoring is preferred, and this would be easily accomplished via the web applications. If water levels and water quality in the basins improve or remains stable, there will be less likelihood that the GSAs would consider imposing limitations or restrictions on well users. This in turn can enhance the relationship between the volunteers providing well data and the GSA when formed.

The GIS for this project supports the existing monitoring currently conducted by the Water Agency for these two groundwater basins. Creating the enterprise geodatabase and the accompanying web mapping application made the current effort more efficient by directly enabling volunteers to report their well data and providing instant feedback on water levels in their wells. In addition, an enterprise geodatabase enabled Water Agency staff to quickly process and analyze well water data. Furthermore, an enterprise geodatabase and accompanying web mapping application supported the continued collaboration of volunteers and the Water Agency.

If the web applications created by this thesis project maintain their effectiveness in their deployment, this project will normalize the method of receiving well data from volunteers. Currently, volunteers e-mail their water level data to WRP in various file formats. Allowing the volunteers to add their monthly water level reading directly into the enterprise database via the web mapping application is more efficient.

1.4.1. How this project meets the requirements of SGMA

In addition to providing efficiency for data management between the volunteers and WRP staff, and improving the management of the submersible pressure transducers data, this thesis project helps with SGMA implementation. SGMA draft regulations require the GSAs to develop and implement a coordinated DMS to store, maintain and share groundwater data for the GSP with other GSA entities and the public. This thesis project is an important first step in the creation of the DMS by assessing all of well data that WRP currently manages and maintains.

More data than the groundwater well data WRP currently maintains must be collected and added to the DMS to meet SGMA criteria. These new data types include groundwater quality, groundwater pumping and well test data, streamflow data and well construction data. An enterprise database is a good foundation for the collection and storage of these data. This thesis project created two enterprise databases and loaded the existing well data for Santa Rosa Plain and the Sonoma Valley basins for WRP's use. This exercise was good preparation for WRP to manage the DMS in an enterprise system.

The DMS must be designed to allow GSA partners to share information amongst themselves and with the public. The creation of the web applications allowed WRP to start sharing data and information with the well volunteers dynamically. These web applications initiated the new protocol for sharing spatial and nonspatial data between WRP and other entities. For this thesis project, nonspatial data means tabular data that can be mapped if a spatial attribute exists in the table, or it can simply be used a table in the database with no spatial attributes present.

Development of a public portal is another important and innovative element to the DMS. As this is a new data management technique for WRP, this thesis project allowed WRP staff an opportunity to test some new techniques and prepare for development of the DMS. Some of the features that are necessary for the DMS were not developed in this thesis, but initial steps were taken to organize data and introduce new techniques to WRP staff.

No User Requirement Document was created in preparation for this thesis project. After informal discussions and an initial meeting with WRP, some basic user requirements were identified. The following list describes the initial user-requirements identified. These requirements were:

1. To improve efficiency for the well volunteers entering data
2. To improve communication between the well monitors in Sonoma Valley and WRP staff
3. To improve efficiency for WRP by creating hydrographs dynamically in web applications
4. To improve efficiency for WRP working with the submersible pressure transducer data
5. To present WRP with options utilizing GIS in new ways

In order to improve communication between the well monitors and WRP, the editable web applications were developed. To improve the efficient creation of hydrographs, a dynamic hydrograph tool was developed in the view-only web applications. In order to improve overall data-management efficiency, the well data was added to relational databases in SSMS. All of these tools presented WRP with new methods of utilizing GIS and databases. Some of the requirements of the DMS were not resolved with this thesis, but these unfulfilled requirements present opportunities for future development by the author and WRP staff.

1.4.2. Motivation

California is experiencing the fourth year of a historic drought. The groundwater resources of California have been particularly hard-hit by this drought (California Department of Water Resources 2015). Using GIS to help residents and public agencies manage groundwater resources in a transparent and efficient way is a great opportunity.

The State of California has never required any kind of statewide monitoring for groundwater use or for the registering of wells on the scale required under SGMA. While the exact method for monitoring private and public wells is not known at this time, preparing local resource agencies and the public to work together will benefit the Water Agency in the long run. The specific requirements for creating the groundwater well database and monitoring of private wells is a process still being worked out by the State (Jasperse 2016). However, what is known is that local water agencies and water systems will collaborate to facilitate this effort (Brown 2014).

GIS is a tool to monitor and manage the groundwater resources of our state and presents an opportunity to implement GIS for the management of locally important water resources for this project. The recognition that groundwater must be monitored to effectively manage the resource is important and necessary, and GIS can assist this effort. The various pressures, from climate change to population growth, have been affecting groundwater levels in the state, and this is a great opportunity to act.

Managing groundwater use in the Bulletin 118 groundwater basins through mandated monitoring in California is needed as climate change and population growth continue to place increasing demands on this important resource. In order to sustainably use groundwater, it is necessary to monitor and manage its use. The general public is coincidentally coming to this realization, as state and local governments work to develop cooperative partnerships to manage groundwater.

1.5 Organization

The remainder of the thesis contains four chapters. Chapter Two comprises an examination of VGI, the literature that focuses on spatial data quality and examines other web mapping applications that are similar to the ones developed for this project. Chapter Three discusses the data used in this thesis; well data, water level data, spatial groundwater data, and the methods used for this groundwater monitoring and management study. Chapter Four presents and discusses the results of this groundwater study, including depictions of the web mapping application and the ability of WRP staff and volunteers to add data to the database and the ability for WRP to conduct basic analysis from the hydrographs created from water level data. Chapter Five presents the potential for future analysis from this data and improvements to the databases and web mapping applications.

Chapter 2 Background

This thesis project is a product of VGI, provided by volunteers, members of the public and government supplied data provided by the Water Agency. These data sets complement each other and are necessary to provide a complete picture of historic and current groundwater supply in these two basins. When using volunteered information, supplied by a willing if untrained public, it is important to frame the data in the correct context and use it with the correct expectations.

Chapter 2 examines the use of the VGI for this project in the literature as 1) a valuable and important source of data, 2) as "e-data" or electronic data used in government projects, 3) as citizen science connecting the public with professionals via scientific spatial data, 4) spatial data quality of VGI and 5) the specific challenges associated with utilizing VGI. This chapter concludes by examining other web mapping applications that are similar to the one developed for this project.

2.1 Volunteered Geographic Information

With the proliferation of affordable spatial technologies and improvements in programming and computing power, the expansion of VGI is great. Untrained citizens provide large amounts of data at a low cost. Much of this data is perhaps unsuitable for professional and scientific work. However, some are valuable. There are a number of different categories of VGI that can be considered useful for inclusion in scientific research (Spyratos, Lutz, and Pantisano 2014). One category of VGI data is data intentionally collected for a scientific endeavor.

Academics and professional geographers must work to support the use of VGI in their professional research due to its potential lack of quality assurance (Goodchild 2007, Goodchild and Li 2012, Waters 2009). However, the uniqueness or potential value of a certain dataset may make it appealing for inclusion in research papers and reports. If the work is conducted in the interest of the public good or in conjunction with a government agency, these VGI data can be even more appealing. Traditionally government funded projects have a limited source of funding making the use of VGI appealing due to its low relative cost. Government funded data can become out of date, with some sources of VGI being more accurate than government data (Goodchild and Li 2012).

VGI is worthy of consideration, but the volunteered data quality screening process should be considerable. Professional geographers must determine if VGI is valid data and if a particular dataset warrants inclusion in professional or academic work. If a professional is going to use a VGI dataset, it should be understood specifically how these data can improve the knowledge of the project. Certain criteria must be met to warrant the use of VGI and the proper use of the data must be considered within the context of a given study.

2.1.1. The Value of VGI

When Michael Goodchild first coined the term, he was acknowledging VGI as a source of user-generated content that was at the time becoming voluminous enough to be recognized and considered for inclusion in academic work (Goodchild 2007). During this time other professional geographers also noticed this increase in volunteered spatial data and evaluated it in the literature, recognizing the volume of data that was emerging as a “flood” of crowd-sourced spatial data (Sui, Goodchild and Elwood 2013). While recognizing the volume and different sources of VGI, professional geographers had to consider which of any of these data were fit for inclusion in their scientific and professional research (Flanagin and Metzger 2008).

The significance or importance of a specific VGI dataset and the ability of professionals to gain extraordinary benefit from this VGI can determine if the use of this data is worth the effort of substantiating its inclusion in scientific or professional GIS. Sometimes the data that professional geographers receive from the public cannot be gained in any other way. These data include scientific information about local phenomena, information about hazardous environments or emergency situations (Roche, Propeck-Zimmerman and Mericskay 2011).

To determine if the VGI offered for a particular study is important enough to warrant consideration, the value of this VGI must be considered. As Feick and Roche (2013) remark, “the sociopolitical dimensions of VGI value are both more interesting and more problematic to consider in light of traditional valuing approaches.” The strategies used by governments and in business to determine value should not be applied to scientific data or studies. However, for addition to a project, the value of a particular VGI dataset must be determined before it can be included.

2.1.2. The Use of VGI for Government Supported Studies

Requiring local governments to take the lead in the monitoring and management of groundwater creates a potential for government-citizen interaction, or as Linders describes it “coproduction” of data (2012). There is a long tradition of coproduction in government programs and projects. With the Internet, there is an increasing opportunity for citizens to actively provide data to government studies and projects. While this may not be considered true government designed by the masses in the “ICT-facilitated strategic planning” fashion, it is the support of a government mandated program with citizen science. This is a great opportunity to take advantage of data that citizens have been collecting for years.

In the context of GIS-based government work, the opportunity for a government agency to take advantage of volunteered information may be invaluable to planning and resource-management. Ganapati acknowledges that in the face of increasing use of GIS technology by the public, there is little mention of this cooperation or coproduction in the literature in terms of policy-making (2011). However, this thesis project and SGMA, in general, provide a direct opportunity for public-supplied data to support local groundwater management policy.

The opportunity for a government to have a "conversation" with the public has improved with Web 2.0 (Johnson and Sieber 2013). Local "sensors" can provide information to government agencies and monitor current situations on-the-ground. The reduction in government spending for projects has increased these opportunities. Involving the public in projects such as a county-wide groundwater monitoring program, may become a necessity in the future. How else can a large-scale project such as this be successful without citizen-involvement?

Providing transparency is another essential element of projects affecting the public (Ganapati 2011). Involvement by citizens improves this transparency and increases successful project implementation. Throughout the SGMA implementation-process, transparency with the public has been required. Identifying the private individuals supplying data for government projects maintains quality assurance of the data, and is essential to determine the acceptable use of this data (Johnson and Sieber 2013).

2.1.3. Citizen Science VGI

There are examples from all over the world of normal citizens engaging with governments and academics to gather data to support a deeper knowledge of for specific projects. Defining the term "citizen scientist" and the projects that these "scientists" may provide data for is helpful (Haklay 2013). Many people who are involved in important data-collection efforts would not identify themselves as scientists. For this project, the volunteers that collect groundwater data for the two identified, project basins, using industry-standard methods, or are "active participants in a scientific project (Haklay 2013)" are citizen scientists.

Historically, scientific endeavors were carried out by individuals who had enough private capital to fund their expeditions or research (Silvertown 2009). This recognition is helpful to prevent suitable data collected by private citizens from exclusion in scientific projects. Criteria must be applied the VGI, but it should not be so strict that it removes legitimate data from use.

There are numerous examples in the literature supporting the use of citizen science. If citizens are trained how to properly use the scientific tools to gather data, then their analysis and gathered data is valid. Different protocols should be used for citizen scientists, and they should not be asked to do more analysis than is practical, but the information that they collect can be valuable and helpful (Cohn 2008). Jeffrey Cohn gives several examples of citizens following strict protocols to collect data for scientific use. Some of these are citizens collecting mammalian data along the Appalachian Trail, Cornell's Laboratory of Ornithology employing citizens for bird monitoring and volunteers tracking the number of native and exotic species of crabs on the Atlantic Coast.

Interestingly, Rick Bonney, director of program development for Cornell University's Laboratory of Ornithology is quoted in Cohn's article stating that "Citizen science is science 2.0", referring to how ecological studies are often conducted today. The 2.0 concept is everywhere as many academic disciplines seek to redefine themselves in the wake of scientist and citizen interaction.

Haklay notes that the fields or archaeology, meteorology and astronomy all have histories of including citizen-gathered data for inclusion in official scientific studies or datasets (2013). The history of scientific exploration and study is filled with non-academic or non-professional scientists providing data that is credible and legitimate. Perhaps the two greatest or most well-known contributions are the Christmas Bird Watch that has been ongoing since 1900 and Charles

Darwin's inclusion on the H.M.S. Beagle as a companion of Captain FitzRoy. Both of these final two examples alone have provided more scientific knowledge and understanding about our natural world than many studies conducted by professional scientists.

2.2 Spatial Data Quality

When using spatial data, there are many potential sources of error. These errors can include positional errors, attribute errors, errors of "logical consistency" and errors of data completeness (Hunter and Beard 1992). Additionally, these errors can be compounded when the initial errors are not communicated via metadata leading to erroneous use of the data. All of these primary and secondary errors create an overall "global error" for the dataset (Devillers and Jeasoulin 2006). This is perhaps more true of VGI, since there is no quality control associated with the collection or distribution of the data.

2.2.1. Spatial Data Quality in VGI

Concerns exist that various aspects of VGI data will make it unsuitable for inclusion in a scientific or professional study. One aspect of VGI that must be verified is the spatial data quality. Spatial data quality can refer to the locational accuracy of the data or the values entered into the tables. If data is not accurate, or the readings are not accurate, then the data will not be valid. Another consideration is the quality of the data entered into the databases. Data inaccuracy is a known issue when using VGI for analysis (Waters 2009).

Regarding the VGI for this project, there are two main types of error that may be encountered: data collection errors and data input errors. The data collection errors may occur in the field where the volunteers mark down or gather their water level data. The equipment may fail to be improperly calibrated. The second type of error potentially introduced by volunteers would be incorrect recording procedures. Volunteers may not accurately transpose or enter the water level data correctly.

Another known type of error with regard to VGI is “thematic quality” (Fonte et al 2015). This refers to volunteers’ ability to correctly assess classes in the collected data. This type of error does not apply to this project as the volunteers collecting water level data are taking objective readings. The issue of credibility of data provided by volunteers does apply. The credibility of the data is used to denote the quality of the data provided by that volunteer (Fonte et al 2015). This is an element of data collection that will be addressed for the VGI in this project.

Positioning errors are not an issue with this project as the well positions exist in the spatial data and are not collected when the well measurements are taking. Conflation errors are not a consideration for this project, as each volunteers observes water level data for a discrete set of wells, and there is no overlap (Fonte et al 2015). The most important characteristic for consideration to determine the spatial data quality for this project are reputation and experience of the volunteers (Senaratne 2016). Since the protocols for VGI-data-collection in this thesis project are established and simplistic, and there is no collection of locations or classes of data, the reputation of these volunteers and the methods they use are the only variables that can be assessed.

2.2.2. Methods to Determine the Validity of VGI

As professional geographers, it is necessary to know how to manage and make the best use of all spatial data used in reports and mapping projects. VGI is no different, and while there is an apparent “novelty” to VGI it should not be viewed as a unique and precious data-type (Haklay Forthcoming). VGI is perhaps newly recognized in the professional sciences but nonprofessionals have been recording information around the world for centuries, and much of the initial phases of science were conducted by novices (Goodchild 2007). Realizing that VGI is just another type of data is important. Determining how to verify the validity of a specific dataset for inclusion into a project is a secondary consideration.

Many methods for determining the fitness of a particular dataset. Bishr and Mantelas (2008) suggest that a verification and reputation model can be helpful to determine the quality of a dataset for use in a citizen-based VGI projects. Reputation is an important method to provide quality assurance in the use of VGI for government projects (Maué 2007). Reputation creates a level of confidence in the data particularly if the volunteers providing the information are responsible to each other and the outcome of the project.

Goodchild and Li provide several approaches for determining the validity of VGI. One of these deemed the "social approach" is helpful if a "hierarchical structure already exists in many self-regulated collaborative efforts" (2012, 114), further supporting the concept of status and self-regulation of the group with a feedback loop for reputation based quality-assurance. A group providing VGI is responsible to each other, and can verify the work of the group.

Control data can be used to determine the spatial and attribute integrity of a VGI dataset (Comber et al. 2012). Using control data to determine the accuracy of a VGI dataset can be tricky. The control data must be of a very high quality, such as surveyed data, or a well-known and vetted dataset. Methods such as random-sampling of the VGI data provided for this thesis were not conducted for this thesis. This method and others are understood for their ability to provide quality assurance. However, the training provided to the volunteers prior to this thesis are considered acceptable as no funding exists for further testing or training.

Government agencies may use VGI in a variety of different ways. Some examples are the public development of accurate road data, created and edited at the local level for the greatest benefit to the citizens, such as the data found in Open Street Map (OSM). The effort to create more accurate data at a local level for OSM began 2004 and this project was significant to supporting disaster response during the Haitian earthquake (Roche, Propeck-Zimmerman, and Mericskay 2011). Emergency response data provided by citizens on-the-ground in the disaster zones can be invaluable (De Longueville et al 2010). It can be the critical element that supports a successful response to an event.

The VGI used for this thesis is critical and supports the success of this thesis project, the implementation of SGMA in Sonoma County and future developments in California to protect groundwater resources. All effort must be made to verify the VGI used in this thesis, to determine if the data-collection methods are standard and acceptable and to determine if these volunteers are trustworthy.

2.3 Web Mapping Applications

Web mapping applications are digital cartographic products that display spatial data in a web browser. This is a relatively new method of displaying digital spatial data. In the past, GIS software programs allowed users to see data on their computers but now users can create web mapping applications using GIS software. Web mapping applications allow members of the public, or other professionals that do not have the appropriate software application, to view spatial data on the Internet in a web browser.

Conducting research on groundwater web mapping applications is challenging due to the confidential nature of the data. Groundwater data typically includes private residential customer information and is not provided to public-facing websites to protect the privacy of these citizens.

However, as groundwater law in California changes, private well information is becoming more available. State governments are providing groundwater data and some water level information has become available to the public.

2.3.1. State Water Resources Control Board Web Mapping Applications

The website that is most similar to the web mapping applications developed for this project is the SWRCB's Groundwater Ambient Monitoring and Assessment (GAMA) Program. GAMA is a part of the SWRCB's Geotracker series of websites that share information and spatial data with the public and other government agencies using GIS (State of California 2016a). GAMA can be accessed by clicking on the Geotracker tab at the GAMA homepage, as shown in Figure 4.

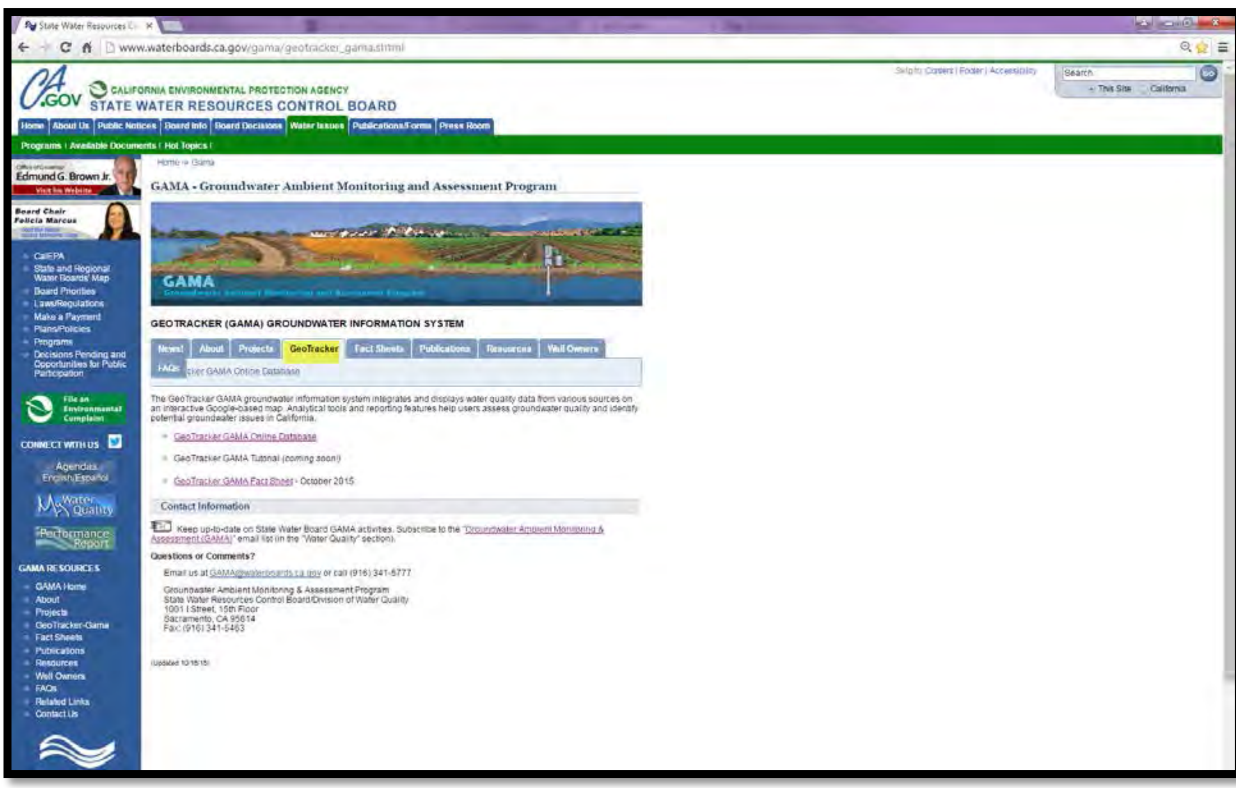


Figure 4 GAMA Homepage. *Source*: State of California 2016a

After clicking the GAMA tab the option to use the GeoTracker GAMA Online Database is available, via a button located directly below the main tabs. Clicking this button opens the Map Water Quality Information page accessing a web mapping application. Entering an address and hitting Map Address on the right opens a map with many different options for data analysis and retrieval on the site. Figure 5 on the following page shows the results of searching in the Santa Rosa Plains groundwater basin.

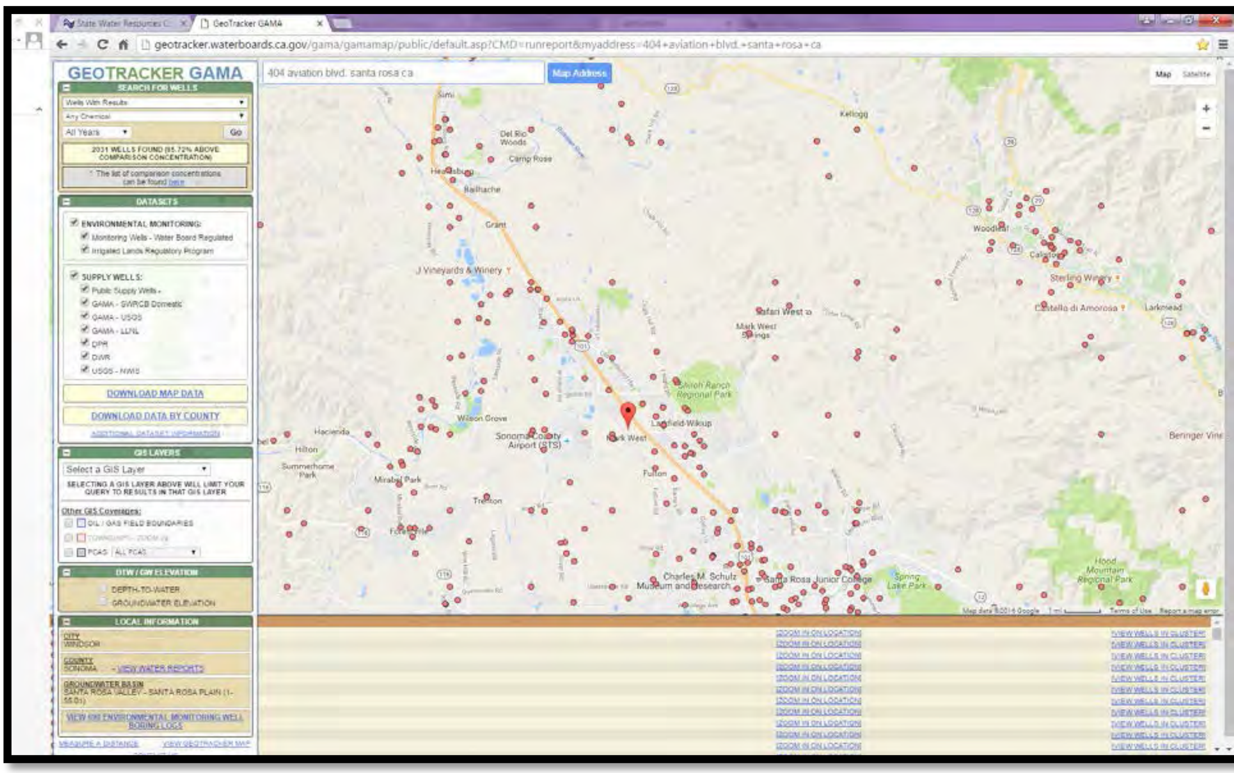


Figure 5 GAMA Web Mapping Application with Wells and Other Data. *Source*: State of California 2016b.

This web mapping application allows the viewer to add or remove different categories of wells, to turn off and on different layers, to view and download tabular data. There are multiple different controls on the left of the screen that can be expanded to expose these options or collapsed to show more map area. The viewer can click on a well in the map to expose another page with specific information about the wells that were clicked on or the viewer can click from the list at the bottom to highlight a well. The viewer can also sort by year or by chemicals that might affect water quality in the wells.

2.3.2. DWR Groundwater Web Mapping Applications

To support SGMA, DWR created several web applications that are similar to the web applications developed for this thesis project. The Water Management Planning Tool (Figure 6) and the Groundwater Information Center Interactive Map Application (GICMA), (Figure 7 on the following page) are two detailed, easy-to-use groundwater web mapping applications providing comprehensive information and downloadable data for the public (State of California 2016c and 2016d).

These web mapping applications depict administrative data such as county boundaries, Adjudicated Groundwater Basins, Groundwater Management Plan Boundaries, CASGEM Groundwater Basin Prioritization and all of the Bulletin 118 groundwater basins for the entire state.

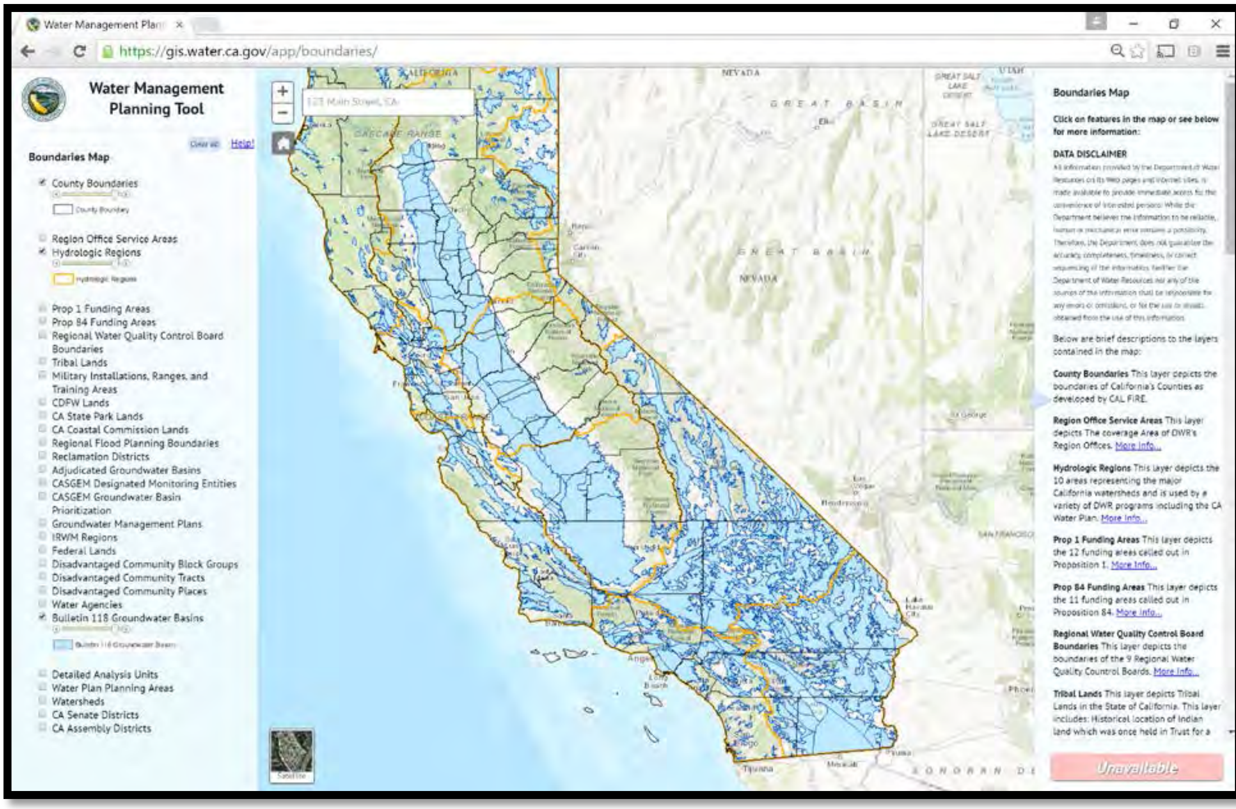


Figure 6 DWR Water Management Planning Tool Web mapping application. *Source*: State of California 2016c.

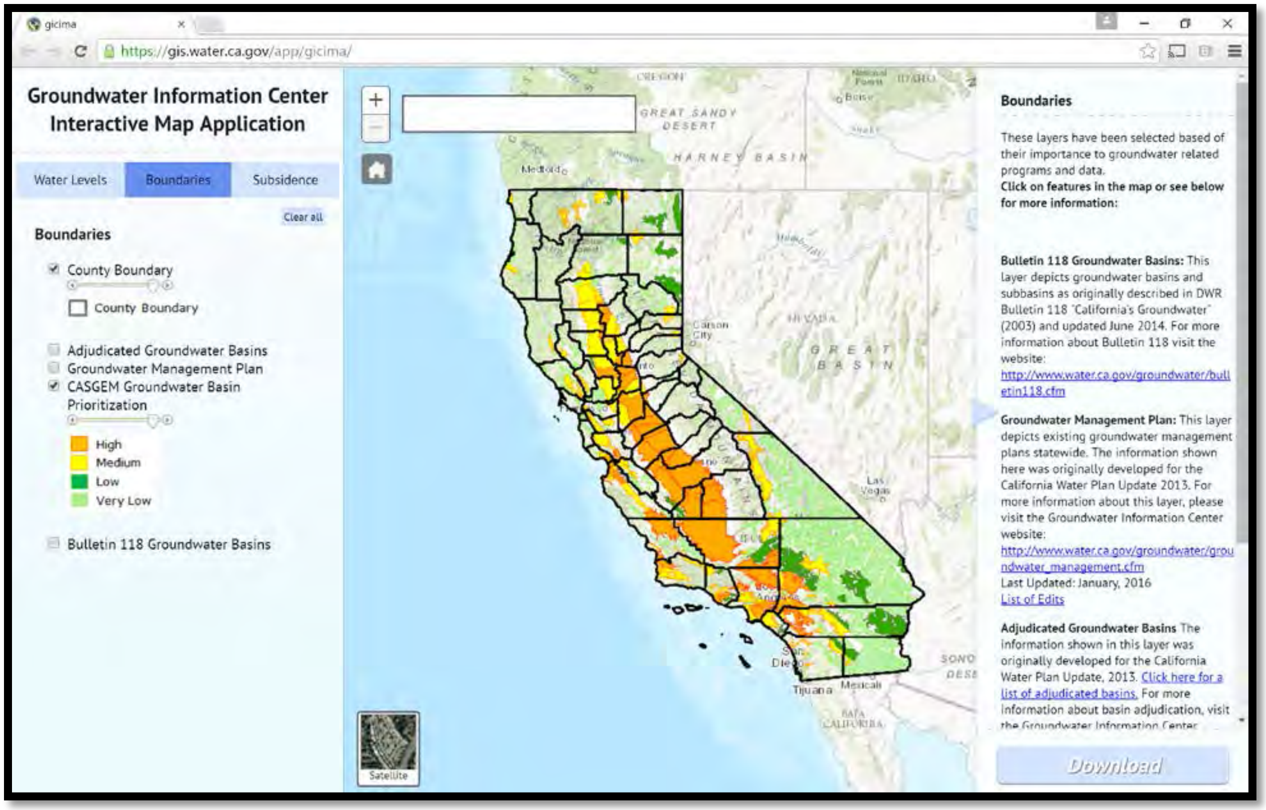


Figure 7 GICMA Web Mapping Application. *Source*: State of California 2016d.

In addition to administrative boundaries, these websites also depict scientific groundwater data such as water level information and the locations of detected subsidence in the state. The detected subsidence layers show locations where subsidence has been measured using extensometers that are monitored by the USGS and DWR. For many of the layers depicting scientific data, there is a detailed explanation of the sensor used and reports that can be accessed from the right-hand column on the web page.

The accessible reports provide information and links to other government websites. The DWR web mapping applications on the aforementioned sites are the most similar to the web applications that were developed for this thesis project. However, as similar as these websites appear to the ones developed for this project, they are primarily informational tools that DWR uses to provide data and information to the public and other government agencies. They are more extensive in the data and groundwater information they offer to the public than the web mapping applications proposed for this project.

While DWR web mapping applications provide more detailed information they do not engage directly with the public entering data, and they are not web editing mapping applications. The web mapping application developed for this project show data for two groundwater basins in Sonoma County and allow the volunteers in these two basins to edit their groundwater level data. The web application developed for this thesis focus directly on these two groundwater basins and the corresponding volunteers and Monitoring Entities.

Other groundwater applications may exist in other states where groundwater management has been ongoing for many years. However, none were found during the research for this project.

2.3.3. Other Government Groundwater Mapping Applications

The USGS has developed a series of websites devoted to providing the public with groundwater information and data. The main page for the USGS groundwater series is the "USGS Groundwater Information Pages" (US Department of the Interior 2016). This website has links to many USGS websites providing data, publications, modeling information and software that is free to download by the public or trained professionals. Basic information is available at this site to educate the public about groundwater. While this is an excellent source of information about groundwater, it is not a web mapping application and does not allow editing, unlike this thesis project.

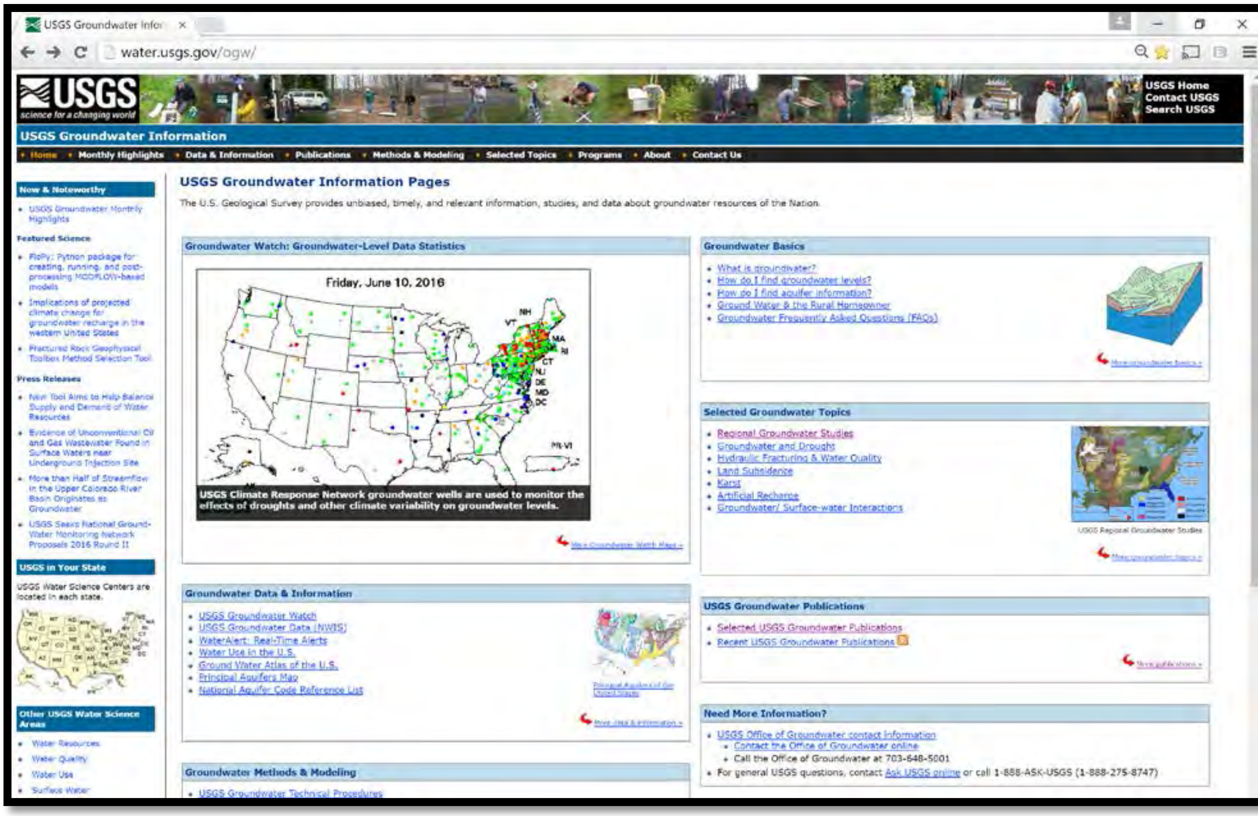


Figure 8 USGS Home Page for Groundwater. Source: US Department of the Interior. 2016.

The National Aeronautics and Space Administration (NASA) Gravity Recovery and Climate Experiment (GRACE) program uses satellites to map variations in Earth's gravity field (National Aeronautics and Space Administration 2014). Using this technology allows NASA GRACE to evaluate groundwater levels and moisture content in the soil. In this regard, this tool and the accompanying website do provide groundwater information as it maps groundwater storage on land. The GRACE website has data to view and results on the loss of groundwater around the world and in the Western United States. GRACE provides scientific data to the public and academics alike, however it is not a web mapping application, nor is it an editable web page.

Internationally, governments around the world recognize the need to protect and manage groundwater resources and to educate the public. The Government of India has a website devoted to managing national groundwater (Central Groundwater Board 2015). This site provides links to reports and groundwater data, though the reports seem to be dated, and the web mapping portion of the website did not function well. While this website is similar in design to the website developed for this project, it is difficult to determine how similar the two sites are given the poor functionality of the Central Groundwater Board site

It is helpful to recognize the global nature of websites and spatial data available regarding groundwater. The ample supply of government-developed websites supports the significance of this topic.

2.3.4. Professional Groundwater Applications

There are websites devoted to groundwater professionals and applications for professional journals on groundwater monitoring and science. However, these professional websites are not web mapping applications; they do not display spatial data in a web map, and they do not provide any spatial data for download.

The National Ground Water Association (NGWA) is a “membership-based nonprofit organization” that provides information and membership for groundwater professionals and scientists nationwide (National Ground Water Association 2014). The NGWA has a web page that hosts peer-reviewed articles, information about groundwater professionals and provides a web application for download. This web application, the Groundwater Monitoring & Remediation allows users to read the “leading ground water and hydrogeology journal.” The website is helpful for groundwater professionals, but it does not provide groundwater data nor is there a map depicting groundwater information.

In addition to the NGWA site, there are a host of sites with products to help professionals and governments manage their groundwater resources and manage the staff that are devoted to managing groundwater resources. Canvas is one such product. “Canvas is a cloud-based software service.” (Canvas 2016a). Canvas software has many “pre-built” applications available for purchase and customizable to many different professional applications such as asset management, building inspection, and employee timesheets. The Canvas website offers the potential to allow for the entering of data in a website format, but it appears to be more of an asset-management software solution and not a government-hosted website to enable the public to enter data.

Canvas also provides the Canvas Ground Water Monitoring Report Mobile Application. This application covers Geothermal Well location, Geothermal Area, Piezometric Head, Date and time of Sampling, Place of Sampling, Firm Performing Water Quality Analysis (Canvas 2016b). This is a web application for the mobile collection of groundwater well data. The online demonstration shows its use for a geothermal well, but it could be customized to collect potable well data. The Canvas mobile site demonstrates the development of mobile technology for groundwater asset management.

Chapter 3 Methodology

This chapter discusses the two user-groups working on this project, the methods employed in this project to meet their individual needs, the volunteer well data and the databases managed by WRP, introduces two significant contributors/well volunteers and their process for well monitoring, and the development methods employed to meet all user requirements including those employed to meet SGMA requirements. This chapter also describes the use of GIS and spatial data at the Water Agency and the process for creating the enterprise databases and the web mapping application software architecture that allows the display and editing of the data in the web mapping applications.

Two different types of web applications were created for two different user-groups; volunteer-editors (private citizens) and view-only (WRP staff). Figure 9 shows the design process for this project.

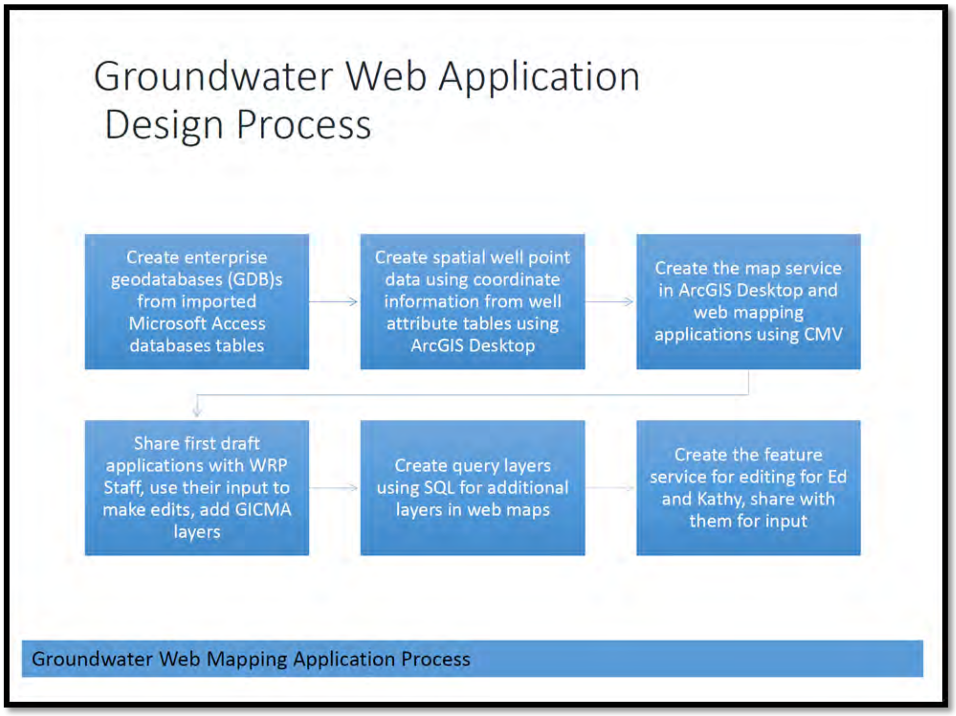


Figure 9 Project Design Process. *Source*: Heather Kelley 2016

Each group has a unique function in this project and uses methods specific to their work. The workflow of both groups were considered in the development of this project as unique user-groups, with specific requirements. The technologies developed for this thesis project were created with the specific user-groups in mind, to supply a unique and necessary solution for their unique tasks.

3.1 Project Design

This project was designed to facilitate an ongoing project with two different user-groups accessing the databases and viewing the groundwater data in web applications. The two different user-groups are comprised of 1) Water Agency WRP staff working internally at the Water Agency managing data for multiple groundwater basins and 2) members of the public (volunteers) taking water level measurements on private wells in the Sonoma Valley groundwater basin. These user-groups have different access needs, perform different tasks and have different requirements. Their access to the data via the web mapping applications is based on their needs and requirements for data access.

3.1.1. User-group 1- View-only Web Mapping Applications

User-Group 1 is the WRP section of the Water Agency's the Engineering Division. GIS is housed in the Water Agency's Engineering and Resources Planning Division, in the Drafting and GIS Department (Sonoma County Water Agency 2007). The Water Agency uses GIS in the general support of all Water Agency Staff, i.e. Environmental, Operations, Maintenance and Engineering Divisions all use maps, spatial data products, and internal web mapping applications created and maintained by the GIS Department. WRP is the section that interacts with the groundwater volunteers, collecting and analyzing water level data from the groundwater basins.

WRP uses GIS to depict the groundwater well data, groundwater management plan boundaries, and groundwater basins. WRP creates posters and small maps for groundwater workshops, public meetings, and groundwater reports. WRP works with data for the management and planning of water supply. These data include layers for the management and planning of surface water use and places of use and points of diversion from surface water sources. WRP also manages the groundwater well data for Sonoma County. The well data depicts the location and amount of groundwater extraction in Sonoma County.

The WRP group uses GIS in their modeling and produces maps using ArcGIS Desktop software. However, the WRP does not utilize GIS in the specific manner presented for this project: the creation of a relational database system that supports the SQL and web mapping applications. An identified user requirement for User-Group 1 was the presentation to WRP of new options utilizing GIS. It is necessary to demonstrate new tools for SGMA implementation so that WRP will be ready to develop the DMS. This project is a continuation of the existing support model for GIS at the Water Agency.

In addition to viewing the well data in web mapping applications, WRP staff also require access to the data through the database interface, using Microsoft Access or SSMS. Another important user requirement for User-Group 1 was to implement a long-term database solution for WRP, creating a stable, long-term repository for the groundwater well data.

This project differed from the other WRP maps and well mapping projects by creating web mapping applications and SSMS enterprise databases as the WRP does not provide these services. WPR manages the groundwater data in Microsoft Access databases. The use of web mapping applications and enterprise databases creates efficiency in both data-sharing and data-management. WRP staff have not edited their well data in ArcGIS Desktop, and they have not asked for an editable web application to edit the well data. They will continue to edit the well data in a database program, such as SSMS or Access.

The GIS Section creates view-only web mapping applications as a part of the day-to-day work-flow of the Water Agency GIS; there is an internal GIS Map Gallery at the Water Agency with 45 view-only web mapping applications. As this is a common work-flow at the Water Agency, during initial project meetings WRP staff requested the creation of two separate web mapping applications to display the wells, groundwater basins and management plan boundaries. One web map was created for each groundwater basin: Santa Rosa Plain and Sonoma Valley. WRP staff requested the layers that they wanted to have available to them, then these layers were downloaded from the DWR’s GICMA website and loaded into the enterprise databases for inclusion in the web maps.

Charts and graphs, typically hydrographs, are made in Microsoft Excel. A hydrograph is a graph that shows water level readings in a well over time. Newly developed reporting functions in the web mapping application give WRP staff the ability to generate the hydrographs dynamically in the web mapping applications. This was an additional requirement for User-Group 1 as the previous method of hydrograph-creation was inefficient and time-consuming.

3.1.1.1. The use of REST Endpoints

The view-only web mapping applications developed for use by WRP staff were designed to view multiple spatial data layers including the well data, query layers, and tabular data served from the internal servers at the Water Agency. Other spatial layers are supplied by the DWR GICMA web mapping application and the USGS Streamer web mapping application. The layers from these web sites, can be added to the Water Agency Well Mapping Applications. These layers can be used in the Water Agency web mapping applications due to the public availability of their REST (representational state transfer) endpoints.

REST endpoints are essentially mapping service addresses whereby any publicly available map service can be accessed and viewed in another web application. ArcGIS Server software generates a REST endpoint when a mapping or feature service is created. A non-public REST endpoint is available to anyone on the server with the correct “address” or uniform resource locator (URL) and the ability to see the layers. Security can be applied to the mapping or feature service to make the REST endpoint viewable only to those with the proper authentication.

Five layers from other public agencies have been added to the web application for viewing at the request of WRP staff and managers. These other layers are provided via their publicly available REST endpoints. The public agencies providing these REST endpoints are the

USGS and DWR. The Water Agency non-editable web applications are a mixture of services provided by the Water Agency, DWR, and USGS. Other public services as may be added as they are identified and requested by WRP managers.

These external services show data from the USGS Streamer web application and DWR GICMA web application. The USGS Streamer website provides stream gauge data as live data providing the stream flows in the state, and GICMA data shows the adjudicated groundwater basins, groundwater management plan boundaries, CASGEM prioritization basins, and all of the groundwater basins identified in the Bulletin 118 series.

There are advantages and disadvantages to connecting to a live REST endpoint from an outside agency. If the outside agency moves the service to another server, the Water Agency will lose its connection to the REST endpoint and the web application will not function properly. But if the outside agency maintains the REST endpoint the Water Agency will always have a connection to the official data supplied by the host agency.

Data supplied by an outside agency will be accurate if the REST endpoint is maintained on the server or if the move of a service is coordinated and communicated between agencies. If the data supplied by the REST endpoint live data, such as the stream gage data provided by the USGS, the Water Agency can take advantage of this live data feed without purchasing and maintaining stream gages itself. This is cost-effective and creates collaborative partnerships between agencies when both parties want to share data amongst themselves.

3.1.2. The Groundwater Well Data

Figures 10 and 11 on the following two pages show the well data that WRP manages for Santa Rosa Plain and Sonoma Valley by data source, the provider of the well data. There are more public entities involved in monitoring Santa Rosa Plain than in Sonoma Valley. Sonoma Valley has five volunteers whereas Santa Rosa Plain has none.

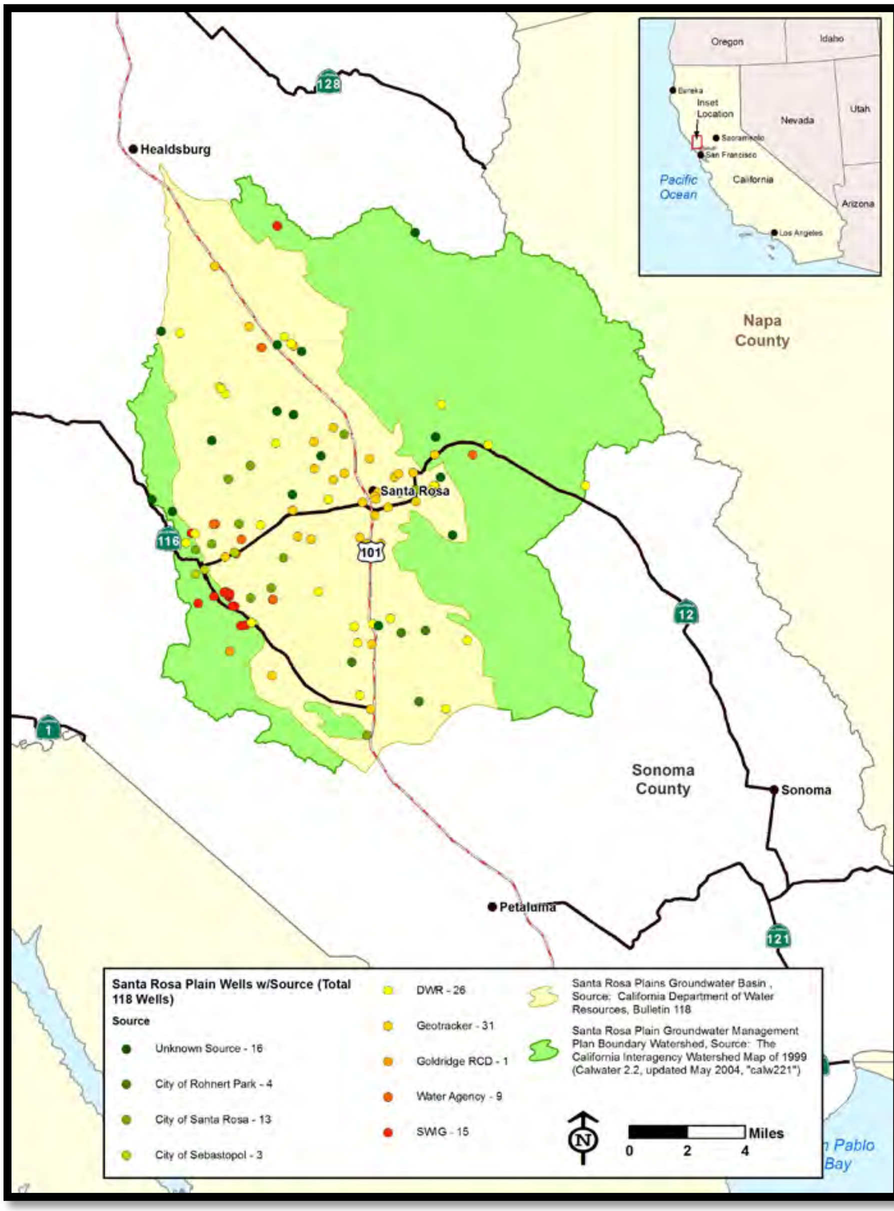


Figure 10 Santa Rosa Plain Well Data by Source. *Source*: Heather Kelley 2016

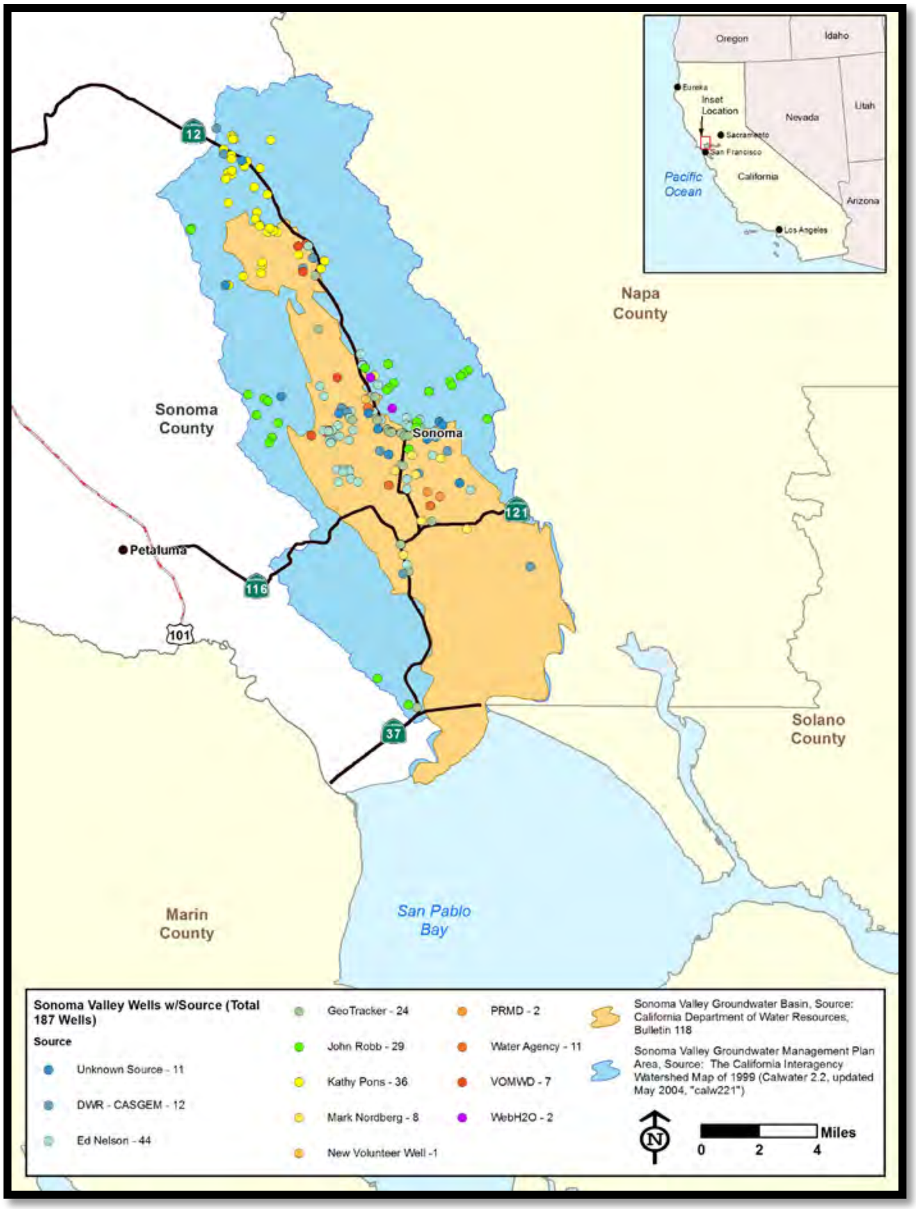


Figure 11 Sonoma Valley Well Data by Source. *Source*: Heather Kelley 2016

Table 2 presents the breakdown of volunteers and public entities that supply water level data for the Sonoma Valley Basin. There are five private entities or volunteers supplying water level data and six public entities. There are 118 wells, and 63% of the wells are monitored by private entities in this basin. There are 58 wells or 31% of wells monitored by public entities.

Some of the wells for the Sonoma Valley Basin and Santa Rosa Plain are Geotracker wells, from the SWRCB's GAMA Geotracker program. It would be helpful to understand why the WRP does not have all GAMA wells in the basins or the county present in the existing Water Agency dataset, but currently this information is not known.

Table 2 Sonoma Valley Sources of Water Level Data

Name	Entity	Number of Wells Monitored	Percent of Total
Null	N/A	11	5.88%
DWR/CASGEM	Public	12	6.42%
Ed Nelson	Private	44	23.53%
Geotracker	Public	24	12.83%
John Robb	Private	29	15.51%
Kathy Pons	Private	36	19.25%
Mark Nordberg	Private	8	4.28%
New Well	Private	1	0.53%
PRMD	Public	2	1.07%
SCWA	Public	11	5.88%
VOMWD	Public	7	3.74%
WebH2O	Public	2	98.93%
Total		187	

There are a small number, 11 or 5.9%, of the wells that have no source information. As this is a small percentage, it is not statistically significant for this study. The two volunteers that gave interviews and tested the web application are monitoring 80 wells in the Sonoma Valley, or approximately 43% of the wells in this basin. These two individuals produce a significant proportion of the data and are a trustworthy and reliable sources of water level data given their commitment to the project.

3.1.3. User-group 2- Editable Web Mapping Applications (Volunteers)

Previously, the volunteers took their measurements in the field, recorded this information in the field and then added these measurements to an Excel spreadsheet. They sent this data to Water Agency Engineering Technician III, Nathan Baskett in the WRP at the Water Agency via email, and he added the data to the Access database. This was a lengthy process for the volunteers and WRP staff, any improvement in efficiency is a benefit for the volunteers and WRP staff.

Improved efficiency and communication with these volunteers was a user requirement for User-Group 2. The editable web mapping application permits well volunteers to contribute water level data creating an opportunity for immediate results and feedback from these important users. This makes it unnecessary for the volunteer to email their water level data to WRP, as they will add it directly to the database. The web applications also provide immediate feedback to the volunteers which improves their communication with WRP. The volunteers can immediately see their data in the database via the web applications.

Using the web mapping application, the volunteers add their bi-annual water level readings to the database via the web mapping application and WRP staff will verify that the new readings have been added. These readings are displayed in the web mapping applications as the most recent reading. The most recent well reading as well as all water level readings are available in the tabular display in the web mapping application. The volunteers only view their well data in the web mapping application; while WRP staff can view all the data in the web mapping application, or they can view these readings in the enterprise database.

The editable web applications meets the user-requirements of improved communication between the well monitors in Sonoma Valley and WRP staff. The previous method of emailing volunteer readings was not efficient in the required steps to get the monitoring data to WRP staff.

Allowing the volunteers direct database access via the web applications allows the volunteers improved efficiency and streamlines the data-entry process.

The different use-cases for the two user-groups are the volunteers for the Sonoma Valley groundwater basins edit data in web applications and WRP staff view data for both basins in two separate web applications. The WRP view-only web applications show all wells and have more layers present than the well volunteers have access to. The volunteer web applications are simplified, depicting only base maps and subsets of the well data, showing only the wells that they each monitor. User -group 1 has access to more data layers and also views the data in a database program. User-group 2 only sees the well data in a web mapping application, and they use the web mapping application to add their water-level readings.

3.1.4. Volunteer Data

The volunteer well information is a critical piece of data for the WRP section and for the establishment of the Sonoma Valley GSP. This volunteer data shows a long-term relationship established many decades ago between DWR and the groundwater well owners in this basin. This volunteer data is provided without any formal requirement or mandate. Initially, the DWR was the agency that collected and housed this well data. Currently, the Water Agency, one of the local entities analyzing Sonoma Valley groundwater basin data and the local lead agency in the formation of the GSP, collects the volunteer well data.

There are five volunteers for the Sonoma Valley basin and none for Santa Rosa Plain. Of these volunteers, one volunteer gathers data for 44 or 23.5% of the wells and another gathers data for 36 or 19.3 % of the data. This is a statistically significant number of the data for this basin comprising almost half of the well data for the basin. The volunteers gather the water level data twice a year and have been doing so for over ten years. Their contribution and commitment to the process is admirable.

The two main volunteers for Sonoma Valley were interviewed to provide details on the volunteer well monitoring program. The questionnaire and their responses are in Appendix B, while a summary of their answers follows. The purpose of the questionnaire was to understand more about the genesis of the volunteer monitoring program, the methods that the volunteers use to obtain the water level data, and how they came to monitor wells that are not on their own property.

3.1.4.1. Interview Results

Kathy Pons and Ed Nelson provided information regarding their involvement in the volunteer well program for the Sonoma Valley groundwater basin. Both volunteers received training from groundwater professionals to read water levels in wells. Both volunteers began monitoring their own private wells first and then reached out to neighbors in the basin to monitor these wells also. Both volunteers know of wells that are not monitored in Sonoma Valley. Also, both volunteers expressed an interest for groundwater information; they want to know what is happening to the water levels in their basin.

3.2 User Requirements

An important part of any GIS project are the user requirements of the system. GIS projects should be designed to make analysis and communication easier and intuitive. An innovative new technology is not worth inclusion in a project if it's not helping someone or improving analysis. The technologies employed for this project were designed to improve data-collection and communication for the two user-groups. The workflows of both groups were considered when this project was designed.

3.2.1. Improve Data-Input Efficiency for the Well Volunteers

The first user requirement considered for this project was to improve data-input efficiency for the well volunteers who monitor the wells in Sonoma Valley. The previous method utilized by the volunteers to share data with WRP was outdated, had never been considered for update and took too much time from these important volunteers. Essentially, the well monitors data was entered into the system three times, once by hand in the field and then transferred into Excel and finally emailed to Baskett. The method proposed by this project allows them to write the data in the field and then enter it directly to the database via the web mapping application.

This is an important addition to this project because any improvement in efficiency for these volunteers will be an incentive to continue participating in the monitoring program. Also, entering the data directly into the database removes one step where errors can be introduced. Baskett will no longer need to enter the data from Excel into the database; he will simply verify that new data was added to the database.

The technological choices to implement this user requirement were to create a new enterprise database and accompanying web mapping application. This implementation was simple and economically feasible. Enterprise databases already exist at the Water Agency; adding two new databases for each groundwater basin was easy and allowed the data to be easily shared between WRP Staff and the volunteers.

3.2.2. Improve Communication Between the Well Volunteers in Sonoma Valley and WRP staff

The second user requirement considered for this project was to improve communication. The previous method of communication between the well volunteers in Sonoma Valley and WRP Staff was not efficient. During the monitoring season, the well volunteers would go out to the field, collect data and then eventually send it to WRP. Once the volunteers emailed their data to

WRP Staff, there was no feedback to communicate to the volunteers that their data was received. WRP Staff were not always aware that the volunteers were conducting monitoring.

Improved communication between the volunteers and WRP Staff is important because it allows both groups to be aware of the activities of the other, and enables both groups to collaborate on data collection and the analysis that occurs once the data is collected. The volunteers can see their data in the database via the web applications. WRP Staff can see the data in the database via the internal web applications or the enterprise database. If something looks incorrect or is missing, the volunteers or WRP can send an email to ask for clarification.

The web applications allow the volunteers to see their data in the database via the tabular interface at the bottom of the web application. Alternatively, the volunteers can click-on the wells they have edited to see if their newest readings have been added. WRP can also verify that new data has been added to the system via the web app or the database. The databases and web applications allow for a passive communication between the two groups that can be active if either group requires more information. However, the system as designed should allow both groups to verify that new data has been added and to conduct analysis.

3.2.3. Improve Efficiency for WRP by Creating Hydrographs Dynamically in Web Applications

The third user requirement considered for this project was to improve efficiency for WRP. WRP previously used Excel to produce hydrographs. Enabling WRP to create hydrographs dynamically in the web applications is more efficient due to improved processing power of SSMS over Access. The submersible pressure transducers generate thousands of records, therefore using SSMS to generate graphs of these wells and perform other analyses for these wells saves a significant time and is more efficient.

Another improvement in efficiency came from allowing WRP managers to generate the hydrographs dynamically in the web application without interrupting the workflow of other WRP staff. Previously, this task required the attention of two WRP staff; one manager requesting the hydrograph for a report, and the WRP technical staff would stop their work and generate the hydrograph for the manager. The ability to create hydrographs dynamically enabled an immediate assessment of water levels in the wells by all staff. The development of this tool created multiple improved efficiencies for WRP.

Improving efficiency via generating hydrographs dynamically in the web applications was a requirement for successful implementation of this thesis project. The demonstration of improved efficiency is critical to provide support for enterprise databases such as SSMS. Enterprise database systems have not been used by WRP staff and successful implementation of the SGMA DMS will require many advanced technological solutions such as enterprise databases. Familiarizing WRP staff with data management in these enterprise database systems and will be important for successful DMS creation.

The hydrographs are viewed in the web applications via a newly developed tool. This tool allows the WRP Staff and Managers to view a hydrograph for any well in the system for any time period that the well has been monitored, Tim McGee of Moosepoint Technology developed this tool for this project. The hydrograph tool will be discussed in Section 4.1.

3.2.4. Improve Efficiency for WRP Working with the Submersible Pressure Transducer Data

The fourth user requirement for this project was to improve efficiency for WRP working with the Submersible Pressure Transducer data. Previously, WRP staff used Access as the database system for the groundwater data. Access is not the correct database tool (Microsoft 2016, CBS Interactive 2016), to store the several million records generated by the submersible pressure transducers. Access can become unstable if too many records are queried at one time and eventually the database may fail and data will be lost.

With SGMA implementation underway and many outside agencies looking to access the groundwater data for these basins, database failure is not an option. The Water Agency and WRP in specific must be prepared to house this data for long-term storage. Access to the database cannot be hampered by technology that does not handle multiple users accessing thousands of records simultaneously. A robust database solution was necessary.

SSMS is a stable enterprise database system that support the millions of records generated annually by the submersible pressure transducers, multiple concurrent editors and online editable web mapping applications required by the volunteer users in Sonoma Valley. The Water Agency has a license for SSMS and the capacity to store this data onsite as well as in-house expertise to work with the system. This user requirement solution was simple and effective and did not cost the project any money other than staff time to load the data.

3.2.5. Present WRP with New Options for Utilizing GIS

Previously WRP has a relatively small GIS-toolbox and did not understand the basics of data management. GIS was used in a limited manner, each user creating and using data in a data silo, not sharing their data with other users at the Water Agency and creating basic paper maps, no web mapping applications were created for this section prior to this thesis project.

Database integrity was compromised with the use of Access for the submersible pressure transducer data, data silos existed in WRP Section, and basic database methods were not followed. The structure and integrity of the databases as received from Baskett was questionable. The maintenance of complete tables with all necessary fields and unique IDs was not followed. The WRP Section is comprised of engineers and hydrogeologists; they focus on the analysis with the data, not the data itself. They do not primarily concern themselves with database and information systems architecture and structure and there was no data integrity policy in place.

This user requirement was important for SGMA implementation. WRP Staff must become aware of new methods to manage the groundwater data required for SGMA, and to understand which technologies should be pursued and how to employ each one. While the GIS Division can supply support in the form of expertise and information, WRP must be able to show some level of independence with the other GSA entities when making decisions regarding data development and sharing. WRP must learn what is important for SGMA and DMS implementation and development, and the tools that they do not need for this project.

This thesis project presented WRP with many new options using GIS and enterprise database systems. The work was performed free-of-charge and allowed them to see what new technologies are available without hiring a consultant. All of the technologies employed in this thesis project were new to WRP and allowed them to see what the GIS Division can do for them before they must choose how to implement SGMA using the DMS. This information will help them to provide sound advice to the GSA and let them make more informed choices.

3.3 Software Used for this Thesis Project

The software used for this thesis project is the typical software that the Water Agency uses for all GIS and database projects. As stated above, the products of this project are two databases and four web mapping applications. Keeping the software consistent with Water Agency standards allows for project continuity and easy management of the data going forward. It is important for the databases and web mapping applications developed for this thesis to be used in the future, beyond the lifetime of this thesis project.

3.3.1. Database Software

The GIS Section uses SSMS for all of its enterprise databases, allowing for nonspatial and spatial database maintenance. SSMS works well with Esri products, and has a user-friendly interface and query language. This software is a good choice for WRP to manage the databases going forward, or if the GIS Section continues to manage the databases for WRP. Using SSMS meets the user requirement for User-Group 1 of managing the submersible pressure transducer data in an enterprise database, and also tangentially for User-Group 2 by allowing for online editing. SSMS is a long-term, stable database solution, providing data integrity where no formal policy currently exists.

If WRP continues using Access instead of SSMS, SSMS allows for an easy interface between Access and itself. To support and maintain future workflows for WRP maintaining the non-spatial well databases in Access, the SSMS tables and query layers will be linked to Access. This provides for a seamless transition to SSMS, while still taking advantage of the enterprise functionality.

Linking Access to SSMS is a straightforward process that ensures all updates will be reflected in both software packages. In this way, if WRP decides not to seek training to manage the well data directly in tables with SSMS, Access can be used to update data and manage queries for reporting without duplicating data. Alternatively, the GIS Section can manage these databases for WRP as it manages all Water Agency enterprise databases.

3.3.2. GIS Software

The GIS software used for this project is Esri’s ArcGIS Desktop and Server software version 10.3. The desktop software is used to create and manage spatial data and create maps to depict and analyze data. The server software is used to create the map and feature services to display the spatial data and tables in an internet browser such as Microsoft's Internet Explorer or Google's Chrome. The Water Agency uses ArcGIS Desktop and Server to routinely to create maps and web mapping applications both of these browsers.

3.4 Database Creation

Two enterprise databases were created for this thesis project, one database for each groundwater basin. The databases were created using the Import command in SSMS. All tables were imported from Access without error. In addition to the Access well data, the SSMS databases contain spatial data. These spatial data depict the groundwater basins and the planning areas for these two groundwater basins. The spatial data were imported into the SSMS databases using ArcCatalog.

3.4.1. Groundwater Data

There were two Access databases, one for each groundwater basin; Sonoma Valley and Santa Rosa Plain. These Access databases were created and maintained by Baskett at the Water Agency. Baskett has been the primary resource for information regarding these data. These databases were originally nonspatial, housing tables with well information. No features classes representing the wells as points were supplied for this thesis.

Two spatial databases were created in SSMS mimicking the setup of the two original Access databases. Using the same database setup facilitated communication between the author and Baskett in the initial phase of this thesis. All table and field names have been kept static from the original databases. The databases may be consolidated into one overall Sonoma County groundwater database in the DMS. Currently, the SSMS databases are consistent with the original Access databases.

3.4.2. SSMS Databases

After the nonspatial Access databases were imported into SSMS, creating the enterprise databases, some spatial feature classes were added. These feature classes included the groundwater basins and the groundwater management plan boundaries. The wells were created as spatial point data using the coordinate attribute fields. The databases had eight spatial and five nonspatial tables in total. Two query layers were also created, one for each database. These query layers are connections from the well attributes to the spatial wells. Figures 12 shows the initial groundwater database design for the Santa Rose Plain Groundwater Database. Figure 13 on the following page show the initial database design of the Sonoma Valley Groundwater Database.

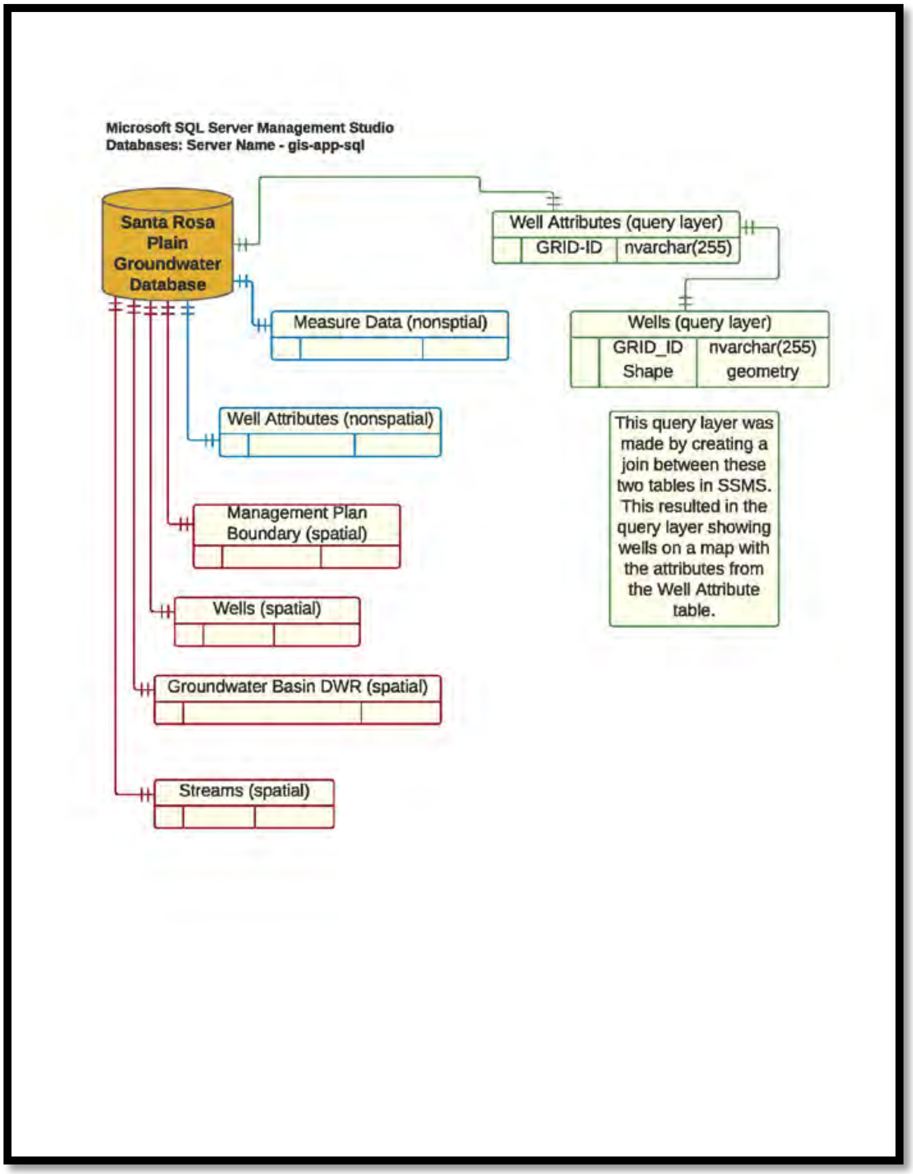


Figure 12 Santa Rosa Plain Initial Database Design. *Source*: Heather Kelley 2016

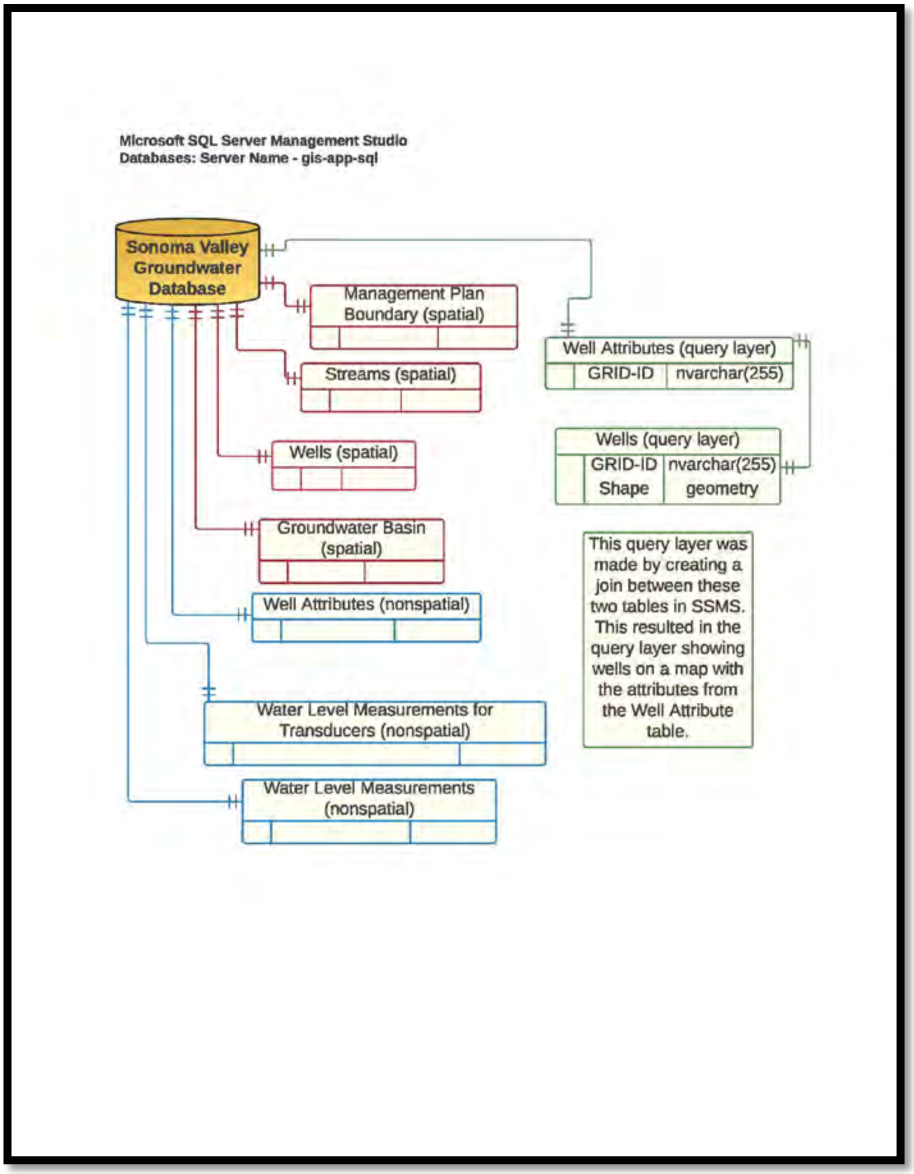


Figure 13 Sonoma Valley Initial Database Design. *Source*: Heather Kelley 2016

The entities in Figures 12 and 13 depict the tables, features classes and the single query layer stored in the Santa Rosa Plain and Sonoma Valley SMSS databases. The entities outlined in blue are nonspatial tables, the features outlined in red are spatial feature classes and the entities outlined in green are the two individual entities that create the Wells query layer. Two figures depicting the database schema in greater detail, such as attribute types of the tables are presented in Appendix A. These more detailed figures show the attribute-types and attribute names in the tables; OBJECTID and integer-type. There are more entities stored in the databases, but these are system tables created by the software when the databases were created and will not be described in detail here.

Initially, the Sonoma Valley database was designed to have two separate tables for water level measurements; transducer and volunteer-based. The Santa Rosa Plain data has these readings combined into one table with no volunteer data in this basin. All water level data for the Santa Rosa Plain is supplied by the Water Agency or other public entities responsible for monitoring the wells; there is no volunteer data for this basin, and no editable web applications were created for it.

3.4.3. Significant Attributes of the Data

The spatial data for this project was used for display in the web mapping applications, no spatial analysis was conducted. One attribute, GridID, was significant for creating relationships in the databases, the other attributes were identified as significant to WRP staff and the volunteers. The Unique ID field for the databases, the GridID, an alpha-numeric field of values generated using a fishnet of 1-mile square grids in ArcGIS Desktop, (Create Fishnet, Data Management tool) (Baskett 2016). Unique IDs are important in relational databases because they allow tables to join together creating more complex relationships to display information.

Unique IDs establish integrity for any database to protect the data from becoming corrupted. An enterprise database system such as SSMS will assign a unique system ID to records in the database, and this unique system ID data was generated when the Access databases were imported into SSMS. However, since WRP has established another unique ID to the wells in each basin using the geoprocessing tool in ArcGIS Desktop, this ID must be maintained and added to in the future if new wells are added to the system.

Another significant field in the tables reports elevation data. Elevation data is used to determine if the water level and the ground elevation are decreasing. Decreasing ground elevation is a response to removing more groundwater from the basin than is replenished. These elevations are monitored over time to determine if subsidence is occurring. This information is significant as it is a part of the required monitoring for the CASGEM program (California Department of Water Resources 2015).

If ground elevations decrease in these groundwater basins, the CASGEM priority will change, and more drastic measure will be taken to manage these groundwater basins. Monitoring elevations in groundwater basins is a good best practice for WRP to maintain as other basins in Sonoma County may be added to SGMA. WRP is currently only collecting and maintaining elevation data for the Santa Rosa Plain and Sonoma Valleys, however, other groundwater monitoring entities in the county may be collecting data for other basins, and this data will be added to the DMS. For consistency, this data must be maintained.

An example of these tables is shown in Table 3, a partial dataset from the Sonoma Valley database. Other fields are significant for the volunteers and WRP staff: Well Name identifies a particular well for the volunteers and Well Depth helps WRP staff to determine the well depth category for the wells. WRP analyzes the wells according to the well depth attribute. The depth-to-water is shown in the table with the attribute name DTW. DTW is the water level reading, and this is the field in the table used to generate the points shown on the hydrographs in the web mapping applications.

Table 3 Sample of Fields and Data from the Well Attribute Table

Well AttrID	GridID	StateID	Well Name	Status	Well Depth	Perf Interval	Depth to Top	Depth to Bot
160	G03-01	007N007W24A	Los Guilicos	Active	622	208-622	208	662
161	G03-02		Pat Hansen	Active	450			
162	G03-03		Jane Ernsberger	Active	215			
163	G03-04		Roger Sanborn	Active	180			
164	G03-05		Rita Nichols	Active	150			
165	G03-06	007N006W19N	Ehle	Active	149	30-149	30	149

The groundwater basin data and groundwater management plan boundaries are stored as polygon feature classes in the databases. DWR supplied the groundwater basin data and groundwater management plan data. These data can be found on the GICMA Application. More layers can be downloaded from the GICMA, however, it will not be necessary to download these layers for display in the web applications as they have been accessed via their representational state transfer (REST) endpoints. The use of REST endpoints was discussed in greater detail in section 3.1.3.1. REST Endpoints are generated in ArcGIS Server when a mapping or feature service is created.

Figure 14 shows the location and extent of WRP-managed wells in the Sonoma Valley and Santa Rosa Plain basins. Also shown are the groundwater basins and management plan boundaries.

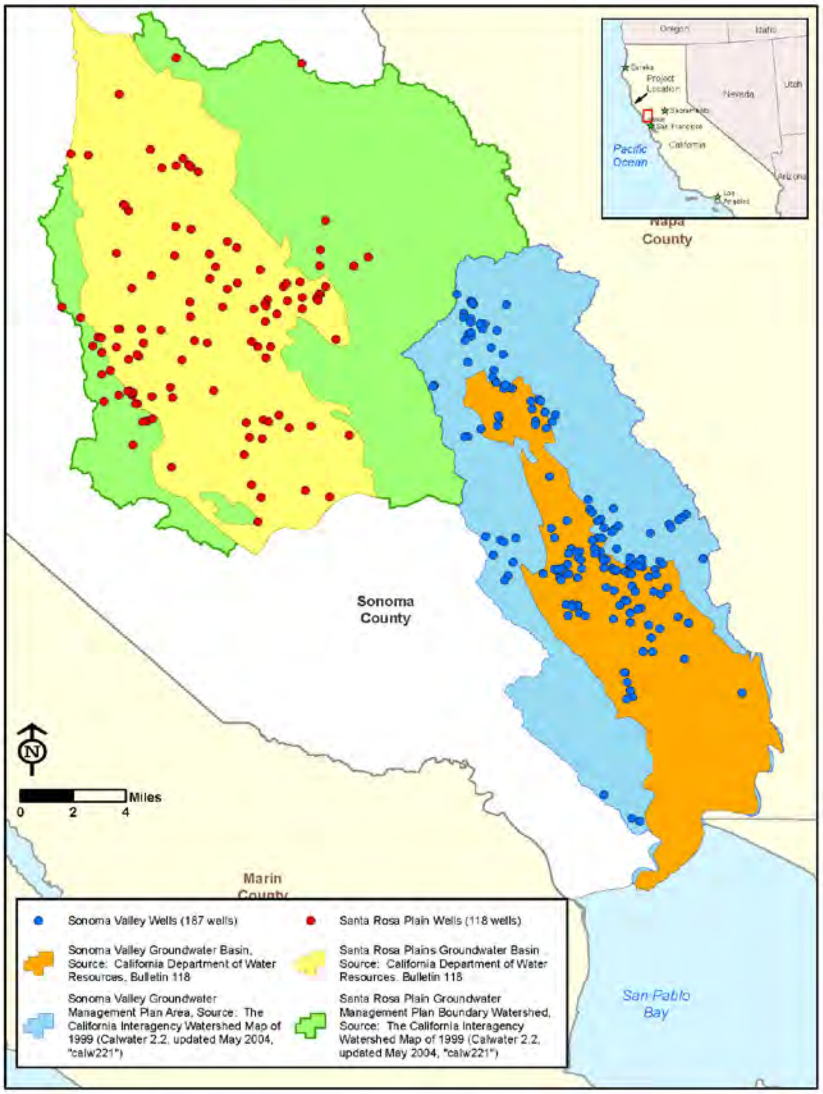


Figure 14 Groundwater Well Data, Groundwater Management Plans and Basins. *Source*: Heather Kelley 2016

3.4.3.1. Query Layers

One of the benefits of using SSMS in GIS is the ability to create and use query layers. In SSMS, SQL commands are used to create query layers. They have traditionally been referred to in SSMS as views. Views or query layers are "logical extractions of specific aspects of the physical database" (Yeung and Hall 2007) and are familiar to any experienced database user. A query layer is the creation of a table that is not a physical table stored in the database, but a temporary connection between two tables. The tables must have a common field with identical attributes; the tables are joined using the common attribute. Esri refers to views as query layers (Esri 2016b), and this is how these data will be referred to hereafter. Figure 15 below shows an example of spatial data, nonspatial data, (a table) and a query layer in ArcCatalog.

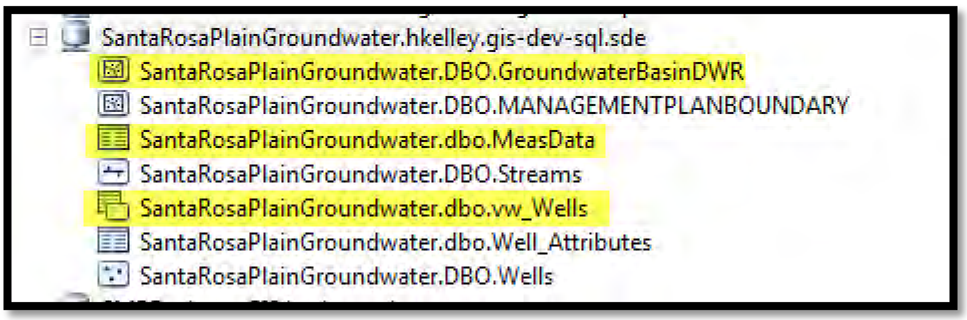


Figure 15 Query Layer as Depicted in ArcCatalog. *Source*: Heather Kelley 2016

In Figure 15 the first highlighted entity is spatial data, a polygon feature class. The icon for this data looks like a polygon and appears just to the left of the feature name, this icon indicates that this feature class is a polygon feature class. The second highlighted feature shown in Figure 15 is a table, nonspatial data. This is a table that has no discrete spatial attribute, such as a coordinate or a geometry, but it can be used in a map by creating a query layer with a spatial feature class in the database. The requirement to create a query layer is that there is a field in this table that has a like field in a spatial feature class. The third highlighted feature in Figure 15 is a query layer. The table icon with a box resting on top of the table indicates that this is a feature comprised of two other features, a query layer.

The SQL query used to create the query layer for the Sonoma Valley wells is shown below:

```
“SELECT     dbo.WELLS.*, dbo.TBLWELLATTRIBUTES.*, dbo.WELLS.Shape AS Expr1,
        dbo.WELLS.GridID AS Expr2, dbo.TBLWELLATTRIBUTES.GridID AS Expr3

FROM        dbo.WELLS INNER JOIN

             dbo.TBLWELLATTRIBUTES ON dbo.WELLS.OBJECTID =
        dbo.TBLWELLATTRIBUTES.OBJECTID.“
```

This query layer was created by opening the database in SSMS, right-clicking on the database Views objects in the Sonoma Valley database and using the command “New View.” The spatial Wells feature class was joined to the nonspatial Well Attribute table using the GridID attribute. This query created the wells that are present in the internal Sonoma Valley web mapping application.

This query layer example depicts one query layer in the Sonoma Valley database, the Wells query layer. The Wells point feature class has no descriptive attribute in the table except for the GridID, which is joined to the GridID in the Well Attribute table. The Well Attribute table has all of the descriptive attributes for each well in the database. These attributes include well name, Perf Interval, Status and well depth. If a new well is added to the database, the only piece of information that has to be collected in the spatial feature class is the GridID and the location of the new well. As long as there is a matching GridID in the Well Attribute table, the feature will exist in the map.

Query layers are powerful tools used to create dynamic connections to specific attributes in the tables of the database. As long as the unique fields are identical in each table the join will work and the query layer will be created depicting the specific attributes in the tables. As data is updated, the query layer changes to reflect this new state of the data. While query layers are not permanent tables in the database but they can be used to create maps and to analyze data. The benefit of query layers is the constant updating of the representation of the data in a web application without the need to create a new, static layer.

A query layer was created for the internal web application to reflect the water level data in the wells by making a connection from the spatial well point data to the nonspatial water level table in the database. The GridID field was used to create this query layer between the tables in SSMS. Query layers can represent more than the water levels in the wells. Other query layers have been created to represent date-based and well-depth-based relationships. Many of these are for testing and to demonstrate to WRP staff what can be accomplished in SSMS.

The SQL for a query layer that depicts the most recent well reading for the submersible pressure transducer wells is shown below:

```
“SELECT     m.GridID, m.DTW, m.Date_Meas, m.WtrElv_DEM, m.WtrElv_USGS1,
    m.WtrElv_JRobb, m.WtrElv_SrvNAD88, m.WtrElv_SrvNAD29, m.WtrElv_JM_Survey,

            m.Qustionable_Meas, m.Currently_Pump, m.Recently_Pump, m.Nearby_Pump,
    m.Comment

FROM       dbo.TBLWATERLEVELMEASUREMENTS AS m INNER JOIN

               (SELECT     GridID, MAX(Date_Meas) AS MaxDate

                FROM       dbo.TBLWATERLEVELMEASUREMENTS

                WHERE      (DTW IS NOT NULL)

                GROUP BY GridID) AS MaxDt ON m.GridID = MaxDt.GridID AND
    m.Date_Meas = MaxDt.MaxDate.”
```

There are several hundred-thousand records in the transducer well-level reading tables and SSMS manages this data quite efficiently displaying the results in seconds. No analysis was conducted with the submersible pressure transducer data, the creation of this query layer was a test to determine if efficiency could be improved using SSMS. The result of this test was that WRP did notice an improved time in the records retrieved from this query.

3.5 Map and Feature Service Creation

ArcGIS provides the user the ability to create online web applications though ArcGIS Server software. This software along with SSMS and Windows Server 2012 allow for the creation of an editable web application. This group of products allows communication through the server software with the Internet to display the web mapping services and applications.

After creating the databases and loading the spatial and nonspatial data into the databases, ArcGIS Desktop was used to create the map and feature services. This is a very straightforward process that only required the necessary hardware and software. Any ArcMap document file (MXD) can be used to create a map or feature service. For this project, four map documents, two map services, and two feature services were created. The map services are for viewing, and the features services allow editing. The two different types of web applications support User-group 1 and User-group 2 with their different needs and requirements.

3.5.1. Mapping Services – View-only Web Applications

The first type of web mapping applications created include view-only web applications for WRP internal staff. No security or special permission is necessary to view these web maps, and they can be exposed to all WRP staff for their viewing and basic visual interpretation. The process for updating and modifying these web mapping applications is informal, and minor changes may occur as WRP staff recognizes other layers to add.

In the view-only web applications, there are more layers available to WRP staff than the volunteers have present in their editable web applications. WRP staff is comfortable viewing spatial data in web mapping applications, so there is no concern of too many layers confusing or overwhelming this group. WRP will not be editing the data in the web applications, so there was no need to allow them access to the feature services. Creating non-editable web applications decreases the chance that the water level data that is editable in the volunteers' application will be accidentally edited. There may be more modifications to these internal web maps over time; more layers added and removed, so it is a good idea to create separate maps for this group.

The decision to make two types of web applications comes from understanding the two disparate groups have different needs and expectations. The edit-group needs to see only the data that is relevant to them, data they need to edit. The view-only-group requested to see more data, and they will not be editing data in the web applications. As these uses are so different, it is a safer choice to not co-mingle these two groups in web applications.

3.5.2. Feature Services -Editable Web Applications

The volunteers have the ability to edit the data in the enterprise databases directly via the web applications. These web applications are feature services which are editable web applications whereas mapping services are for viewing only. Creating feature services in ArcGIS Desktop allows users access to the data in an enterprise database via a web application. To create an editable web application, the feature service radio button must be selected when the service is created in ArcGIS Desktop, and the enterprise database has to be a versioned database. Setting a database to be versioned is also a straightforward process, these databases were set to be versioned using ArcCatalog.

ArcGIS Server software also allows for security through server authentication. Each user has a login and a password generated for them. New roles and users were added to the server store for each volunteer, named Ed, and Kathy. Each user was given a password and permission to access the data through their role in ArcGIS Server. Each user will edit the records for their wells in the SSMS table that is part of the query layer exposed in the web application. This query layer is named SonomaValleyGroundwater.dbo.vw_Wells and the Where clause is used in separate MXDs for each source; Ed or Kathy.

The data that the volunteers have access to is sensitive, so they need to use passwords to ensure that they are the only person viewing and editing the data via the web application. The volunteers are only editing three fields; DTW, Date and potentially Comment if they need to add a comment. Two query layers were created, one for each user. Each volunteer only views the wells that they monitor. This simplifies the editing process and the map-view for each volunteer. They see only their wells and a base map for context. As this is a new method of entering their water level data, it has been created to be a simple interface.

3.6 Web Mapping Application Creation

After a mapping or feature service is created, these services can be displayed in a web mapping application by referencing their service URL in an application program interface (API). Once a service is referenced in an API, this service is viewable in a web browser. Depending on the API various tools will be in the web mapping application for users. There are many APIs available to developers, so this section presents a relevant use case for the API used at the Water Agency and for this project.

3.6.1. Web Application API

An API is a set of routines and tools for building software applications, sets of code to help create web and software applications. The Esri JavaScript API was used for this project to create web mapping applications. This API allows developers to embed maps in web pages using JavaScript as the interface between the browser and the viewer. The Esri JavaScript API has all of the building blocks to make a spatial web map function like an ArcGIS Desktop map document; zoom-in and zoom-out tools, identify tools, a print tool, a legend tool and a base map switcher to allow the web map viewer to switch between a series of base maps that Esri provides for use in web mapping applications. Base maps are displayed behind the main data, in this case well and groundwater data to provide context.

For this project, The Configurable Map Viewer (CMV) code, Version 1.3.4 was used to support the web mapping applications (CMV - The Configurable Map Viewer 2016). This code and development tools work with Esri mapping and feature services. The Water Agency is using CMV for all of its web mapping applications, thereby ensuring that this project is consistent with all other Agency applications. The mapping and feature services are displayed in the CMV mapping framework using the Esri JavaScript API and the Dojo Toolkit. The CMV can be downloaded for use from the website GitHub (2016).

The CMV provides an intuitive application "wrapper" for web mapping applications. The Dojo Toolkit is a modular JavaScript library of tools for use in a web mapping applications. Both CMV and Dojo are open source frameworks so while they are freely available, they do require development to make them run properly. Tim McGee is the President of MoosePoint Technology in Santa Rosa, California, and provides the development expertise required by the Water Agency. The Water Agency is currently using this CMV for all internal and external web mapping applications. To keep the workflow consistent with Water Agency standards, this code was used for this thesis project.

To maintain consistency with existing applications at the Water Agency, the CMV was chosen for developing this project. Esri Arc GIS Online (AGOL), Web AppBuilder or WebApp Studio for ArcGIS are a common choices for Esri customers. However, the Water Agency has already chosen CMV over AGOL due to the relative ease with which this API can be implemented. For example, web applications created using the CMV have shorter and more intuitively named URLs whereas the AGOL URLs can be very long with alphanumeric naming conventions that are not intuitive and difficult to remember for general staff.

Chapter 4 Results

Chapter 4 outlines the preliminary results of this thesis project and shows screen-shots of the editable and view-only web mapping applications that have been developed. In addition to the web mapping applications which are the main product, the results of volunteer-testing on the editable web applications are reviewed. Finally, the spatial accuracy of the well data and the accuracy of the volunteer well-reading data are discussed.

4.1 Web Mapping Applications

Four web mapping applications were developed for this project: two for viewing and two for editing. The two view-only web mapping applications, developed for each groundwater basin, Santa Rosa Plain and Sonoma Valley, were created for WRP staff to view groundwater data. The two editable web applications show subsets of the Sonoma Valley data, and these were developed for use by the two Sonoma Valley volunteers, Ed Nelson and Kathy Pons. These volunteers gave interviews and tested these web applications.

The hydrograph tool was developed by Tim McGee to display the water level data in the web application as a chart. The hydrograph chart opens in a second web page. McGee developed this tool after the development of editable and view-only web mapping applications were completed for this thesis project. The creation of the hydrograph was considered to be critical for successful project implementation. The hydrographs are generated dynamically through a button-click and depict the water level measurement over time for each well. Creating the hydrographs in the web mapping application provides immediate feedback for WRP managers that relied on technical staff to manipulate the data in Excel for hydrograph production.

4.1.1. Non-Editable Web Mapping Applications

Figure 16 shows a screen shot the Santa Rosa Plain Groundwater Basin view-only web application developed using CMV. Figure 17 on the following pages shows a screen shot for the Sonoma Valley Groundwater Basin. The REST Endpoint layers from external public agencies (DWR and USGS), appear as a sub-category on the left in the Table of Contents under the title "USGS Stream Gages" and "DWR GICMA Layers."

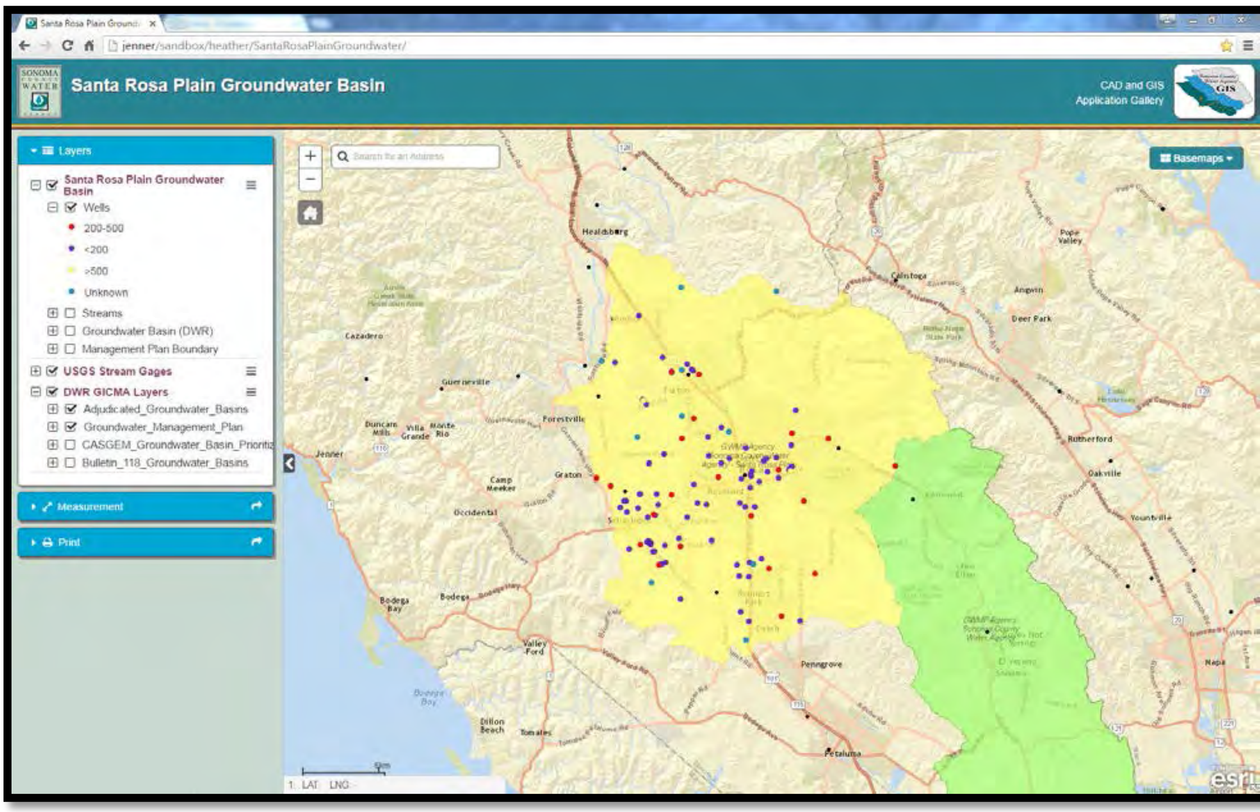


Figure 16 Standard Groundwater Web Application Santa Rosa Plain. *Source*: Heather Kelley 2016.

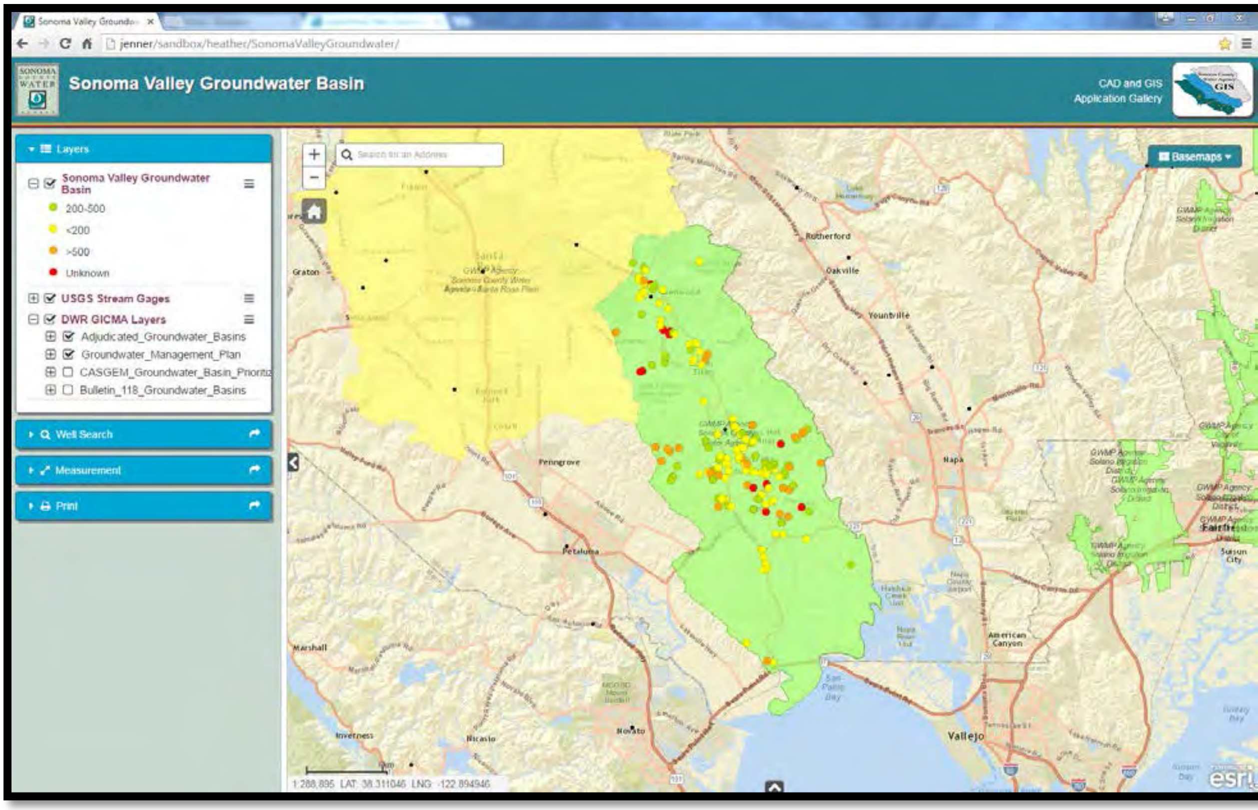


Figure 17 Standard Groundwater Web Application Sonoma Valley. Source: Heather Kelley 2016.

The wells were symbolized using the well depth attribute in the legend tool to the left. There are several elements that are standard in the CMV that can be seen in Figures 16 and 17 such as the Basemap Switcher tool in the top right of the application, the Table of Contents element, titled “Layers” lists all layers in the web application. The symbology on the map and in the Table of Contents comes from the symbology as created in the ArcMap Desktop MXD.

There is a Measurement tool allowing the viewer to measure either distances or areas and the units (meters or feet) can be specified interactively from the tool. A print tool allows the user to print the on-screen display to a PDF or a physical print to a printer device. Addresses can be found in the search tool at the top, and the home key under the plus and minus sign returns the display to the original extent the web mapping application originally opened.

With regard to these web mapping applications meeting the user requirements for User-Group 1, WRP expressed to the author that the dynamic creation of hydrographs was much improved from the previous method. Baskett was the WRP Staff person most often required to create the hydrographs for management. Baskett mentioned that he has noticed a significant drop-off in hydrograph-creation requests. This user-requirement was successfully fulfilled.

The internal, view-only web mapping applications demonstrated to WRP new capability for their groundwater data using GIS. These web applications also facilitated internal communication regarding the groundwater data via the dynamic hydrograph creation. While improved internal communication was not an identified user requirement, the results of improved communication for this project has been impressive to WRP managers.

The testing of querying the millions of submersible pressure transducer records seems to have been successful. Unfortunately, no previous records were kept regarding these queries using Access, so this is mostly tangential information. Baskett thought that SSMS was able to return the records more quickly than Access has. The author has not tested running these queries in Access vs. SSMS at this time, no tests are currently planned.

The user-requirement determining the successful presentation of new GIS-techniques to WRP has been informal. A debrief meeting was held with WRP Staff, the author and Tim McGee. During this debrief meeting WRP Staff mentioned that they were impressed with the volunteer-feedback and the results of the internals web applications and hydrographs. Currently, GIS Division is involved with the planning for the DMS but no specific plans have been developed. The goals for this user requirement were accomplished. WRP is talking about implementing the DMS using the techniques and tools presented in this thesis.

Creating the enterprise databases that allows for online editing took less than one business-day, web application-creation took less than one day. The greatest time involved for this process was retrieving the data from Baskett and creating attractive maps. This step also took less than one day. All user requirements for WRP were implemented successfully and affordably. For a government project, this is important.

4.1.2. Editable Web Applications

The editable web applications each used a definition query in ArcGIS Desktop MXD, one for each volunteer. The source column was used to create the definition query for Nelson and Pons to add their water level data to the feature service. The definition query was used to simplify adding data, as both Nelson and Pons monitor several wells it is easier for them to open a web mapping application that only has the wells they are monitoring present in the web app.

Figure 18 shows the editable web mapping application interface for Pons' data, Figure 19 on the following page shows Nelson's data.

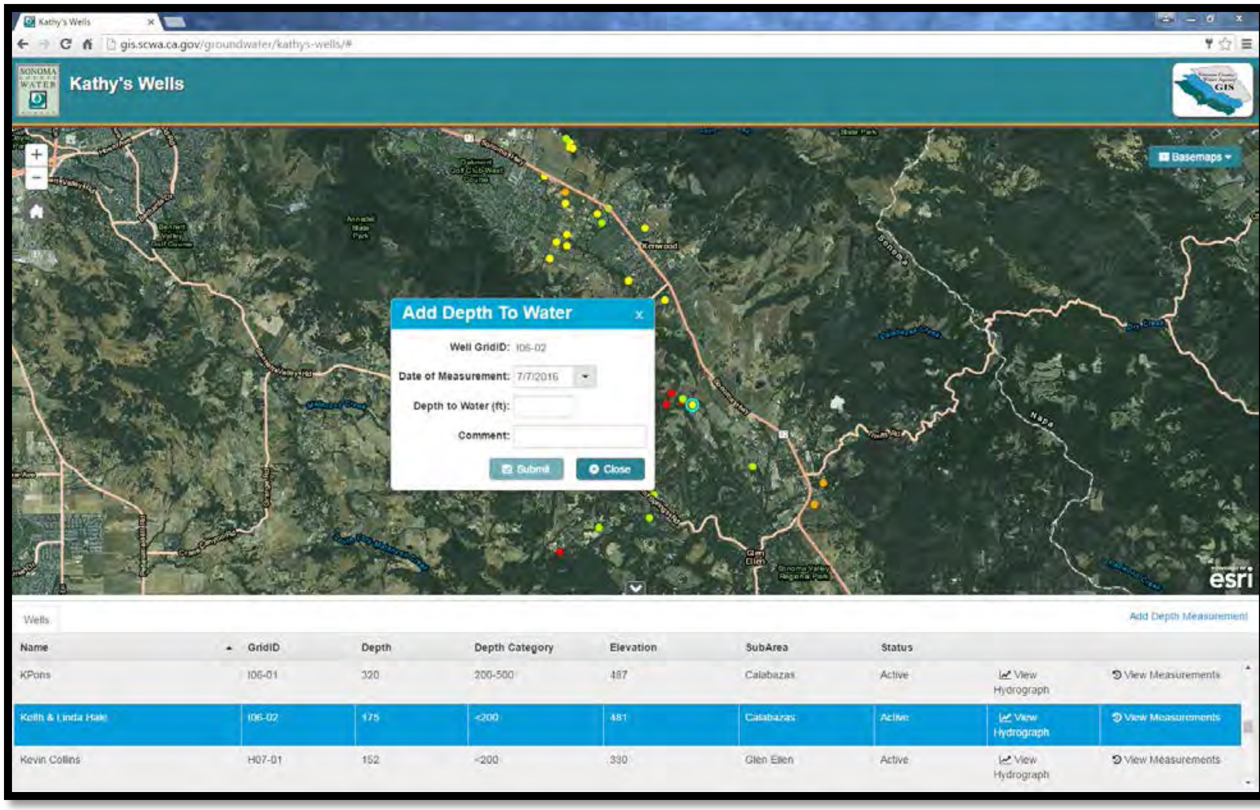


Figure 18 Pons Web Mapping Application Interface. Source: Heather Kelley 2016.

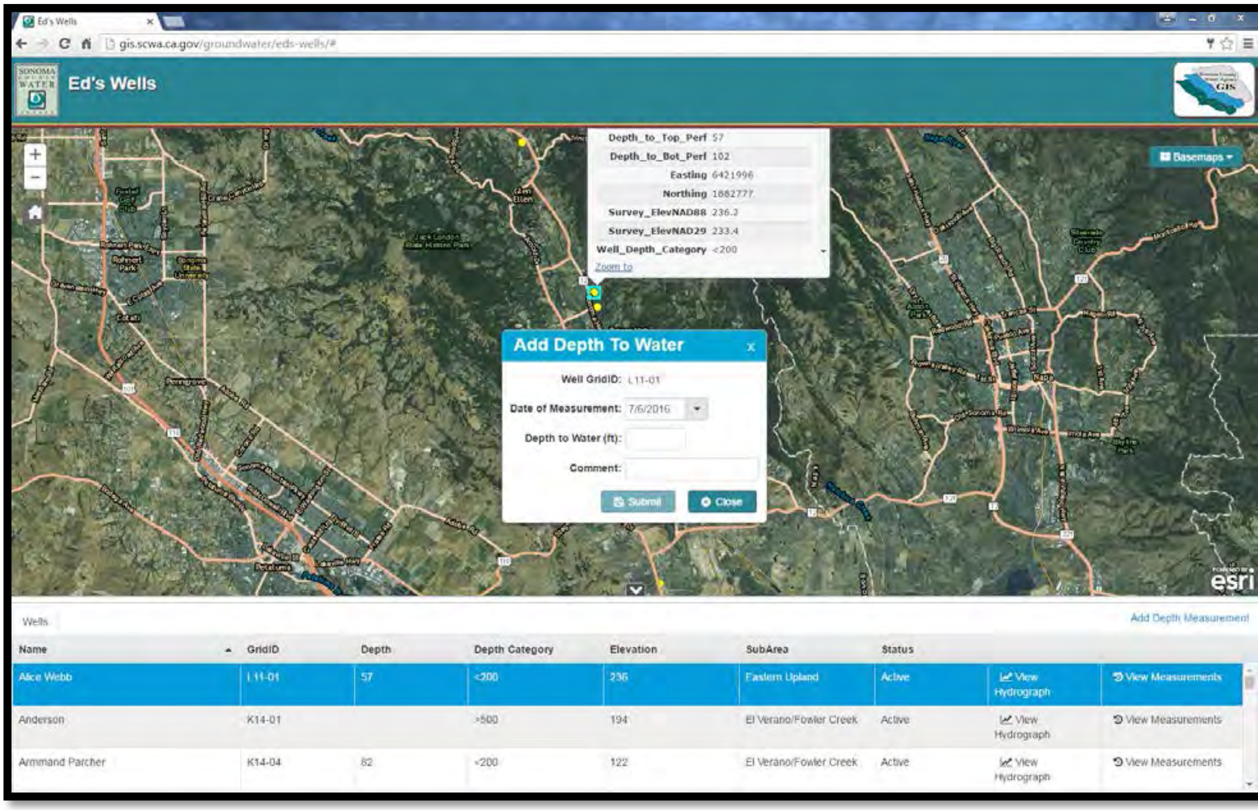


Figure 19 Nelson’s Web Mapping Application Interface. *Source*: Heather Kelley 2016.

Each volunteer can edit a specific well record by locating the well in the table or on the map. The tables can be sorted by any attribute column, in ascending or descending order by clicking on the column name. Currently, the volunteers report that they sort the well data using the GridID and locate the well they intend to update. The volunteer clicks a record in the table and a second smaller window appears where they add their data in the table, seen in Figures 18 and 19.

Alternatively, the user can pick the well from the map, but this is a more haphazard method for editing data. There are only three editable fields in the table: Depth to Water, Date, and comment. The comment field is necessary because there may be something precluding the volunteer from accessing the well such as a locked gate or a dog.

When the user has completed entering data for the session they simply close the page, there is no log out button. After the user has entered their well reading information to the database, they can send Baskett an email informing him that they have conducted their monitoring activities for this season. Baskett can check the database to see if the values are entered correctly.

The feedback from the volunteers suggests that communication between the volunteers in Sonoma Valley and WRP Staff was improved with the editable web applications. The volunteers were able to assess the water level data, determine that they had successfully added new data and verified this through both the hydrograph and the tabular display at the bottom of the user interface. Both Nelson and Pons described their user-experience as positive and thought the web application was intuitive.

The typically emails sending data between WRP and the volunteers were not sent, an email notifying WRP that the volunteers had added their data was sent. Both WRP and the volunteers could tell that the web mapping application worked as designed. Both user-groups could see that data had been added. Both volunteers also expressed a desire to use the web applications in the fall.

4.1.2.1. Testing the Editable Web Applications

The last phase of this thesis project involved the volunteers testing the web applications. Both Nelson and Pons were able to test the web application for adding water level data to the database via the web applications. They were each sent a unique URL to their own individual web mapping application, with their subset of data and user instructions via email. In order to determine if the web mapping applications improved efficiency for the volunteers, it was necessary for them to view and test the capabilities of the application.

The well volunteers were able to log in to the server using their individual user name and password. Once the volunteers were able to see the maps with their subset of data, they followed the instructions provided via email. The volunteer picked the current date from a date-picker interface and added their current water-level readings in the Depth-to-Water field in the table. They did not test the comment field.

Nelson was able to add his data and mentioned in an email that is was intuitive and easy to use. Pons also entered some test data and found the web application interface to be easy. She also enjoyed viewing data on the map. Both users mentioned in emails that they thought seeing the dispersion of their wells in the map was helpful to understand where they are monitoring in relation to the basin boundary. Both also tested the hydrograph tool developed by McGee of Moosepoint and found that tool to be helpful also.

These two volunteers were willing to test the web mapping application for usability and to provide the author with some feedback regarding their participation in the volunteer program. Their willingness to test the web applications and give interviews is an additional testament to their desire to contribute to the process of monitoring the resources of the groundwater basin.

The interviewing and web application test provided feedback to the author to know if the site is working as expected, how the volunteers like the web mapping interface and if changes are needed to make the web mapping application interface more user-friendly. This information was very valuable and could not be gained in any other way.

4.1.4. Spatial Accuracy of Well Data

The locational accuracy of the well points varies depending upon their origin. The wells that are monitored by the Water Agency via pressure transducer have been surveyed and are of the highest quality, survey accuracy. The other public agencies monitoring wells in Santa Rosa Plain and Sonoma Valley have captured their wells using a GPS unit or a survey station. For these wells, the spatial accuracy should be high. If a sub-meter post-corrected GPS unit was used by the monitoring entity, the location of the wells will be accurate to within a meter or less.

The volunteer wells are of varying accuracies, the locations of these well were digitized in the GIS. The source of the digitized wells is not known as there was no metadata provided by WRP. If the volunteer wells were captured with a GPS unit, the GPS units used by the volunteers were recreation grade. The accuracy of these measurements is accurate to about 10 meters or approximately 30 feet. The source information is stored in the "Surveyed" columns in the tables: SantaRosaPlainGroundwater.dbo.Well_Attributes and SonomaValleyGroundwater.dbo.tblWellAttributes.

Figures 20 on the following page depicts this locational accuracy of the wells in the Santa Rose Plain basin. Some of the wells have been surveyed, but many of the wells have been located using a GPS unit or had their coordinate information generated by some other method, as discussed above. Figure 21 on the following page shows the Sonoma Valley plain accuracy. Figures 20 and 21 show the varying accuracies in the well location data across the basins.

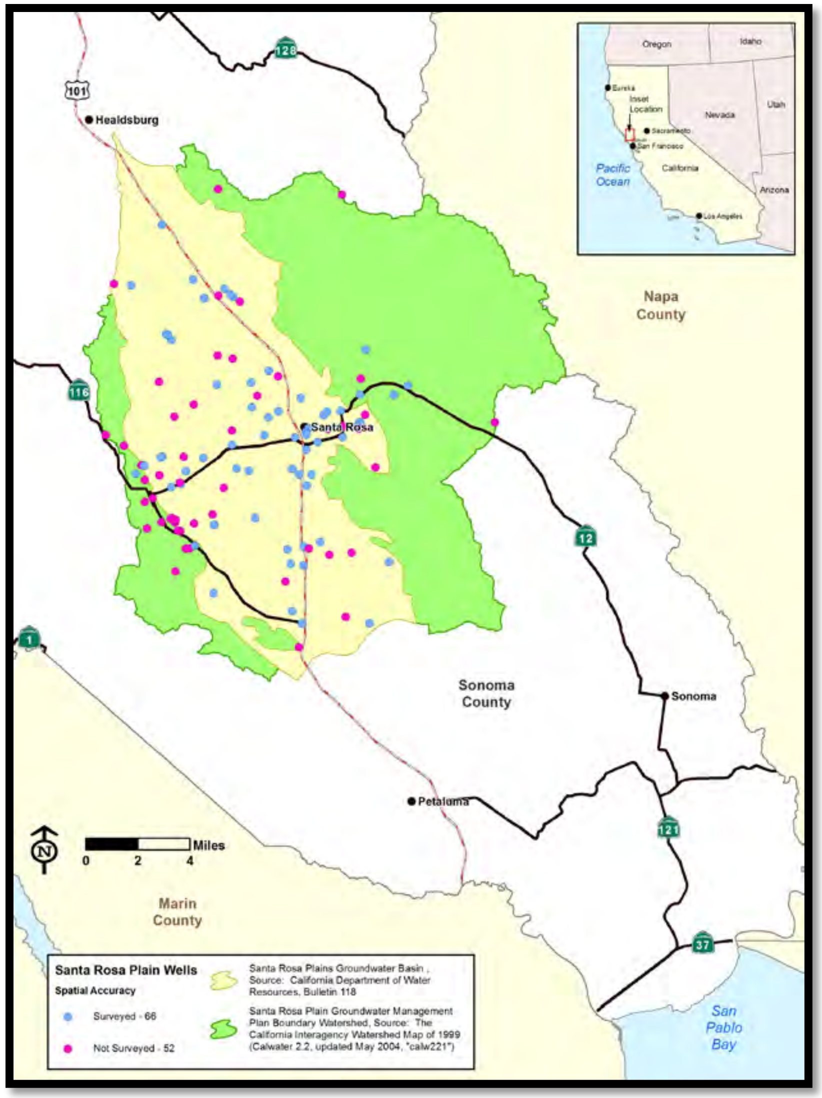


Figure 20 Santa Rosa Plain Well Accuracy. Source: Heather Kelley 2016.

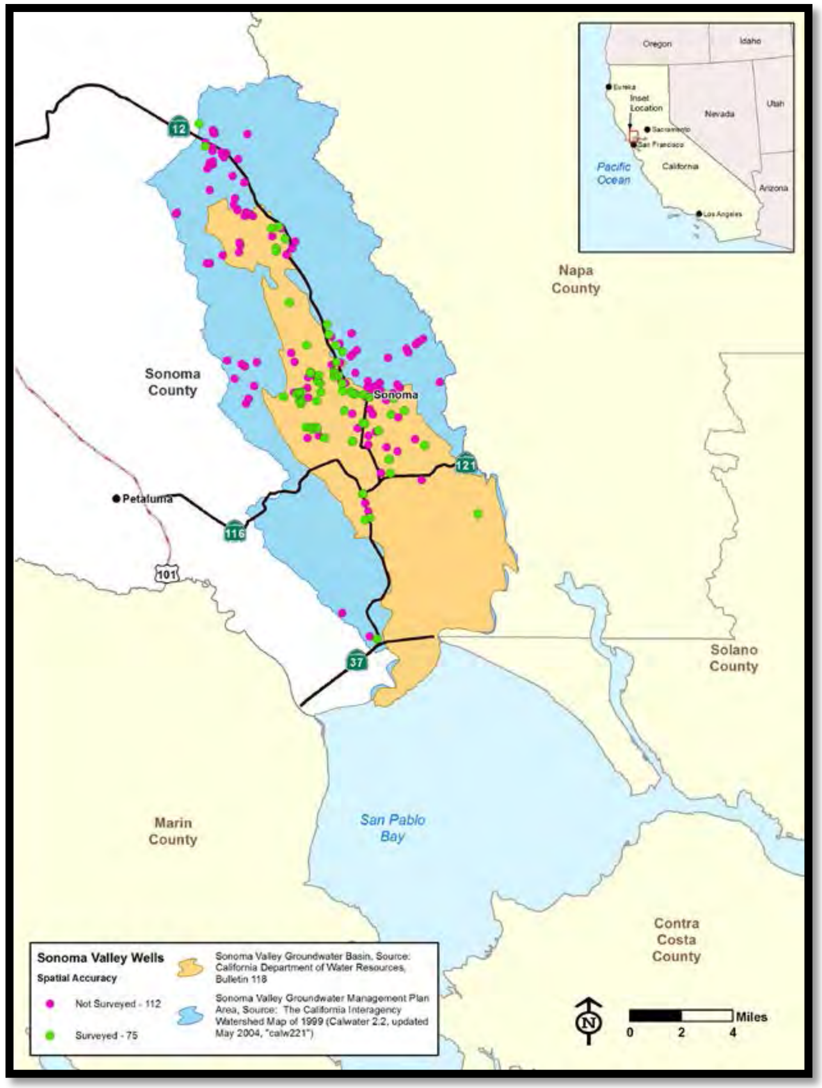


Figure 21 Sonoma Valley Well Accuracy. *Source*: Heather Kelley 2016.

From the surveyed data, it can be seen that approximately 56% of the wells managed by WRP in Santa Rosa Plain have been surveyed and 44% have not. In Sonoma Valley, the percent surveyed is 40%, while approximately 60% of the wells have not been surveyed. This information makes the location of the wells questionable, as only a relatively small percent have been surveyed, but the locational accuracy of the wells might not be critical.

Dan McManus, Supervising Engineering Geologist for the Sustainable Groundwater Management, a section of DWR, stated that the groundwater basin data provided by DWR has an accuracy of approximately 2,600 feet (Dan McManus, March 15, 2016, email message to author). This is not considered to be high-level accuracy, but this is the state-vetted dataset and it is the dataset that SGMA will use to determine if individual well owners are inside or outside of a particular groundwater basin. According to Dan McManus, better data will be available by 2020. Until that time, this is the groundwater basin that will be used for this thesis project.

The spatial accuracy of the wells is better than the spatial accuracy of the groundwater basin data. As a result, this report suggests that the accuracy of all of the wells will be sufficient for this thesis project and further analysis. Whether or not a well is accurate to within 30 feet will not change the effect the well has on the groundwater basin. The volunteer-supplied water level measurement data itself is the most significant piece of information.

4.1.5. Accuracy of Volunteered Water Level Data

Determining the accuracy of the volunteer water level readings is difficult. To determine the accuracy of these reading the volunteers' monitoring methods have to be considered as well as their motives for conducting these monitoring activities. These two aspects of the volunteers' monitoring protocols can be assessed to determine if the data these volunteers share with the Water Agency can be included for use in the GSPs and any other official groundwater work or analysis going forward in the SGMA process. If these data are valid, these data will be one component to support the management of the groundwater resources in these two basins.

The best source to determine the validity of the volunteers' monitoring methods is the community of groundwater science professionals. Both Nelson and Pons were trained by groundwater professionals to use the methods they employ for groundwater monitoring. During their interviews Ed and Nancy mentioned the training they received to become groundwater well monitors. As the methods themselves are valid, a secondary consideration is that Ed and Nancy may be operating the equipment incorrectly.

The only test for this parameter is if the results are wildly out-of-the-range for the normal and expected groundwater measurements. So far Baskett and others who examine this data have not identified any erroneous readings. The volunteer readings can be compared to readings that come from other sources monitoring groundwater data in the basins to determine if they are correct. Alternatively, a verification protocol can be developed and employed by the Water Agency or another monitoring entity to determine if the volunteer measurements are accurate.

The final consideration of the volunteers' accuracy is the motives for their involvement with the program. After the interviews with the volunteers, their motives seem to be well-intentioned. Both Ed and Nancy expressed an interest in preserving the groundwater resources of their basin. Citizens of the groundwater basins have the most to benefit or to lose if water quality or levels fail. If mandated monitoring of the water level data is required due to decreasing water levels and water quality this would also be an unfortunate outcome. The volunteers would longer no longer be given a choice whether or not to participate, rather they would be mandated to do so. This could create a potentially antagonistic relationship between government agencies and private citizens.

The current Sonoma Valley volunteer program is the result of citizen science in Sonoma County. Initiated by a few interested users 65 years ago, it would be nice to understand why these original well-owners decided to freely offer their water level data all those years ago. However, none of the original volunteers who began volunteering this data are available to determine why they began this effort. As this information cannot be obtained directly from them, understanding why the current volunteers gather this data and share it with the Water Agency is an important component of this thesis. If a motivation for this volunteer service can be established, this information may shed light on the best way to attract new volunteers.

The volunteers currently send their water level data freely to the Water Agency have a genuine interest in understanding the water levels in the groundwater basin where they live. This interest motivates these contributors to collect data and support research to understand more about a place and the resources of this place (Budhathoki and Haythornthwaite 2012). Some of these volunteers have been sharing their data for many years, and at this point have developed a "reputation" of reliability among their volunteer peers and with the professionals at the Water Agency (Maué 2007). They want to submit accurate data about their water-level information to protect this reputation and remain involved in the volunteer program.

This thesis project is a scientific project and as such, examination of the value of this VGI, the water level data provided by the volunteers, from a scientific perspective is essential. Scientific data is traditionally expensive and can be challenging to gather. Additionally, acquiring scientific data spanning many decades would be very hard to come by and again, expensive. The time-range for the volunteered well data is substantial, covering over 60 years of data collection. For the purpose of understanding the long-term water levels in these two groundwater basins, this volunteered data can be considered unique and important enough to warrant its inclusion in this thesis project (Longhorn, Blakemore 2008). The VGI for this project is valuable, since it is a unique contribution and a necessary source of data for this project.

Chapter 5 Future Work

Chapter 5 describes proposed future modifications and additions to the web mapping applications, and suggested changes as provided in the feedback from the volunteers. Changes are planned for this project to prepare for SGMA implementation, and plans to assist WRP implementation of the DMS using SSMS databases to manage the well data. Finally, the ongoing management of the system as developed and potential projects outside of Sonoma County are considered.

5.1 Volunteer Suggested Changes

After Nelson and Pons had tested the web mapping applications both users had suggestions to modify the web maps for future use. Pons suggested giving the user the ability to edit the location of a well as she noticed that some of her wells were not in the correct location. Pons also thought it would be better if there were a logout button to end the session securely. She wanted to modify the name of a well and definitely wants to use the web application in the future as her method to add water level readings.

With regard to Pons, a desire to edit the well location and other attributes in the table was presented, and this is an issue that will need to be addressed with WRP. These are good suggestions from Pons, but it questions the validity of WRP's data. As they have been the stewards of this data until this time, they should be consulted before the data is modified. And perhaps it should be considered how they manage the data going forward. Inherent errors need to be removed or changed before outside editors such as the volunteers become involved in editing the data.

Nelson also found data that he thought was in error in his web mapping application. He wanted to add a new well and delete a redundant record. He also recommended edits for the hydrograph, such as plotting water surface elevation instead of water depth. Rename elevation to reference surface elevation; subtract water depth from reference surface elevation in the database to get water surface elevation.

Ed mentioned coloring the points from the spring reading differently from the fall reading. Currently, both are the same color. Figure 22 shows the current hydrograph display.

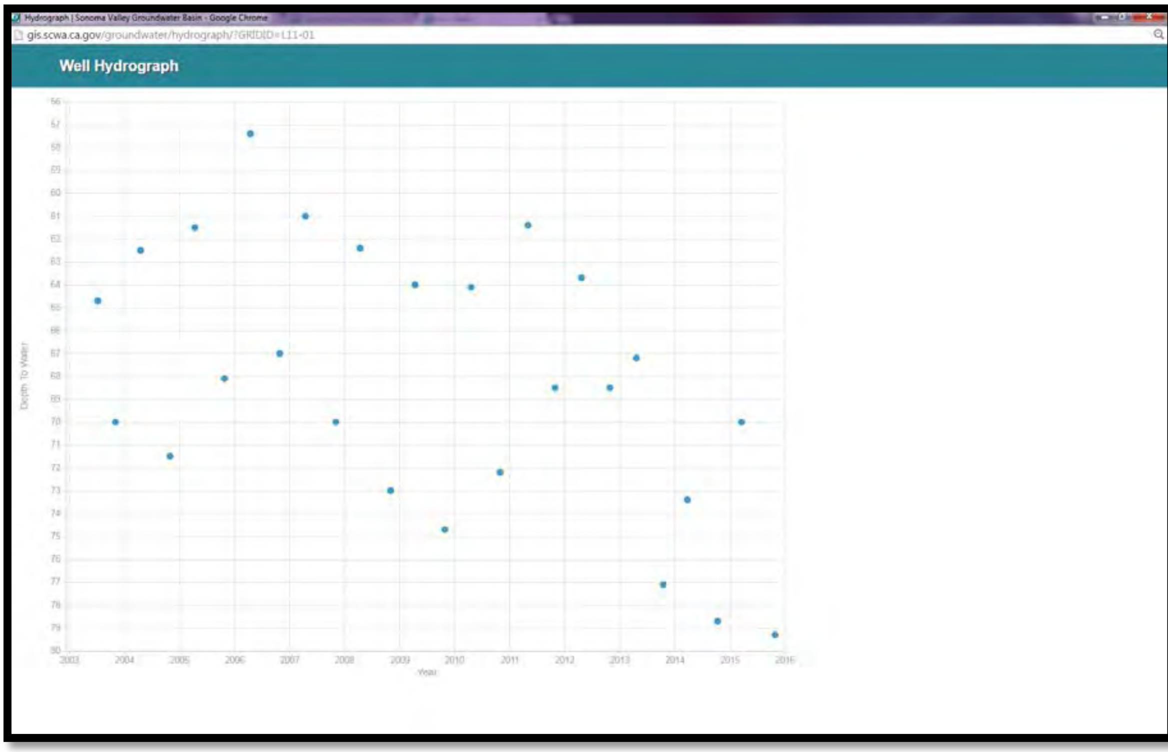


Figure 22 Hydrograph Display. *Source*: Heather Kelley 2016.

Nelson mentioned that he found this method to be very convenient and would like to use it again in the fall. He thought it would be helpful for his analysis as he could easily access water surface elevation data and hydrographs. The responses from my web application testers indicate the web application development was successful. This will be a better way for the volunteers to enter their water level data. Communication between WRP and the volunteers has definitely been improved, evidence of this are the requested changes by the volunteers to the editable web mapping applications.

WRP Staff tested the view-only web applications and thought they were impressive. They are curious about adding REST Endpoints for weather data and appreciate the convenience of the dynamic hydrograph-creation from the web applications. This will save them time and allows them to run quick analysis in the web applications. WRP staff would also like the points in the hydrograph changes for each season, spring and fall. This is currently under development by McGee.

As previously stated, there was no formal speed test for queries on the submersible pressure transducers performed in Access vs SSMS. However, informally Baskett has reported that he thinks the queries execute more quickly in SSMS. The stability of the database system is improved as SSMS is a more appropriate repository for these records. In the future, more records will be added to these tables so this is a more stable place for these data to reside.

5.2 Changes to Prepare for SGMA Implementation

One important aspect of this project is to prepare the well data and to change the procedure that WRP use to manage the well data in preparation for the DMS. As SGMA defines the management of groundwater resources in the local basins and across the state, the methods used to manage the data must become more sophisticated.

The DMS will require the public as well as other monitoring entities in the county to be able to access, share and analyze data collaboratively. Each GSA will work together, with other GSAs in the county to manage these data and develop policies that support the groundwater resources of the county. WRP will need to manage the data using tools such as SSMS and perhaps a cloud environment to support the public access element.

No longer will WRP be able to work in a data silo, all of the groundwater data that they manage, will be the collective data of the GSA. So their methods and tools will need to change. This thesis project was a good first step. All of the groundwater data that WRP manages has been moved into an enterprise database. They now have web mapping applications to allow outside entities, the volunteers to share data and communicate collaboratively with them. Now WRP must try new techniques to work with their data. The first technique will be loading data from the transducer wells into SSMS.

Baskett will attempt this as he routinely works with the transducer data in Access. A connection from Access will be made SSMS database so that he can use familiar methods to add the new transducer data. The author will work with Tim McGee to see if there are other methods that might streamline the process more, for example, adding the *.mon files directly to SSMS.

Another proposed improvement is to automate the data retrieved from the submersible pressure transducers. These readings were retrieved from the wells at the well locations by Water Agency Staff and were exported from the transducers in *.mon file format. These readings were then manipulated and converted into *.csv file format. These Comma Separated Values (CSV) files were then imported into the Access database. Research is ongoing to determine if SSMS can automate this process, perhaps a native *.mon file can be imported to SSMS, increasing efficiency. The rest of the wells monitored by other monitoring entities email their readings to Baskett.

5.2.1. Ongoing Management of the System

To maintain the system developed in this thesis training must be explored to allow WRP to manage the system. WRP must understand Relational Databases and how to use them for the DMS even if they themselves do not perform this maintenance. A data integrity policy must be developed to protect the data stored in the DMS. As developed, the Water Agency GIS Division can support the existing system. The ongoing maintenance will include a continuing support structure for WRP provided by the GIS Division.

One component of the DMS's mission is data-sharing with outside entities, and receiving data from outside entities, there is no infrastructure at the Water Agency to accomplish this. A cloud-computing solution may be pursued in the future. If this is the final repository for the DMS and all of the data, an outside consultant will be hired to continue this maintenance.

The REST endpoints that are used from outside entities must be maintained for the web applications to function. If the DMS moves to a cloud computing structure, the consultant that maintains the system will determine how to ensure these REST endpoints continue to function. Currently the author is exploring all options to see if a script exists that will determine if a REST endpoint has been moved from the original location or has not been maintained. If such a script can be found, it will be added to the current system.

5.3 Future Development in Sonoma County and Beyond

Considering that SGMA implementation is underway in Sonoma County, this thesis project can provide some benefits to this implementation. As previously discussed, Figures 10 and 11 depict the sources of well information for Santa Rosa Plain and Sonoma Valley. There are more public entities involved in monitoring Santa Rosa Plain than in Sonoma Valley. Both basins have a varied well monitor pool to pull from. With regard to the development of the GSA for these basins, currently untapped resources could be utilized.

The expansion of the volunteer pool might occur as other residents in this basin learn about the web mapping application for well data input. Additionally, the Santa Rosa Plain may use the web mapping application to attract volunteers as there are currently none in this basin working with the Water Agency. The availability of public entities is encouraged through the existing SGMA process so it is unlikely that new public agencies will become involved with the process due to the development of the web mapping application alone. However, the DMS and enterprise databases could become a shared resource for the Monitoring Entities in Sonoma County to collaborate. The web mapping applications and enterprise databases may be moved to a cloud environment to facilitate data-sharing.

Lastly, perhaps other entities in the state would be interested in conducting a project like this one for at-risk groundwater basins. Sonoma County has relatively healthy groundwater resources, comparing the resources in the Central Valley and Southern California using the GICMA web map this is clear. Many of the groundwater basins in the Central Valley and Southern California are high priority according to CASGEM. Surely these basins could benefit from a GIS and enterprise database to help manage these groundwater resources if none currently exists.

REFERENCES

Bishr, Mohamed and Mantelas, Lefteris. 2008. "A Trust and Reputation Model for Filtering and Classifying Knowledge about Urban Growth." *GeoJournal* 72 (3/4): 229-237. doi:10.1007/s10708-008-9182-4.

Brown and Caldwell, 2016. "Draft 2015 Urban Water Management Plan." A report prepared for the Sonoma County Water Agency.

Brown, Edmund G. 2014. Governor's Signing Message. State of California.

Budhathoki, Nama R. and Haythornthwaite, Caroline. 2012. "Motivation for Open Collaboration Crowd and Community Models and the Case of OpenStreetMap." *American Behavioral Scientist*. May 2013 57(5): 548-575. doi: 10.1177/0002764212469364.

CMV - The Configurable Map Viewer. 2016. "Home Page." CMV website. Accessed August 27, 2016. http://docs.cmv.io/en/1.3.4/.

California Department of Water Resources. 1992. "1992_AB3030_Summary_02202014.pdf." 1992 Assembly Bill 3030 (AB3030) website. Accessed June 19, 2016. http://www.water.ca.gov/groundwater/docs/1992_AB3030_Summary_02202014.pdf

———. 2002. "2002_SB1938_Summary_02202014.pdf." 2002 Senate Bill 1938 (SB 1938) website. Accessed June 19, 2016. http://www.water.ca.gov/groundwater/docs/2002_SB1938_Summary_02202014.pdf.

———. 2003. 'California's Groundwater Bulletin 118 Update 2003." State of California, the Resources Agency, Department of Water Resources. October 2003.

———. 2012. "2012 CASGEM Status Report." The Resources Agency, Department of Water Resources. October 2012.

———. 2015. "Groundwater Information Center, Key Legislation." Key Legislation website. Modified 12/29/2015, accessed 2/16/2016. http://www.water.ca.gov/groundwater/groundwater_management/legislation.cfm.

———. 2016a. "California Statewide Groundwater Elevation Monitoring (CASGEM)." California Statewide Groundwater Elevation Monitoring (CASGEM) Program website. Modified 07/05/2016, accessed 07/05/2016. http://www.water.ca.gov/groundwater/casgem/.

———. 2016b. "Groundwater." Groundwater website. Modified 05/09/2016, accessed 2/16/2016. http://www.water.ca.gov/groundwater/.

———. 2016c. "Groundwater Sustainability Agencies." Groundwater Sustainability Agencies website. Modified 05/04/2016, accessed 6/6/2016, http://water.ca.gov/groundwater/sgm/gsa.cfm

———. 2016d. “Sustainable Groundwater Management Program: DRAFT Groundwater Sustainability Plan (GSP) Emergency Regulations Guide.” The Resources Agency, Department of Water Resources. March 2016.

California Legislative Information. 1992. “Water Code – Wat Division 6. Conservation, Development and Utilization of State Water Resources [10000 - 12999]. (Heading of Division 6 amended by Stats. 1957, Ch. 1932.). Part 2.75. Groundwater Management [10750 - 10755.4] website”. Accessed August 29, 2016. http://leginfo.legislature.ca.gov/faces/codes_displaySection.xhtml?sectionNum=10750.&lawCode=WAT.

California Legislative Information. 2002. “SB-1938 Groundwater management: state funding”. California Legislative Information website. Accessed August 29, 2016. http://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=200120020SB1938.

California Legislative Information. 2013-2014a. “AB-1739 Groundwater management.” California Legislative Information website. Accessed August 29, 2016. http://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201320140AB1739.

California Legislative Information. 2013-2014b. “SB-1168 Groundwater management.” California Legislative Information website. Accessed August 29, 2016. http://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201320140SB1168.

California Legislative Information. 2013-2014c. “SB-1319 Groundwater.” California Legislative Information website. Accessed August 29, 2016. http://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201320140SB1319.

Canvas. 2016a. “Home Page.” Canvas website. Accessed August 28, 2016. https://www.gocanvas.com/content/getting_to_know_canvas.

———. 2016b. “Ground Water Monitoring Report Mobile App.” Canvas website. Accessed March, 25, 2016. http://www.gocanvas.com/mobile-forms-apps/4926-Ground-Water-Monitoring-Report.

CBS Interactive. 2016. “10+ reasons why IT pros hate Microsoft Access (but really shouldn't).” TechRepublic website. Accessed August 28, 2016. http://www.techrepublic.com/blog/10-things/10-plus-reasons-why-it-pros-hate-microsoft-access-but-really-shouldnt/.

Central Groundwater Board. 2015. “HomePage.” Central Ground Water Board website. Accessed August 28, 2016. http://www.cgwb.gov.in/.

Cohn, J. P. 2008. Citizen science: Can volunteers do real research? *Bioscience*, 58 (3), 192–197.

Comber, Alexis, See, Linda, Fritz, Steffen, Van der Velde, Marijn, Perger, Christoph, Foody, Giles. 2012. “*Using control data to determine the reliability of volunteered geographic information about land cover*.” International Journal of Applied Earth Observation and Geoinformation, 23 (2013) 37–48.

De Longueville, Bertrand, Annoni, Alessandro, Schade, Sven, Ostlaender, Nicole and Whitmore, Ceri. 2010. “Digital Earth's Nervous System for crisis events: real-time Sensor Web Enablement of Volunteered Geographic Information.” International Journal of Digital Earth, 3:3, 242-259. http://dx.doi.org/10.1080/17538947.2010.484869.

Devillers, Rodoplhe and Jeasoulin, Robert. 2006. “Chapter 2. Spatial Data Quality: Concepts.” Fundamentals of Spatial Data Quality, edited by Rodoplhe Devillers and Robert Jeasoulin. Copyright 2006.

Esri. 2016a. “What is a feature service?” ArcGIS for Desktop website. Accessed August 28, 2016. http://server.arcgis.com/en/server/10.3/publish-services/linux/what-is-a-feature-service-.htm.

Esri. 2016b. “What is a query layer?” ArcGIS for Desktop website. Accessed August 28, 2016. http://desktop.arcgis.com/en/arcmap/10.3/map/working-with-layers/what-is-a-query-layer-.htm

Feick, Rob and Roche, Stephane. 2013. "Understanding the Value of VGI." In *Crowdsourcing Geographic Knowledge Volunteered Geographic Information (VGI) in Theory and Practice*, edited by Daniel Z. Sui, Sarah Elwood and Michael F. Goodchild. 1st ed. Vol. 1, 15: Springer.

Flanagin, Andrew J. and Miriam J. Metzger. 2008. "The Credibility of Volunteered Geographic Information." *GeoJournal* 72 (3/4): 137-148.

Fonte, Cidália C., Bastin, Lucy, See, Linda, Foody, Giles and Jacinto Estima. 2015. “Good Practice Guidelines for Assessing VGI Data Quality.” In Proceedings of the AGILE’2015 International Conference on Geographic Information Science, 9-12 June 2015 - Lisbon, Portugal, pp. 1-4.

Ganapati, Sukumar. 2011. “Uses of Public Participation Geographic Information Systems Applications in E-Government.” *Public Administration Review* 71 (3): 425-343.

Github. 2016. “Home Page”. Github website. Accessed August 27, 2016. https://github.com/.

Goodchild, Michael F. 2007a. "Citizens as Sensors: The World of Volunteered Geography." *GeoJournal* (69): 211-221.

Goodchild, Michael F., Li, Linna. 2012 “Assuring the Quality of Volunteered Geographic Information.” *Spatial Statistics* 1, 110-120.

Governing: The States and Localities. 2014. “California Becomes Last Western State to Regulate Groundwater.” Tribune News Service. September 17, 2014. http://www.governing.com/news/headlines/mct-california-groundwater-regulations.html. Last Accessed 7/11/2016.

Haklay, M. 2013. “Citizen Science and Volunteered Geographic Information: Overview and Typology of Participation”. pp. 105–122. *Crowdsourcing Geographic Knowledge*

Volunteered Geographic Information (VGI) in Theory and Practice, edited by Daniel Z. Sui, Sarah Elwood and Michael F. Goodchild. 1st ed. Vol. 1, 15: Springer.

Haklay, Muki. Septemeber 19, 2014. (Forthcoming). "Volunteered Geographic Information, Quality Assurance", Muki Haklay's Personal Blog, Accessed June 1, 2016. https://povesham.wordpress.com/2014/09/19/international-encyclopedia-of-geography-quality-assurance-of-vgi/

Hunter, Gary G. J. and Beard, Kate, "Understanding error in spatial databases", *Australian Surveyor*, 1992, Vol. 37, number 2, p 108–19. doi: 10.1080/00050326.1992.10438784.

Jasperse, Jay. 2016. Interview by author. Santa Rosa. February 19.

Johnson, Peter A. and Sieber, Renee E. 2013. "Situating the Adoption of VGI by Government." Pp. 65-81. In *Crowdsourcing Geographic Knowledge Volunteered Geographic Information (VGI) in Theory and Practice*, edited by Daniel Z. Sui, Sarah Elwood and Michael F. Goodchild. 1st ed. Vol. 1, 15: Springer.

Joshi, Sanjay Raj. 2005. "Comparison of Groundwater Rights in the United States: Lessons for Texas." A Thesis in Civil Engineering Submitted to the Graduate Faculty of Texas Tech University in Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering.

Linders, Dennis. 2012. "From e-government to we-government: Defining a typology for citizen coproduction in the age of social media." *Government Information Quarterly* 29 (4): 446-454.

Longhorn, R. and Blakemore, M. 2008. Geographic information: Value, pricing, production and consumption, Boca Raton, FL, CRC Press.

Maué, Patrick. 2007. *Reputation as Tool to Ensure Validity of VGI*. From the Workshop on Volunteered Geographic Information.

Microsoft. 2016. "How many record Microsoft Access can Hold?" Microsoft Community website. Accessed August 28, 2016. http://answers.microsoft.com/en-us/office/forum/officeversion_other-access/how-many-record-microsoft-access-can-hold/967f1817-aba9-44fa-b058-1b895c25fa19?auth=1.

National Aeronautics and Space Administration. 2014. "NASA GRACE Home Page." Last Accessed August 28, 2016. https://www.nasa.gov/mission_pages/Grace/#.V8N0L5grLD5.

National Ground Water Association. 2014. "Home Page." National Ground Water Association website. Accessed August 28, 2016. http://www.ngwa.org/pubs/gw/pages/download-the-groundwater-app.aspx.

Roche, S., Propeck-Zimmerman, E., and Mericskay, B. 2011. GeoWeb and risk management: Issues and Perspectives of Volunteered Geographic Information. *GeoJournal* 78, 21-40.

Senaratne, Hansi, Mobasheri, Amin, Ali, Ahmed Loai, Capineri, Cristina, and Haklay, Mordechai (Muki). 2016. “A Review of Volunteered Geographic Information Quality Assessment Methods.” International Journal of Geographical Information Science. http://dx.doi.org/10.1080/13658816.2016.1189556.

Silvertown, Jonathan. 2009. “A new dawn for citizen science.” Trends in Ecology & Evolution, Vol. 24 (9), 467–471. http://dx.doi.org/10.1016/j.tree.2009.03.017.

Sonoma County Water Agency. 2007. "Facilities Guide." Internal document for staff use. Sonoma County Water Agency, Sonoma County, CA.

Sui, Daniel, Goodchild, Michael, Elwood, Sarah. 2013. " Volunteered Geographic Information, the Exaflood, and the Growing Digital Divide." *Crowdsourcing Geographic Knowledge Volunteered Geographic Information (VGI) in Theory and Practice*, edited by Daniel Z. Sui, Sarah Elwood and Michael F. Goodchild. 1st ed. Vol. 1, 15: Springer.

Spyratos, Spyridon, Lutz, Michael, and Pantisano, Francesco. 2014. "Characteristics of citizen-contributed geographic information." In Proceedings of the AGILE’2014 International Conference on Geographic Information Science, Castellón, Spain, pp. 3-6. 2014.

State of California. 2016a. “Geotracker Home Page.” State Water Resources Control Board website. Accessed August 28, 2016. http://geotracker.waterboards.ca.gov/.

———. 2016b. “Geotracker GAMA Search for Wells.” State Water Resources Control Board website. Accessed August 28, 2016. http://geotracker.waterboards.ca.gov/gama/gamamap/public/default.asp?CMD=runreport&myaddress=404+aviation.

———. 2016c.” Groundwater Basin Boundary Assessment Tool.” California Department of Water Resources website. Accessed August 28, 2016. https://gis.water.ca.gov/app/bbat/.

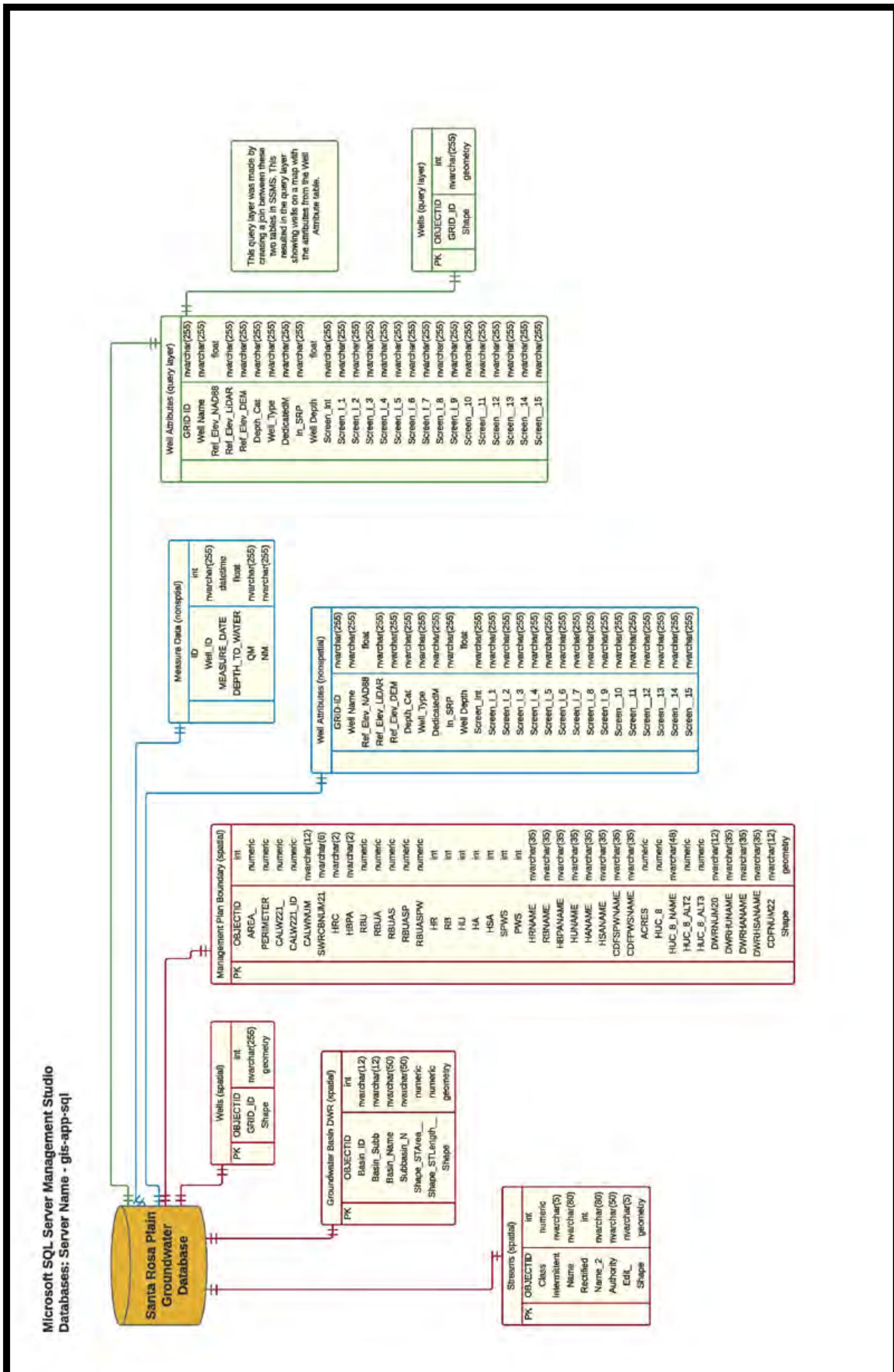
———. 2016d.” Groundwater Information Center Interactive Map Application.” California Department of Water Resources website. Accessed August 28, 2016. https://gis.water.ca.gov/app/gicima/.

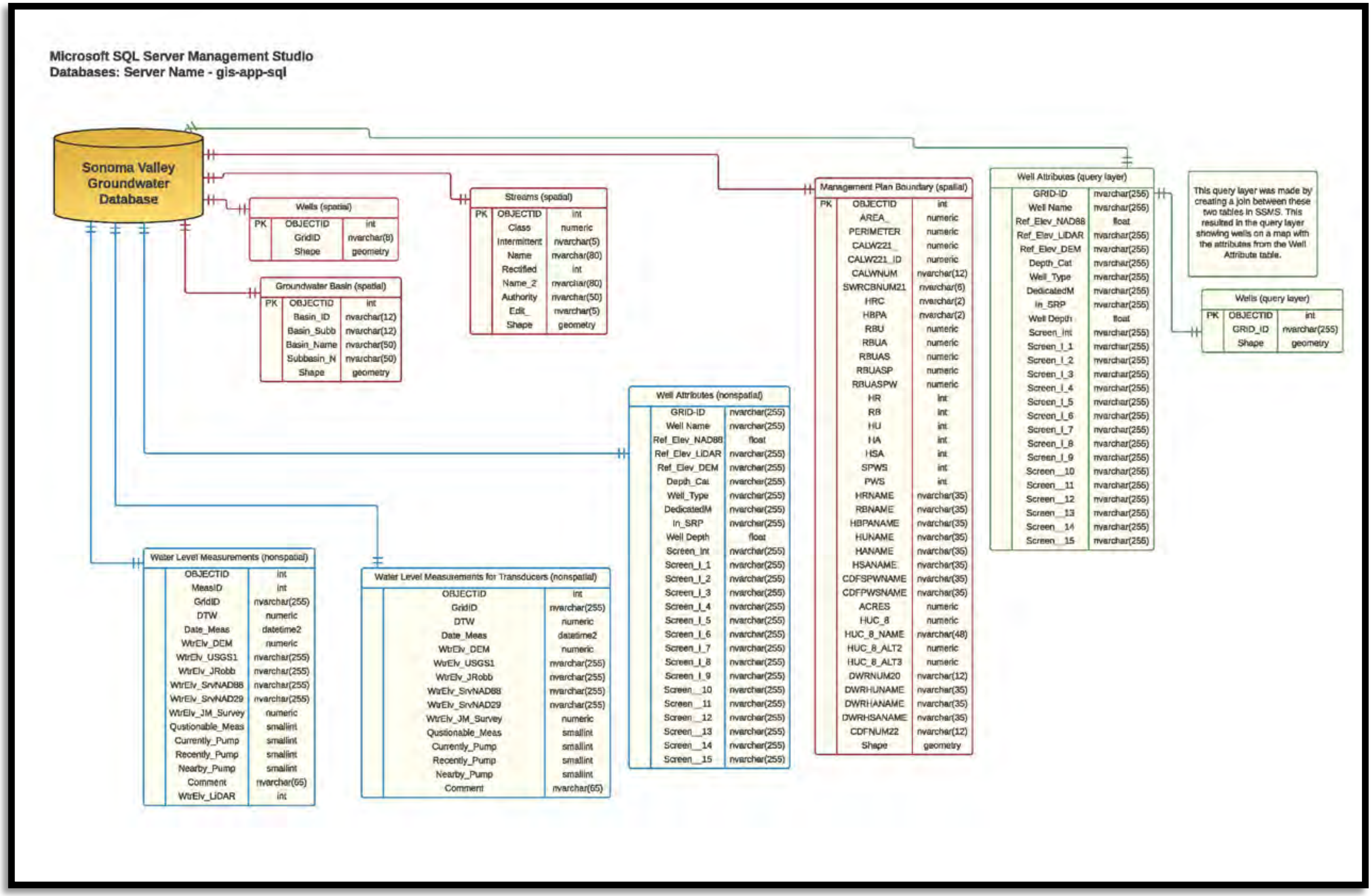
US Department of the Interior. 2016. “USGS Groundwater Information Pages.” US Department of the Interior website. http://water.usgs.gov/ogw/.

Waters, Nigel. 2009. "Reputation Systems: The Dark Side of VGI." *GEO World* 22 (8): 18.

Yeung, Albert K.W., Hall, Brent G. 2007. Spatial Database Systems Design, Implementation and Project Management. Springer.

APPENDIX A: DETAILED DATABASE DIAGRAMS





Microsoft SQL Server Management Studio
Databases: Server Name - gis-app-sql
Sonoma Valley Groundwater Database
Wells (spatial)
PK OBJECTID int
GridID nvarchar(8)
Shape geometry
Groundwater Basin (spatial)
PK OBJECTID int
Basin_ID nvarchar(12)
Basin_Subb nvarchar(12)
Basin_Name nvarchar(50)
Subbasin_N nvarchar(50)
Shape geometry
Streams (spatial)
PK OBJECTID int
Class numeric
Intermittent nvarchar(5)
Name nvarchar(80)
Rectified int
Name_2 nvarchar(80)
Authority nvarchar(50)
Edit_ nvarchar(5)
Shape geometry
Management Plan Boundary (spatial)
PK OBJECTID int
AREA_ numeric
PERIMETER numeric
CALW221_ numeric
CALW221_ID numeric
CALWNUM nvarchar(12)
SWRCBNUM21 nvarchar(6)
HRC nvarchar(2)
HBPA nvarchar(2)
RBU numeric
RBUA numeric
RBUAS numeric
RBUASP numeric
RBUASPW numeric
HR int
RB int
HU int
HA int
HSA int
SPWS int
PWS int
HRNAME nvarchar(35)
RBNAME nvarchar(35)
HBPANAME nvarchar(35)
HUNAME nvarchar(35)
HANAME nvarchar(35)
HSANAME nvarchar(35)
CDFSPWNAME nvarchar(35)
CDFPWSNAME nvarchar(35)
ACRES numeric
HUC_8 numeric
HUC_8_NAME nvarchar(48)
HUC_8_ALT2 numeric
HUC_8_ALT3 numeric
DWRNUM20 nvarchar(12)
DWRHUNAME nvarchar(35)
DWRHANAME nvarchar(35)
DWRHSANAME nvarchar(35)
CDFNUM22 nvarchar(12)
Shape geometry
Well Attributes (query layer)
GRID-ID nvarchar(255)
Well Name nvarchar(255)
Ref_Elev_NAD88 float
Ref_Elev_LIDAR nvarchar(255)
Ref_Elev_DEM nvarchar(255)
Depth_Cat nvarchar(255)
Well_Type nvarchar(255)
DedicatedM nvarchar(255)
In_SRP nvarchar(255)
Well Depth float
Screen_Int nvarchar(255)
Screen_I_1 nvarchar(255)
Screen_I_2 nvarchar(255)
Screen_I_3 nvarchar(255)
Screen_I_4 nvarchar(255)
Screen_I_5 nvarchar(255)
Screen_I_6 nvarchar(255)
Screen_I_7 nvarchar(255)
Screen_I_8 nvarchar(255)
Screen_I_9 nvarchar(255)
Screen__10 nvarchar(255)
Screen__11 nvarchar(255)
Screen__12 nvarchar(255)
Screen__13 nvarchar(255)
Screen__14 nvarchar(255)
Screen__15 nvarchar(255)
This query layer was made by creating a join between these two tables in SSMS. This resulted in the query layer showing wells on a map with the attributes from the Well Attribute table.
Wells (query layer)
PK OBJECTID int
GRID_ID nvarchar(255)
Shape geometry
Well Attributes (nonspatial)
GRID-ID nvarchar(255)
Well Name nvarchar(255)
Ref_Elev_NAD88 float
Ref_Elev_LIDAR nvarchar(255)
Ref_Elev_DEM nvarchar(255)
Depth_Cat nvarchar(255)
Well_Type nvarchar(255)
DedicatedM nvarchar(255)
In_SRP nvarchar(255)
Well Depth float
Screen_Int nvarchar(255)
Screen_I_1 nvarchar(255)
Screen_I_2 nvarchar(255)
Screen_I_3 nvarchar(255)
Screen_I_4 nvarchar(255)
Screen_I_5 nvarchar(255)
Screen_I_6 nvarchar(255)
Screen_I_7 nvarchar(255)
Screen_I_8 nvarchar(255)
Screen_I_9 nvarchar(255)
Screen__10 nvarchar(255)
Screen__11 nvarchar(255)
Screen__12 nvarchar(255)
Screen__13 nvarchar(255)
Screen__14 nvarchar(255)
Screen__15 nvarchar(255)
Water Level Measurements (nonspatial)
OBJECTID int
MeasID int
GridID nvarchar(255)
DTW numeric
Date_Meas datetime2
WtrElv_DEM numeric
WtrElv_USGS1 nvarchar(255)
WtrElv_JRobb nvarchar(255)
WtrElv_SrvNAD88 nvarchar(255)
WtrElv_SrvNAD29 nvarchar(255)
WtrElv_JM_Survey numeric
Questionable_Meas smallint
Currently_Pump smallint
Recently_Pump smallint
Nearby_Pump smallint
Comment nvarchar(65)
WtrElv_LIDAR int
Water Level Measurements for Transducers (nonspatial)
OBJECTID int
GridID nvarchar(255)
DTW numeric
Date_Meas datetime2
WtrElv_DEM numeric
WtrElv_USGS1 nvarchar(255)
WtrElv_JRobb nvarchar(255)
WtrElv_SrvNAD88 nvarchar(255)
WtrElv_SrvNAD29 nvarchar(255)
WtrElv_JM_Survey numeric
Questionable_Meas smallint
Currently_Pump smallint
Recently_Pump smallint
Nearby_Pump smallint
Comment nvarchar(65)

APPENDIX B: INTERVIEW QUESTIONNAIRE AND RESPONSES

Volunteer Well Monitoring Program

This is an evaluation of the Sonoma Valley Well Monitoring Program. All answers will be used in a Master thesis.

* Required

1. **Name** *

2. **Email** *

Well Monitoring Questions

3. **Approximate Date you first started volunteering well data** *

Example: December 15, 2012

4. **How did you hear about the volunteer program?** *

5. **What data do you send to the Water Agency?** *

6. **Is this the only data that you collect?** *

7. **How often do you collect data?**

8. **How often do you submit data?**

9. **Is there ever a lag-time between collection and submission?**

10. **Do you ever miss collections or submissions?**

11. **How did you come to be the person submitting data for other people's wells?**

12. **Have you ever had trouble accessing other people's wells?**

13. **Do you know if they submitted data before you began submitting on their behalf?**

14. **Have you asked the other people if you could submit for them but they declined?**

15. **Do you know people who don't submit their well data?**

16. **What is your method for checking the water level?** *

17. **Do you have various methods for checking the well data?** *

18. **How many wells do you monitor?** *

19. **Have you trained other volunteers? Who trained you?**

20. **How do you get access to other people's wells?**

21. **Do you know other volunteers?**

22. **Is there anything that you would like to share about the Volunteer program? ***

____

____

____

____

Powered by
Google Forms

Kathy Pons Interview

Pons was the first volunteer that I interviewed. She decided to conduct the interview face-to-face at the Water Agency. Initially she became interested in monitoring groundwater well data at the inception of the Sonoma Valley Groundwater Management Plan process in 2004. She started monitoring her own well and then gradually began monitoring data for neighbors and acquaintances in the Sonoma Valley who did not want to monitor their own wells.

She was trained to collect water level data by Stephen Fuller-Rowell of the Sonoma County Water Coalition at a seminar held in Sonoma Valley. The Sonoma County Water Coalition is an organization comprised of 30 nonprofit groups in Sonoma County that are interested in the protection of local water resources. Pons has also attended groundwater well monitoring methods classes taught by Marcus Trotta of WRP. Marcus is a professional Hydrogeologist. Both of these individuals are acceptable training sources.

The only data that Pons sends to the Water Agency is the water level depth data and this is the only data that she collects. The first time she monitors a well she also collects location information with a simple hand-help GPS unit. Pons collects the water level data twice a year, in the spring and the fall and she submits as soon as she has collected all depth data with no lag time between collection and submission. Pons stated that she never skips collecting the data, the date of collection may change a little from year-to-year but she's essentially consistent in her data collection.

Pons came to collect data on other people's wells due to the fact that these other private well owners do not want to collect their own data. She mentioned in passing that some other well owners have concerns about sharing data with the government and with regard to some well owners, they will not allow Pons to monitor their wells for this reason. The only trouble Pons has ever had with collecting data is due to an unfamiliar dog or a locked gate. Typically Pons will contact the well owner the first time that she sets out to collect data and after the initial contact she only send emails or may phone call to let the well owner know she intends to check the well on the upcoming weekend.

The method that Pons uses to check the well depth level is a cable or tape that she drops into the well. When the weight on the end of the cable hits the water she records the measurement. Over the past year Pons has been working in conjunction with an intern from the Water Agency to help in the field collection. Typically, the intern will go into the well, take the measurement and call out the reading to Pons who then writes the measurement down in a journal. She then transposes this information into an Excel spreadsheet when she returns home. When she has completed all of her measurements she sends this information to the Water Agency.

Pons monitors 36 wells and has not trained any other volunteers. The only volunteer that she knows is Ed Nelson. Pons shared that she thinks the monitoring program is very important and she finds this information about water depth in her well and the surrounding wells to be very interesting. Pons was an interesting person to interview, her own desire to know more about the resources in her area makes her a concerned citizen and perhaps a citizen scientist. She is collecting this information purely for the benefit of knowledge, without any desire for personal gain other than her own understanding and to inform the Water Agency about water levels in her basin.

Ed Nelson Interview

Nelson started monitoring well data in 2005. Nelson was part of the group that worked on the formation of the Sonoma Valley Groundwater Management Program in 2007. Currently Nelson sends well water depth data twice a year, in the spring and the fall. He also collects and submits well location and water depth reference level when a well is first added to the volunteer program. He submits the data shortly after he takes the measurements and there is no significant lag time between collection and submission.

Nelson began collecting water level depth data from wells on other private citizen's property as a result of his involvement with Sonoma Valley Groundwater Management Program in 2007. He sometimes has trouble accessing wells on private properties and wrote in his interview that when people volunteer their wells for the monitoring program, they agree to allow access. He accesses some wells at any time without making an appointment, and for others he makes an appointment. He does know other volunteers but did not elaborate on other volunteers.

With regard to other well monitors, no one but Nelson or other official well monitors submit data to the Water Agency. As far as Nelson is aware, no one has submitted water level data before him. According to Nelson, a number of people that he has asked to volunteer their wells for the monitoring program have declined. There are many well owners that have not been contacted personally to volunteer their wells for monitoring. There are many people that Ed knows who do not volunteer their well data.

Nelson has two basic methods for collecting water level depth data. The first is to drop a cable down the well until it reaches water, and the second is to use a sonic meter. The meter sends a sound wave from the reference surface to the water surface. The wave is reflected back to the meter and the round trip time is measured. Knowing the speed of sound in the path between reference surface and the water surface allows calculation by the meter of the water depth.

Nelson mentioned in his interview that he monitors 34 wells in the volunteer program, while the source information received from WRP shows him as the Source for 44 wells. This discrepancy will be cleared up in the future. However, Nelson also mentions in his interview that he occasionally monitors a few others that are not signed up for the program, these numbers change with time because of both additions and subtractions. This may explain the discrepancy.

With regard to training, Nelson has not trained other volunteers. Nelson was trained in the cable measurement method in 2004 by Paul Gradolph (Operations and Maintenance Supervisor of the Valley of the Moon Water District at the time), this is an acceptable training source. He trained himself to use the sonic method simply by reading the sonic meter manual. To verify the sonic method, he took many measurements to compare the two methods.

In his final comment, Nelson writes that the current program is an outgrowth of an earlier program initiated jointly by the Valley of the Moon Water District (VOMWD) and the City of Sonoma (COS) in fall 1999. Nelson started collecting data from both VOMWD and COS in 2001 and started making the VOMWD measurements himself in 2004. In 2005 and 2006, supplying all the data to the USGS for use in their Sonoma Valley groundwater study (USGS Report 2006-5092). This data (together with data collected by the Department of Water Resources) were the initial data for the current monitoring program.