Water Well Record Databases and Their Uses

Gavin Kennedy

THE GROUNDWATER PROJECT

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The Groundwater Project
Guelph, Ontario, Canada
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THE GROUNDWATER PROJECT

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The Groundwater Project Foreword

The Year 2022 marks as an important year for groundwater because the United Nations Water Members and Partners chosen the theme of this year's March 22 World Water Day to be: "Groundwater: making the invisible visible". The goal of the Groundwater Project (GW-Project) is in sync with this theme.

The GW-Project, a registered charity in Canada, is committed to contributing to advancement in groundwater education and brings a unique approach to the creation and dissemination of knowledge for understanding and problem solving. The GW-Project operates the website https://gw-project.org/↗ as a global platform for the democratization of groundwater knowledge, founded on the principle that:

"Knowledge should be free and the best knowledge should be free knowledge." Anonymous

The mission of the GW-Project is promoting groundwater learning. This is accomplished by providing accessible, engaging, high-quality, educational materials, free-of-charge online in many languages, to all who want to learn about groundwater. In short, providing essential knowledge tools for developing groundwater sustainably for humanity and ecosystems.

This is a new type of global educational endeavor in that it is based on volunteerism of professionals from different disciplines and includes academics, consultants and retirees. The GW-Project involves many hundreds of volunteers associated with more than 200 hundred organizations from 27 countries and six continents, with growing participation.

The GW-Project is an on-going endeavor and will continue with hundreds of books being published online over the coming years, first in English and then in other languages, for downloading wherever the Internet is available. An important tenet of the GW-Project books is a strong emphasis on visualization via clear illustrations that stimulate spatial and critical thinking to facilitate absorption of information.

The GW-Project publications also include supporting materials such as videos, lectures, laboratory demonstrations, and learning tools in addition to providing, or linking to, public domain software for various groundwater applications supporting the educational process.

The GW-Project is a living entity, so subsequent editions of the books will be published from time to time. Users are invited to propose revisions.

We thank you for being part of the GW-Project Community. We hope to hear from you about your experience with using the books and related material. We welcome ideas and volunteers!

The GW-Project Steering Committee

January 2022

Foreword

Half of the global population uses groundwater for part or all of their drinking water and, in many regions, agriculture is dependent on groundwater. Although nearly all wells are located on private property, the extracted groundwater is a public resource because groundwater is not influenced by property boundaries. When information about wells and the geology they encounter is publicly available as a well record database, the groundwater resource can be managed and protected for the benefit of all. Sometimes, the databases are used to construct sophisticated computer models of aquifer systems that supply water to millions of people in order to properly manage the groundwater resource.

In developed countries with substantial groundwater use, government organizations are responsible for maintaining and disseminating the well record database. In many areas, most of the knowledge about groundwater and geology is derived from the information recorded by water well drillers. Typically, drillers record the data on a paper form and many jurisdictions require that these forms be submitted to the government for inclusion in the database. Onsite inspections are rare, thus the quality and availability of well records depends on drillers contributing their time and effort for the public good. The design of well record forms needs to balance the collection of valuable information with what is reasonable for drillers to record while operating a drill rig, often in difficult weather and in challenging terrain conditions.

This book summarizes the nature and state of well databases with emphasis on Canada and the USA. Well records in these countries are the responsibility of provinces in Canada and states in the USA and hence there are dozens of databases with differing content and format. Some jurisdictions initiated their databases many decades ago and others only recently. Some have only paper records available, which are not easy to access, while others have electronic records readily available to the public. Today, there is widespread recognition that reliable and readily available electronic records are important to the development, management, and protection of groundwater but many jurisdictions are lagging behind. There is room for improvement. Even leading jurisdictions do not yet have database systems that meet the criteria proposed in this book which are ideal for serving the needs of well drillers, well owners, environmental consultants, water managers, researchers, educators, and the community as a whole. The author of this book, Gavin Kennedy, is a senior hydrogeologist with the Geological Survey of Nova Scotia, Canada, a province where over 40 percent of the population is served by domestic wells, and over 50 percent of the population relies on groundwater for their source of drinking water. Nova Scotia's well database was started 55 years ago and is continually being improved. The Groundwater Project book, Domestic Wells: Introduction and Overview by John Drage, is a companion to this book about well record databases.

John Cherry, The Groundwater Project Leader
Guelph, Ontario, Canada, January 2022

Preface

This book highlights the importance of well record management as a critical component of groundwater and drinking water management programs. It provides an overview of the history, availability, uses, shortcomings and best practices of these databases, which is useful background for students, educators, researchers, groundwater professionals and managers interested in learning about this topic.

Over the past 50 years well record databases have evolved in many jurisdictions from a hard copy archive of well record forms to the open distribution of well record data over the internet in a digital format. An internet search for well record databases around the world shows that the availability and accessibility of water well record databases is highly variable. Where available, however, weblinks to digital well record databases from various jurisdictions are provided in the book.

The book also identifies the diverse types of users of well record information and provides several examples of how well record data are used to support groundwater assessment and research.

The discussion of common deficiencies and best practices for well record data management contained in the book may be used as a framework for realizing improvements to well record management programs. Continued improvements to data quality and internet accessibility will foster greater utilization of these datasets for groundwater management and research.

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1 Introduction

Approximately 45 percent of the world's population live in rural areas (United Nations, 2019), and in these rural areas, household water is commonly provided by domestic water wells. Domestic wells are defined herein as privately owned water wells supplying a household's domestic water, including the water used for drinking, cooking, flushing and bathing. These wells are also sometimes referred to as private wells or residential wells.

In Canada and the United States, it is estimated that more than one tenth of its population relies on domestic wells for household water supply, while globally, about half of the world's population relies on groundwater for drinking water (Margat and van der Gun, 2013). Unfortunately, we do not have sound global estimates of the population supplied by domestic wells, but it is likely that hundreds of millions of people rely on domestic wells for their household water supply.

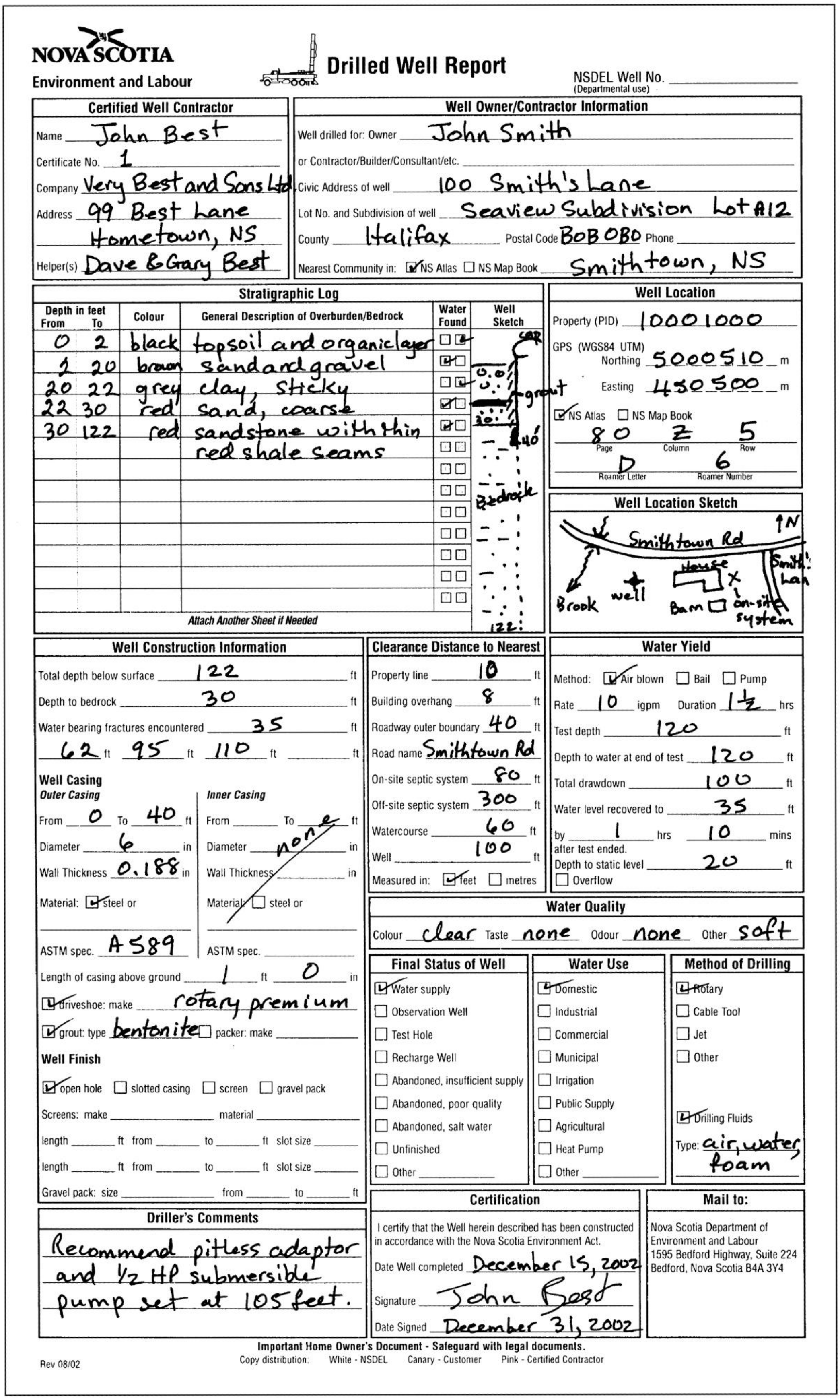
Collection of information about the construction of domestic water wells is widely considered an important component of groundwater and drinking water management programs. Well construction records are usually compiled in a database that is made available to various users of the information who use the records for a wide range of purposes. For example, well records are used by homebuyers to confirm an adequate water supply, government regulators to ensure proper well construction for safe drinking water and groundwater protection, groundwater managers to estimate groundwater utilization, public health officials to investigate potential exposure to groundwater contaminants, and researchers to better understand aquifer characteristics.

Well record databases are arguably the largest and most important archive of information on groundwater and geological conditions worldwide, and in many jurisdictions, they are the only groundwater data collected and published by government organizations. These databases may be more than 50 years old, while in other cases the databases were only recently developed (Perrone and Jasechko, 2017; Perrone and Jasechko, 2019; Nova Scotia Environment, 2020; Government of Yukon, 2021).

This book provides an overview of well record databases, including the history, availability, uses and shortcomings of these databases, as well as a few examples of how they are used to support groundwater research. This book is part of a series of books that focus on domestic wells, and therefore the emphasis of this book is on domestic well data. Well record databases, however, can include wells drilled for public water supply (community or municipal supply) or other uses such as groundwater exploration (test wells), agricultural, industrial, commercial, monitoring, dewatering or geothermal uses. Well record databases are also used to record details about well decommissioning or well alteration activities (e.g., well deepening, rehabilitation, or redevelopment). Although the emphasis of this book is on domestic well record data, much of the discussion contained in the book will also be applicable to these other types of well record data. The intended audience of this book includes students, educators, researchers, groundwater professionals, groundwater managers and policy makers with a background in water science and a professional interest in water well record databases. The book focuses on North America, although some information from other countries is presented.

2 Water Well Record Information and Submission Requirements

During the installation of a water supply well, which may be constructed for domestic, public, municipal or other water uses (e.g., industrial, irrigation), a well contractor will typically record details about the construction of the well on a standardized form (Figure 1). Categories of well record information include well construction items, such as grout, casing, screens and drilling method; hydrogeologic items, such as static water level, geologic material and estimated yield; and general information, such as the well location, the owner's name, and the driller's name (Table 1; Ganley, 1989). According to a 1989 survey of well record databases in the United States, the three most commonly reported items on a well record were the owner's name, the driller's name and the static water level, whereas the three least commonly reported items were well packers, drilling fluid and the geologic formation.



NOVA SCOTIA Environment and Labour — **Drilled Well Report** — NSDEL Well No. ________ (Departmental use)

Certified Well Contractor

Name: John Best
Certificate No.: 1
Company: Very Best and Sons Ltd
Address: 99 Best Lane, Hometown, NS
Helper(s): Dave & Gary Best

Well Owner/Contractor Information

Well drilled for: Owner: John Smith
or Contractor/Builder/Consultant/etc.: ________
Civic Address of well: 100 Smith's Lane
Lot No. and Subdivision of well: Seaview Subdivision Lot A12
County: Halifax — Postal Code: BOB OBO — Phone: ________
Nearest Community in: ☑ NS Atlas ☐ NS Map Book — Smithtown, NS

Stratigraphic Log

Depth in feet From	To	Colour	General Description of Overburden/Bedrock	Water Found
0	2	black	topsoil and organic layer	
2	20	brown	sand and gravel	☑
20	22	grey	clay, sticky	
22	30	red	sand, coarse	☑
30	122	red	sandstone with thin red shale seams	☑

Well Sketch: grout, 40', Bedrock, 122'
Attach Another Sheet if Needed

Well Location

Property (PID): 10001000
GPS (WGS84 UTM) Northing: 5000510 m; Easting: 450500 m
☑ NS Atlas ☐ NS Map Book — Page: 80; Column: Z; Row: 5; Roamer Letter: D; Roamer Number: 6

Well Location Sketch: Smithtown Rd, N, Smith's Lane, House, well, Brook, Barn, on-site system

Well Construction Information

Total depth below surface: 122 ft
Depth to bedrock: 30 ft
Water bearing fractures encountered: 35 ft, 62 ft, 95 ft, 110 ft

Well Casing — Outer Casing: From 0 To 40 ft; Diameter 6 in; Wall Thickness 0.188 in; Material: ☑ steel or ____; ASTM spec. A589
Inner Casing: none

Length of casing above ground: 1 ft 0 in
☑ driveshoe: make rotary premium
☑ grout: type bentonite ☐ packer: make ________

Well Finish: ☑ open hole ☐ slotted casing ☐ screen ☐ gravel pack
Screens: make ____ material ____; length ____ ft from ____ to ____ ft slot size ____; length ____ ft from ____ to ____ ft slot size ____; Gravel pack: size ____ from ____ to ____ ft

Clearance Distance to Nearest

Property line: 10 ft
Building overhang: 8 ft
Roadway outer boundary: 40 ft
Road name: Smithtown Rd
On-site septic system: 80 ft
Off-site septic system: 300 ft
Watercourse: 60 ft
Well: 100 ft
Measured in: ☑ feet ☐ metres

Water Yield

Method: ☑ Air blown ☐ Bail ☐ Pump
Rate: 10 igpm; Duration: 1½ hrs
Test depth: 120 ft
Depth to water at end of test: 120 ft
Total drawdown: 100 ft
Water level recovered to: 35 ft by 1 hrs 10 mins after test ended.
Depth to static level: 20 ft
☐ Overflow

Water Quality: Colour: clear; Taste: none; Odour: none; Other: soft

Final Status of Well: ☑ Water supply ☐ Observation Well ☐ Test Hole ☐ Recharge Well ☐ Abandoned, insufficient supply ☐ Abandoned, poor quality ☐ Abandoned, salt water ☐ Unfinished ☐ Other

Water Use: ☑ Domestic ☐ Industrial ☐ Commercial ☐ Municipal ☐ Irrigation ☐ Public Supply ☐ Agricultural ☐ Heat Pump ☐ Other

Method of Drilling: ☑ Rotary ☐ Cable Tool ☐ Jet ☐ Other; ☑ Drilling Fluids — Type: air, water, foam

Driller's Comments: Recommend pitless adaptor and ½ HP submersible pump set at 105 feet.

Certification: I certify that the Well herein described has been constructed in accordance with the Nova Scotia Environment Act.
Date Well completed: December 15, 2002
Signature: John Best
Date Signed: December 31, 2002

Mail to: Nova Scotia Department of Environment and Labour, 1595 Bedford Highway, Suite 224, Bedford, Nova Scotia B4A 3Y4

Important Home Owner's Document - Safeguard with legal documents.
Copy distribution: White - NSDEL; Canary - Customer; Pink - Certified Contractor
Rev 08/02

Figure 1 - Example of a well record form from Nova Scotia, Canada using fictitious data (Nova Scotia Environment and Labor, 2004).

Table 1 – Examples of information collected on well record forms (after Ganley, 1989).

Category	Description
Well Construction	• Unique well number (well labels affixed to water wells are used in some jurisdictions, as shown in Figure 2) • Method of well construction, including grouting and installation of screens • Well depth and casing depth • Well construction materials, including details about well screens, grout and casing (material, diameter, drive shoe) • Well pump details (in some jurisdictions a separate form may be used to record this information) • A sketch of the well components in profile
Hydrogeology	• Stratigraphy encountered during drilling and lithological types • Depth of water bearing zones • Static water level • A sketch showing stratigraphy, water bearing zones and water level • Water yield and details of the yield test (e.g., specific capacity, which is the volumetric rate of well discharge per unit decline of water level) • General water quality information (e.g., temperature, salinity, turbidity, color, odor)
General	• Well contractor information (company name, driller license number) • Well owner information (name and address) • Location of water well, including method used to locate water well and estimated accuracy of location (could be a grid reference, community name or location coordinates) • Distance between the well and key features, such as roads, septic systems, oil tanks, surface water drainage • A sketch of the well location relative to important features

Figure 2 - Drilled well in Ontario, Canada, with well tag showing unique code (Well ID) affixed to the casing.

Following the completion of a water well, the well construction record (also known as the well log) is usually submitted by the well contractor to the appropriate government agency responsible for the oversight of well construction activities in that jurisdiction. The well construction record is then stored in a centralized location as part of a well record database (Ganley, 1989). Nowadays, well records are typically stored in an electronic database, which makes it easier to share the data with users of the information. Nevertheless, well record databases remain difficult to access in many jurisdictions (Perrone and Jasechko, 2019).

The construction of a water well, especially a drilled well, often requires specialized heavy machinery that is expensive to mobilize and operate, and therefore provides a valuable opportunity to collect subsurface groundwater and geological information that is otherwise difficult to obtain. Well records permit this valuable information to be captured in a consistent format during the construction of water wells and archived for future access.

In some jurisdictions the submission of well records is voluntary, while in others it is required by law, often as part of a regulation concerning water well construction. The requirement to submit a well record can also depend on the intended use of the well. For example, some jurisdictions may only require the submission of a well record for public water supply wells and so domestic water wells are not captured in the database. A voluntary framework for the submission of well records can result in a lower rate of submission compared to a mandatory framework (Perrone and Jasechko, 2017). In Canada, all provinces have enacted legislation requiring the submission of well logs, with British Columbia being the most recent (e.g., 2016) province to require contractors to submit well records (GW Solutions Incorporated, 2013; Province of British Columbia, 2016).

The number of available well records in any given jurisdiction can vary significantly and is often related to the size of the population reliant on domestic water wells for their water supply. For example, the heavily populated state of California in the United States has about one million records in their compiled state-level well record database (Perrone and Jasechko, 2017) whereas the province of Prince Edward Island (2021) in Canada has about 28,000 well records. The number of available records in a database can also depend on the regulatory framework, including whether well record submission is voluntary (e.g., Yukon Territory in Canada) or legislated, and for which types of water supplies (e.g., domestic versus public).

Compliance with applicable regulatory requirements for mandatory well record submission is another key factor that will determine the number of available records in a database because enforcement of well submission requirements is a persistent challenge. For example, it is estimated that the Nova Scotia Well Logs Database (Nova Scotia Environment, 2020) contains records for only about 50 to 60 percent of the domestic wells currently in use in the province (Kennedy and Polegato, 2017). In a national survey of well record database managers in the United States, the estimated proportion of wells captured in well record databases ranged from 5 percent to 100 percent (Perrone and Jasechko, 2017; Perrone and Jasechko, 2019).

Although the governance level of well record databases can vary anywhere from the subregional (e.g., counties in California, USA↗) to the national level (e.g., well record data managed by the British Geological Survey↗ or Australian Bureau of Meteorology↗), governance of well record data is typically at the same level as the jurisdiction's governance of groundwater resources. For example, in Canada, just as provinces and territories have jurisdiction over the management of freshwater resources, they are also responsible for managing well construction activities and well record databases.

3 History of Well Record Databases

The practice of recording well construction information for water wells was likely originally adopted from practices related to petroleum or geotechnical drilling, in response to the need to find and consistently reproduce viable well water supplies. Historically, well contractors recorded well construction information in logbooks, which were later replaced by handwritten forms that were archived in a central location. Some jurisdictions now allow electronic submission of well records (e.g., Province of Alberta↗) while others continue to manually enter well log information from hard copy forms into a digital database (e.g., the Province of Nova Scotia↗).

The earliest well logs were voluntarily recorded by well contractors, likely as a useful record of well construction details and geological and groundwater conditions encountered during well installation that could be later referenced by the well contractor. During the 1960s and 1970s there was an increased awareness of the vulnerability of domestic water wells to contamination, and legislation ensuring best practices for well construction was commonly adopted. Perrone and Jasechko (2017) reported that in the United States, most states were collecting well record information by the mid-1970s.

Initially, well logs, or a summary of the logs, may have been published annually in a hard copy format, which has evolved over the years to digital databases that can be searched online (Ganley, 1989). The conversion of hard copy databases to a digital format is a significant undertaking, and for those well record database managers that have completed the work, it represents an important milestone whereby the usefulness of the dataset was greatly enhanced. Another important relevant technological advancement was the availability of inexpensive handheld GPS (Global Positioning System) devices, including smartphones, that allowed well construction contractors to record the location of a water well more accurately (Figure 3).

Figure 3 - Well location coordinates being recorded in the field.

The evolution of Nova Scotia's well record database over the past 55 years is presented in Box 1↴. Many other jurisdictions have followed a similar evolution in terms of the development of their well record databases, moving from a hard copy format to internet distribution of well record information.

4 Availability of Well Record Databases

Given that the requirement for well contractors to submit well construction reports has been standard practice in many countries now for decades, and about 45 percent of the world's population resides in rural areas (United Nations, 2019) where domestic wells are the preferred water supply source, it is estimated that there could be up to 100-million water well records archived worldwide. Access to water well records, however, is highly variable, ranging from hard copy reports that were filed or scanned, to digital data that can be readily shared over the internet. About 39 million digital, water well records were compiled from 40 countries or territories in a global study of the sensitivity of groundwater wells to water level declines over the period of 1950 to 2015 (Figure 4; Jasechko and Perrone, 2021). In some countries, national level well record datasets are available (Table 2) while in other countries the data is published by subnational governments.

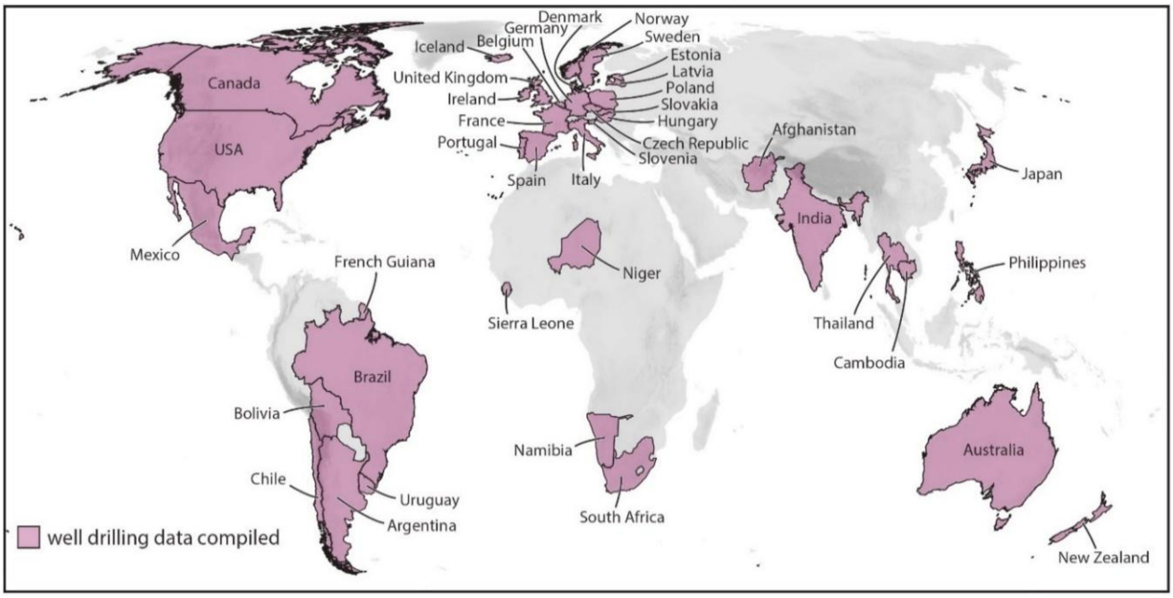


Figure 4 - Compiled water well records for a study of the sensitivity of groundwater wells to water level declines from 1950 to 2015. Only partial data coverages were available for the United States, Argentina, Bolivia and Germany (after Jasechko and Perrone, 2021).

Table 2 - Selected water well databases that provide publicly available, digital, harmonized (i.e., disparate file formats brought into one cohesive data set) or country-scale views of water well data.

Country	Data Source
Tanzania, Malawi, Mozambique, Zimbabwe, Botswana, South Africa, Lesotho, Swaziland, Namibia, Madagascar	Southern African Development Community (SADC) Groundwater Information Portal↗
Australia	National Groundwater Information System↗
Brazil	SIAGAS Groundwater Information System↗
Cambodia	The Online Well Database of Cambodia↗
Canada	Groundwater Information Network (GIN)↗
Denmark	National Well Database (JUPITER)↗
Germany	Borehole Map of Germany↗
Norway	National Groundwater Database (GRANADA)↗
Spain	Institute of Mining and Geology of Spain – Water Points Database↗
United Kingdom	GeoIndex Onshore – Water Wells↗
Uruguay	Mining Geological Viewer – Well Data↗

Over the past several decades, many jurisdictions around the world have moved to an open data, internet distribution model for well record databases, where well record data is freely available and offered for download in multiple formats (e.g., database, text, web map service, Esri™ shapefile/geodatabase, Google Earth™ data files). Although the availability of online well record information is growing quickly, privacy concerns in some jurisdictions continue to restrict opportunities for open sharing of this information.

The inter-operability of these datasets, however, is limited, which can be an important consideration for the overall hydrogeological assessment of a management area, especially one that crosses political borders. Challenges with respect to the discovery of, and access to, harmonized datasets are largely related to the distributed custodianship (e.g., subnational) and heterogeneity of well record information (Brodaric et al., 2018). Approaches to resolve these challenges include standardizing the terminology of hydrogeologic data recorded on well logs at a national level (e.g., Australia's National Aquifer Framework↗) or the translation of well record data from different data providers into a common language (e.g., Borehole Map of Germany↗ or Canada's Groundwater Information Network↗). More information about Canada's approach to harmonizing data from various sources is provided in Box 2↴. The Southern African Development Community (SADC) Groundwater Management Institute (GMI) commissioned the development of a Groundwater Information Portal↗—developed and maintained by the International Groundwater Resources Assessment Centre—for accessing harmonized groundwater information in southern African countries, including water well records (Figure 5).

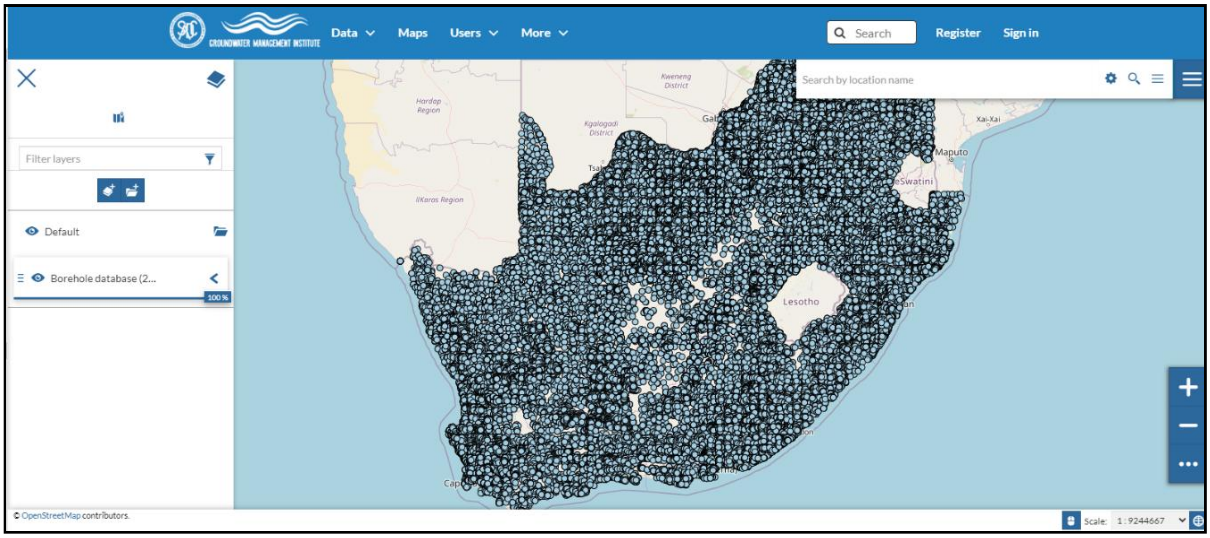


Figure 5 - Screenshot of the SADC Groundwater Information Portal showing the location of borehole records for various southern African countries.

These new models of data distribution have also permitted the development of new tools and widgets for the visualization and analysis of well record data, including the dynamic generation of graphic logs of well completion and stratigraphy information (Figure 6).

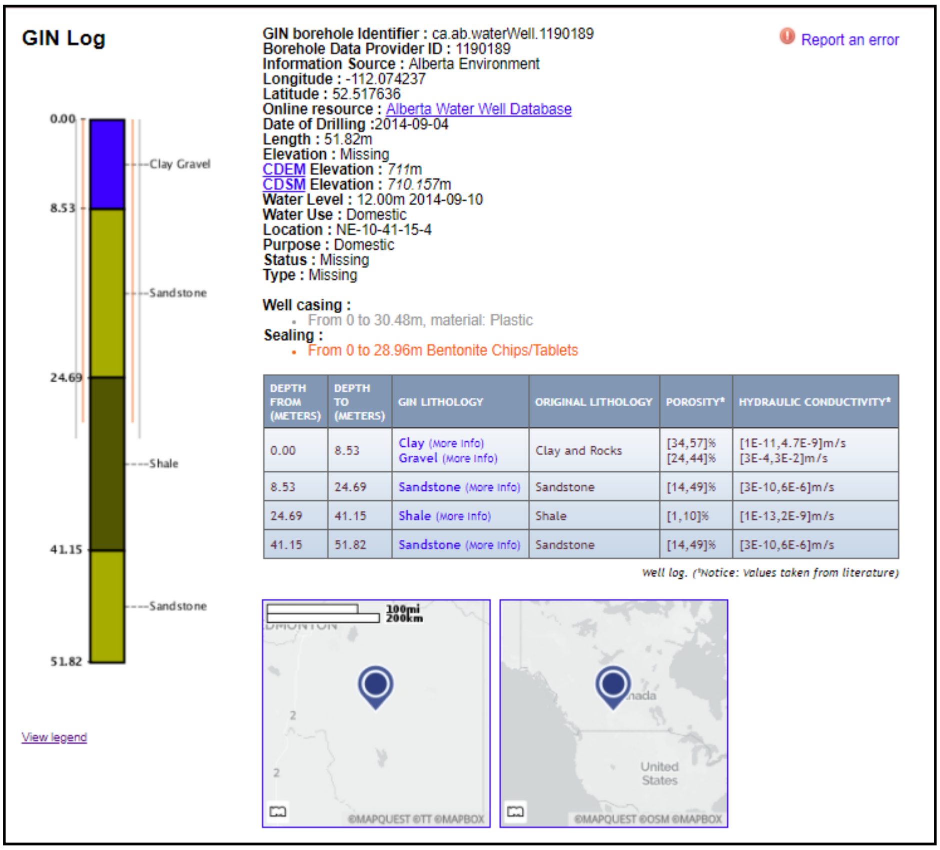


Figure 6 - Screenshot of the tool for visualizing well record stratigraphy information as part of Canada's Geographic Information Network (GIN, 2020). Data for the selected record is from the Alberta Ministry of Environment and Parks, provided by GIN.

5 Uses of Well Record Databases

Well record databases are a critical source of information for the effective management of groundwater and are utilized by diverse groups of users ranging from homeowners and realtors to well contractors, groundwater managers and researchers. The databases are important for the sound management of groundwater resources, and the availability of these databases tends to increase confidence in the management and use of the resource.

Critical information provided by well record databases includes the location and construction of water wells and details about the aquifer supplying the water well. Following the release of a groundwater contaminant, this information is commonly used to assess the extent to which nearby water wells are vulnerable to contamination, and how many people may be potentially exposed. Some other common uses of well record databases include the following.

- Evaluating water well quality for home buyers and sellers during property transactions.
- Evaluating well construction details for well owners in the event that well repairs or modifications are required, or to diagnose or repair well water quality issues.
- Determining the ongoing capacity of the well to produce water as compared to initial static water level and well performance (i.e., the volumetric rate of discharge per unit decline in well water level).
- Monitoring of trends in the well construction industry.
- Checking regulatory compliance (e.g., ensuring contractors are performing work properly, by documenting whether well construction complies with regulatory requirements in terms of construction, materials, clearance distances).
- Monitoring of trends in groundwater use and reliance on domestic wells to support estimates of groundwater utilization and demographics of drinking water supply.
- Assessing environmental impacts and approving industrial activities (e.g., assessment of the impact of various activities on domestic well users and where to focus risk management activities).
- Mapping exposure and targeting interventions (e.g., awareness programs, well water quality testing programs) based on the distribution of domestic wells relative to the location of areas of naturally occurring groundwater contaminants.

Well record databases are also used for a wide variety of scientific purposes by professional geoscientists and researchers. These databases serve as a critical tool for hydrogeologists to develop a three-dimensional understanding of the hydrogeologic system for studies of aquifer vulnerability (e.g., Stempvoort et al., 1992), aquifer mapping (e.g., Reeves et al., 2017) or groundwater flow modeling (e.g., Camp and Brown, 1993). Other common applications of these databases include groundwater exploration, regional groundwater resource assessment, oil and gas reservoir modeling, groundwater recharge and flow model calibrations, and hydraulic conductivity, water yield and water use estimates.

Although there are biases and data quality issues associated with these datasets (see Section 6, *Shortcomings of Well Record Databases*), they tend to contain a large number of records and can be useful (given the appropriate data quality filters) in capturing regional trends without the errors and biases significantly affecting scientific conclusions. Box 3⤵, Box 4⤵, Box 5⤵, Box 6⤵, and Box 7⤵ provide examples of recent research projects that have used well record databases. The large and growing volume of data contained in well record databases (Figure 7) makes them suitable for big data and artificial intelligence analysis.

It is critical that the beneficial uses of well record databases for the various types of users be promoted through education and outreach efforts to foster support for the continued maintenance and improvement of these databases, or the initiation of well record data collection in those jurisdictions lacking a program. For example, domestic well owners should be educated on the type of information recorded by contractors on well record forms, and how this information may be used by the well owner as part of on-going well stewardship activities.

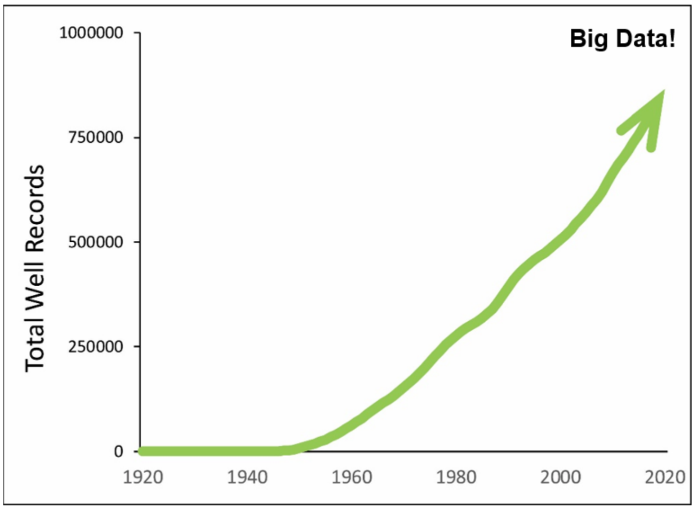


Figure 7 - Cumulative number of well records in the Ontario Water Well Information System from the 1920s to 2019 (Ontario Ministry of Environment, Conservation and Parks, 2021).

Well water quality data are the next most common type of domestic well data collected by government organizations after water well records. In some jurisdictions, governments conduct domestic well water quality survey programs or have developed a system for the collection and organization of domestic well water quality results, but there is rarely a regulatory requirement for the submission of these data. Open sharing of water quality datasets can be more challenging compared to water well records because domestic well owners may be concerned that the publication of their data will negatively impact property values or insurance rates (Zipper et al., 2019), or given that providing the information is voluntary, they prefer it remain confidential. Hence, well water quality databases are often used only for internal purposes, such as human health risk assessments, and are not usually available in a digital, publicly accessible format. In other cases, well water quality data may be published but the data is aggregated or the sampling location is anonymized by moving it to a less accurate map reference location (i.e., topographical or land subdivision map).

6 Shortcomings of Well Record Databases

A common shortcoming of well record databases is that they typically do not capture the more detailed geological data interpreted from boreholes by experts during hydrogeological or geotechnical investigations. Because water well contractors often lack specialized geological training, the geological data captured by well contractors can be rudimentary and lead to inconsistent classification of different geological units by different well contractors, which makes direct comparison of adjacent records challenging. In addition, water wells are usually drilled using rotary techniques that provide only an approximate representation of the subsurface geology because an intact geologic core is not obtained, but rather geology is interpreted from rock chips that rise to the surface during drilling, where the original depth of the chip is imprecisely known. Water well records can reveal more about aquitards than aquifers because it is common to terminate well construction when a suitable aquifer is encountered without drilling to the base of the aquifer.

Another common shortcoming of well record databases is the poor accuracy of water well locations recorded in the database, especially for domestic wells. Prior to the proliferation of handheld GPS technology, the coordinates of older wells were typically recorded relative to a map reference (e.g., approximate position on a topographical or land subdivision map) and may be only accurate to several hundred meters at best. In jurisdictions where there is no system for physically tagging wells with a unique identifier label, it can be challenging for well owners to find a record of their well in the database, especially where location coordinates are not accurate and property ownership has changed a number of times since the well was constructed. Surface or wellhead elevation information can be useful for interpreting water level and groundwater flow patterns; however, this data is seldom recorded by well contractors during well construction due to the challenges associated with accurately measuring elevation using simple, inexpensive devices.

Well record databases can have large gaps where well construction activity pre-dates the adoption of well record reporting. A voluntary well registration program for older wells can help fill in some of these gaps. For example, in as the Province of British Columbia↗, the practice of voluntary reporting of well records before the implementation of mandatory reporting in 2016, and the subsequent implementation of a program to register older wells, has contributed to building a considerable database of historical well records.. In other cases, well records may be missing, incomplete, or contain significant errors due to a lack of regulatory compliance or enforcement of submission requirements. Basic well screen details are often lacking in well record databases (e.g., presence of screen, depth of screen), which can make it impossible to associate water well information with aquifers, especially in layered glacial aquifers (Holysh and Gerber, 2014), and therefore difficult to meaningfully interpret water level elevations and yields.

Some well types, such as dug wells, may be under-represented in well record databases due to a bias with respect to well log submission rates by contractors. For example, the distribution of well types in the Nova Scotia Well Logs Database (Nova Scotia Environment, 2020) indicates that only about 10 percent of water wells are dug wells, whereas regional field survey data in mostly rural areas of the province suggests that the proportion of dug water wells may be as high as 30 percent (Kennedy and Drage, 2020). Dry wells may also be underreported (Misstear et al., 2017) because failed boreholes or 'unfinished' wells are often not reported by well contractors. This information, however, may be especially important for predicting areas where groundwater quantity is limiting or for constructing accurate yield distribution curves as detailed in Box 5 (Misstear et al., 2017).

Well records tend to be static, capturing information only at the time of well construction, which can limit their usefulness in terms of identifying active wells and current well usage patterns. A common problem is that the water level in the well is in the process of recovering to its static level when the well contractor leaves the site, so the recorded static water level is lower than the water level in the aquifer. Misstear and others (2017) emphasized the need for well record data to be more dynamic in order to be used effectively as a management tool, recording operational data such as water quality, water level and yield over time, in addition to any maintenance activities or modifications to the well.

Standard methods for estimating the yield of domestic wells (e.g., in drilled wells the placement of the drill stem toward the bottom of the borehole, injecting air, and measuring the rate of displaced water as return flow over a period of about an hour with a bucket and stopwatch) often result in the overestimation of well yield. This effect is largely due to the short-term duration of the test, as short-term yields are controlled mainly by the transmissivity of the geologic materials/fractures near the borehole and may not be representative of the longer-term sustainable yield of the aquifer. For fractured bedrock aquifers the longer-term yield will be controlled by the connectivity, storage and recharge properties of the fracture network in the wider aquifer (Misstear et al., 2017). On the other hand, if the well has been insufficiently developed, the well yield estimated by the well contractor following well completion may be underestimated.

In jurisdictions that receive hard copies of well records and then manually enter the information into a database format, keeping the databases current is a persistent, resource intensive challenge. As a result, most jurisdictions favor recording information as submitted on the well logs, making only minor corrections rather than conducting a robust expert review of the accuracy of submitted information.

A lack of consistent policy for governing groundwater data management across national and subnational scales can result in dissimilar data availability and access. Even where groundwater records are widely available, a lack of consistent terminology or standards for the reporting of well record information, especially lithology, is a major challenge for researchers looking to aggregate well record information at spatial levels that cross political boundaries. There can be significant differences in how data is collected and managed even at small spatial scales (e.g., county or subregional level). Inconsistent terminology can be mitigated through expert interpretation and correction, but this process is time-consuming and costly.

7 Best Practices for Water Well Record Management

Following best management practices for managing well records directly contributes to the advancement of safe drinking water and the protection of groundwater resources. The collection of good quality well record data can also have ancillary benefits, such as the use of this data as a research tool for understanding opportunities, hazards and threats to aquifers. While there is no universally accepted standard, the previous section on the shortcomings of well record databases is useful in formulating an idealized scenario for well record data management. Four overarching objectives, and associated recommended system components for achieving these objectives, are outlined in Table 3.

Table 3 - Key objectives for well record management to support drinking water and groundwater management program goals and recommended system components to achieve the objectives.

Objective	Recommended System Component
Water well record data is effectively captured	• Mandatory submission of well record data to a centralized authority by water well contractors as a legislated requirement • Well records are required for all types of water wells (e.g., public, domestic, agricultural, industrial) • Regulatory tools and resources are used to ensure compliance with mandatory well record submission requirements, including outreach, training, inspection and enforcement activities
High quality, useful, accurate information is captured in water well record forms and databases	• Well record forms are designed to achieve compromise between the amount of data collected by well contractors and the utility/importance of these data (e.g., emphasis should be on critical well construction information and especially useful data such as accurate water level measurements and yield estimates) • Submitted well record data is complete (i.e., all fields have been filled out) • Well locations are recorded in the field using GPS or equivalent • Unique well identifier label is physically affixed to each water well and is referenced to the well record • Minimum standards are established for geological training for water well contractors so that they are collecting reasonably good quality water level and yield information and so that lithological descriptions are useful for geological interpretation • Where applicable, well screen details (e.g., screen depth) are adequately captured on the well record so that the aquifer(s) supplying the water well can be identified and related to the well information • Field measurement of simple water quality parameters are recorded, such as electrical conductivity • Pump installation details are recorded (could be separate form) and related to the well record • Consistent standards are established for geological nomenclature for use by water well contractors at regional scales, and preferably a unified nomenclature adopted at national and even international scales • Rigorous quality-assurance/quality-control review of submitted well records is conducted to ensure high quality data is captured in well record databases • Following a change in status of a water well (e.g., decommissioning, modification), the updated status is related to the original record so that current well status information can be accessed

Water well record publication is timely	• The data management system allows for online submission of well record forms, including user-friendly phone applications, to reduce labor intensive manual well record data entry and to improve timeliness of well record submission by contractors • The system allows for the timely review and publication of a well record following water well construction and the submission of the associated record (e.g., days to months)
Water well record data is findable and accessible in various formats	• Well record data is easily found on the internet and is publicly available • Well record data is distributed in various open file formats, including printable reports for well owner's records • Various options are available for searching of well records, including a map interface • Graphical viewers or widgets are available to enhance the communication of well record information

A regulatory framework for the mandatory submission of well records is the most critical component of a successful well record management system. Where the regulatory framework is absent or inadequate, it can require a significant level of effort to create new legislation. For any jurisdiction looking to strengthen the regulatory framework, or make other improvements to well record management systems, it is important to provide evidence-based linkages between well record best management practices and the goals of drinking water and groundwater management programs, such as drinking water safety and groundwater protection.

Barriers to achieving the four key objectives presented in Table 3 are often related to resource constraints. For example, auditing and enforcement of well construction activities in relation to the completion of good quality well records may consume significant resources, especially if compliance mechanisms are not easy to implement. Data entry and review processes can also be extremely resource intensive, depending on the design of the data collection system. The design and implementation of an efficient system for the collection, review, and publication of well record data, however, usually requires the adoption of an advanced data management solution, with suitable information technology infrastructure. These types of solutions can be expensive to acquire, implement and maintain, although over the long-term they offer cost efficiencies and improved data quality. They also offer significant opportunities for automated data validation, standardization (e.g., online drop-down lists to constrain geological descriptions to standard nomenclature), and analytics. An idealized information flow of well record data is presented in Figure 8.

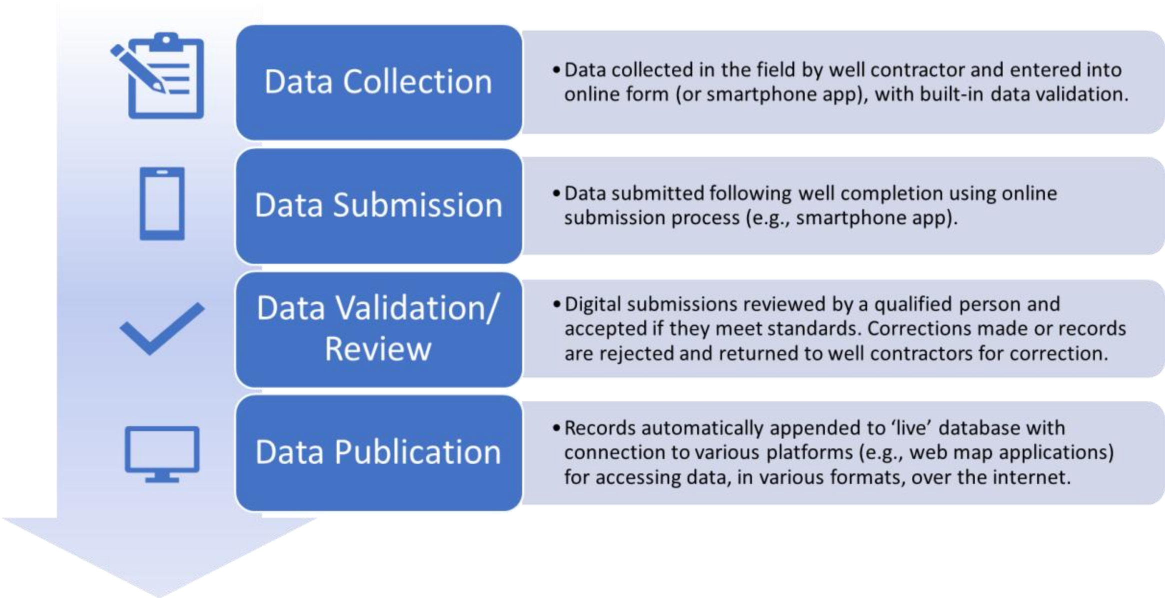


Figure 8 - Ideal information flow for well records from data collection in the field to publication over the internet.

Another barrier to achieving some of the objectives outlined in Table 3 includes the requirement for the development of standards and training for well contractors and data managers. Training programs can help achieve minimum standards for identifying lithological types and improve the quality of the data contained in well record databases. Recognizing that water well contractors are not geoscientists, a compromise is required to ensure that well record data is high quality and supports drinking water and groundwater management program goals without causing undue burden on water well contractors. There is no international standard available, and in most cases standards and training programs related to well record management must be developed by local governments administering the program, where resources can be limited. Groundwater associations (e.g., the National Groundwater Association in the United States) can have an important role in working with governments to develop and deliver consistent training standards.

A productive working relationship between government/regulatory bodies and water well contractors (often represented by an industry association) is an important aspect of the success of any well record management system, as it requires cooperation and investment from both parties. Where the quality of well record data is limited by the capacity of well contractors to purchase critical equipment, such as water level, flow or specific conductance meters, government support (e.g., subsidies) can be impactful. For example, the Province of Nova Scotia provided GPS units to all well drillers in 2004 to improve the spatial referencing of well record data. The Nova Scotia Well Logs Database now contains GPS locations for about 20 percent of all well records in the database.

Although the recommended best management practices are difficult for most jurisdictions to implement, they may be useful in providing a road map for incremental improvement. For jurisdictions that would like to start collecting well records but have limited capacity, the most important elements of a well record management program is the collection and digitization of a well record form (ideally under a mandatory regulatory framework), completed in the field by a well construction contractor, recording basic information about the water well, including a unique well identifier, the location, the driller, the owner, the depth and the static water level. To build long-term support for the collection of this data, it is critical that the database is made publicly available in a searchable digital format (e.g., simple database or spreadsheet and ideally on maps) so that it may be used by a diverse range of clients.

8 Conclusion

Water well record databases, which store information about water well construction, are widely viewed as an important component of groundwater and drinking water management programs. Records of well construction are typically compiled in a central database and made available to various users of the information which may include anyone from homeowners and well contractors to groundwater consultants, managers and researchers. These databases are arguably the world's largest and most important source of groundwater information and it is estimated that there could be up to a 100 million water well records archived worldwide. The main types of information recorded in well record databases include details pertaining to the well location, construction, and hydrogeological conditions.

The number of records in a jurisdiction's well record database varies depending on factors such as the size of the population reliant on domestic wells, the jurisdictional framework for managing and reporting well construction activities (e.g., voluntary versus mandatory) and the enforcement of reporting requirements where well record submission is a legal requirement.

Over the past 50 years well record databases have evolved in many jurisdictions from hard copy forms filed in a central location to open distribution of well record data over the internet. The digitization of well record information in these jurisdictions has engendered enhanced access and utilization of the datasets and permitted the development of new tools for data visualization and analytics. Despite these technological improvements, however, the availability of water well record databases is highly variable, ranging from hard copy reports to digital data.

A robust system for collecting, managing, and disseminating well record data, in addition to adequate standards for training and data quality, are important components of drinking water and groundwater protection programs. Key objectives for well record management include the effective capture of water well location and construction activities, the collection of high quality and useful data, the timely publication of well record data and the open distribution of this data in various formats that can be easily found and accessed on the internet.

Adopting best practices in well record management can yield high quality hydrogeological data suitable for various types of uses relating to water well stewardship, groundwater protection, human health protection and groundwater assessment and research. As a research tool, well record databases have contributed significantly to our understanding of groundwater resources at local to regional scales. Continued improvements to the online accessibility of well record data will foster greater utilization of these datasets for groundwater management and research.

9 Exercises

Exercise 1

Is there an online well record database for your jurisdiction? If so, how many well records are in the database? Does it include domestic water wells?

Click for solution to Exercise 1↓

Exercise 2

Consult the well record database for your jurisdiction (or see Table 2 for some examples of online well record databases) and determine whether the well records found in the database are part of a mandatory or voluntary well record submission program.

Click for solution to Exercise 2↓

Exercise 3

Consult the well record database for your jurisdiction (or see Table 2 for some examples of online well record databases) and locate an example of a domestic water well record. Write down any hydrogeology information you find on the log.

Click for solution to Exercise 3↓

Exercise 4

Consult the well record database for your jurisdiction (or see Table 2 for some examples of online well record databases) and retrieve at least 100 records from a chosen geographic area. Summarize the data to include the average well depth and yield.

Click for solution to Exercise 4↓

Exercise 5

How might a home buyer use the information available in well record databases?

Click for solution to Exercise 5↓

Exercise 6

How might a domestic well owner use the information available in well record databases?

Click for solution to Exercise 6↓

Exercise 7

What are some of the reasons that water well logs are missing from well record databases?

Click for solution to Exercise 7⤵

Exercise 8

Provide at least two examples of information that is not usually collected by water well contractors but could be useful and readily obtained during well construction.

Click for solution to Exercise 8⤵

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11 Boxes

Box 1 History of the Nova Scotia Well Logs Database

A timeline that covers the last 100 years shows milestones for the development of the Province of Nova Scotia's (Canada) well record database (Figure Box 1-1). Although the oldest well construction record in the Nova Scotia Well Logs Database↗ is from the 1920s, the submission of water well logs was originally required in 1965 when the province's first generation of well construction regulations were developed (1965 Well Drilling Act). The Act made it mandatory for a well contractor to provide well logs to the government according to a prescribed form within 30 days of well completion. As part of the new system for tracking well construction in the province, a parallel effort was made to collect older well records volunteered by well contractors. These records were published annually in books (Figure Box 1-2). The province adopted an electronic database format for compiling well log data in the 1980s, with the digitization of older logs and the development of the modern database occurring in the early 2000s. In 2009 a version of the database was published for the first time in a spatial format as an online map viewer application (Figure Box 1-3).

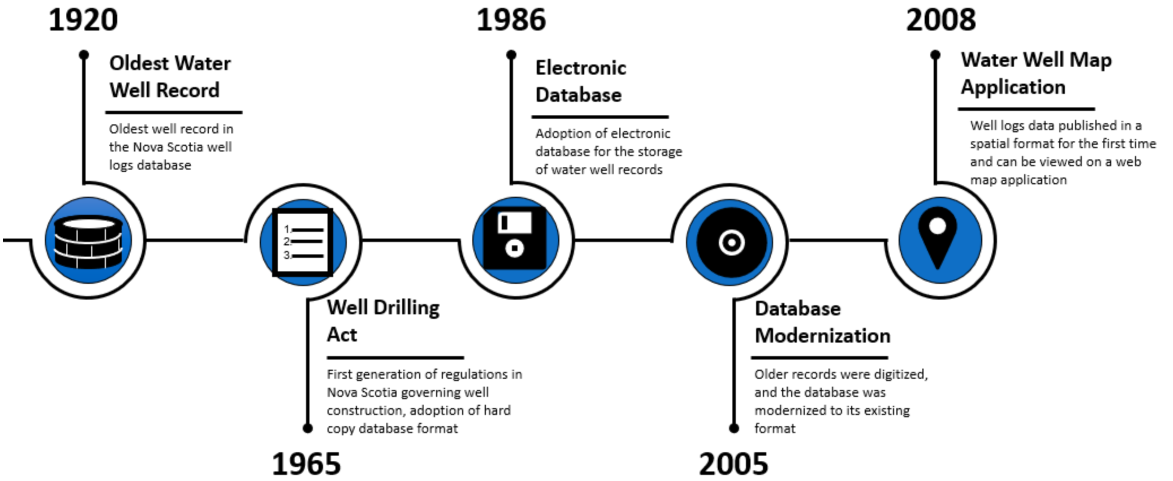

Figure Box 1-1 - History of the development of the Nova Scotia Well Logs Database.

Water Well Records 11D

M.T.	Ref. Map	S.T. Map	Year Drilled	Owner	Driller Lic. No.	Well Depth (ft.)	Water Depth (ft.)	Hole Diam. (in.)	Csg. Lgth. (ft.)	Use	Qual.	Sur. Elev. (ft.)	Aquifer	Pump or Bail Test	Lithologic Log and Remarks
64	D	2	1966	Hollirgum, R.B.	3	270	35	6	36	D				1.5 gpm	0-29 gr & bldrs; 29-270 quartzite
64	D	2	1966	MacInnes, I.C.	3	340	60	6	29	D				3 gpm	0-24 cl & bldrs; 24-340 quartzite
83	A	5	1966	Shornys, David	22	165	18	6	21	D				1 gpm-1 hr.	0-11 cl; 11-165 granite
83	A	5	1966	Burns, B.	22	75		5	16	D				10 gpm-1 hr.	0-3 sd; 3-75 granite
95	C	5	1966	Cormier, W.J.	22	110	95	6	18	D					0-10 cl; 10-110 granite
98	C	5	1966	LeBlanc, M	30	24	13		8	D					0-2 dr; 2-24 granite
98	C	6	1966	MacMillan, R.	5	33	8	6	12	D				3.5 gpm DD-16'2 hrs. REC-8'12 min.	0-33 granite
98	C	5	1966	Vaughan, P.	5	53		6	18	D				3 gpm-2.5 hrs. DD-53' REC-ground level 60 min.	0-12 sd; 12-53 granite
101	C	5	1966	Corney, A.	5	46	9	6	16	D				3 gpm DD-46'3 hrs. REC-9'30 min.	0-46 granite
101	C	5 .	1966	Duggan, J.	5	80	10	6	18	D				2.5 gpm DD-80'3.5 hrs. REC-10'30 min.	0-8 sd; 8-80 granite
85	D	5	1966	Drage, Mr.	30	50	50	6	20	D				3 gpm	0-15 hard rock; 15-20 hard rock: 20-50 granite
56	D	8	1966	Graham, Lonis	3	150	70	6	150	D					0-150 sd & gr
82	B	11	1966	D.N.D. (Navy)	3	212	40	6	136	I				8 gpm	0-136 gr, cl, bldrs; 136-212 black sl
85	B	11	1966	Pothier, Mr.	30	125	125	1.5	14	D				1.5 gpm	0-14 sd to br
88	B	11	1966	D.N.D. (Navy)	3	212	68	6	136					8 gpm	0-110 cl, gr, bldr; 110-212 sl & quartzite
108	B	11	1966	Mont, Bill	22	75		5	27					overflow	0-2 mud; 2-75 quartzite
108	B	11	1966	Houlihan, F.	30	113	30	2.25		D					0-2 dr; 2-60 whinrock; 60-113 quartzite
108	B	11	1966	Mont, W.	22	145	145	6		D				1.5 gpm	0-3 mud; 3-150 quartzite
108	B	11	1966	Mont, W.	22	75	S	6	21	D				1 gpm	0-2 mud; 2-75 quartzite
108	B	11	1966	Mont, W.	22	120	120	6	18	D				.5 gpm	0-3 cl; 3-120 quartzite
16	C	11	1966	Morrine, Gerald Bates, Earl	8	70	10	6	20	D				4 gpm REC-10'	0-2 topsoil; 2-70 sl
16	C	11	1966	Humphreys, B.	13	73	23	6.25	54	D				3 gpm	0-57 cl; 52-73 quartzite
19	C	11	1966	DeYoung, Mrs.	22	195	195	6	30	D				1.5 gpm-1 hr.	0-25 cl; 25-195 quartzite
26	C	11	1966	Hirtle, L.H.	22	150	130	6	18	D				1 gpm	0-3 mud; 3-150 quartzite
42	C	11	1966	Cormier	30	117	117	6		D				1.25 gpm	
42	C	11	1966	Hartley, R.	30	39.5	39	6	12	D				5 gpm REC-8'20 min.	0-12 bldrs & br; 12-39 hard rock
78	C	11	1966	Jackson, G.	13	100	50	6.25	9	D				3 gpm REC-50'	0-9 ground and stones; 9-100 sl, rock

Figure Box 1-2 – Example of original hard copy book format for publishing Nova Scotia (Canada) well record information (Nova Scotia Department of Energy and Mines, 1968).

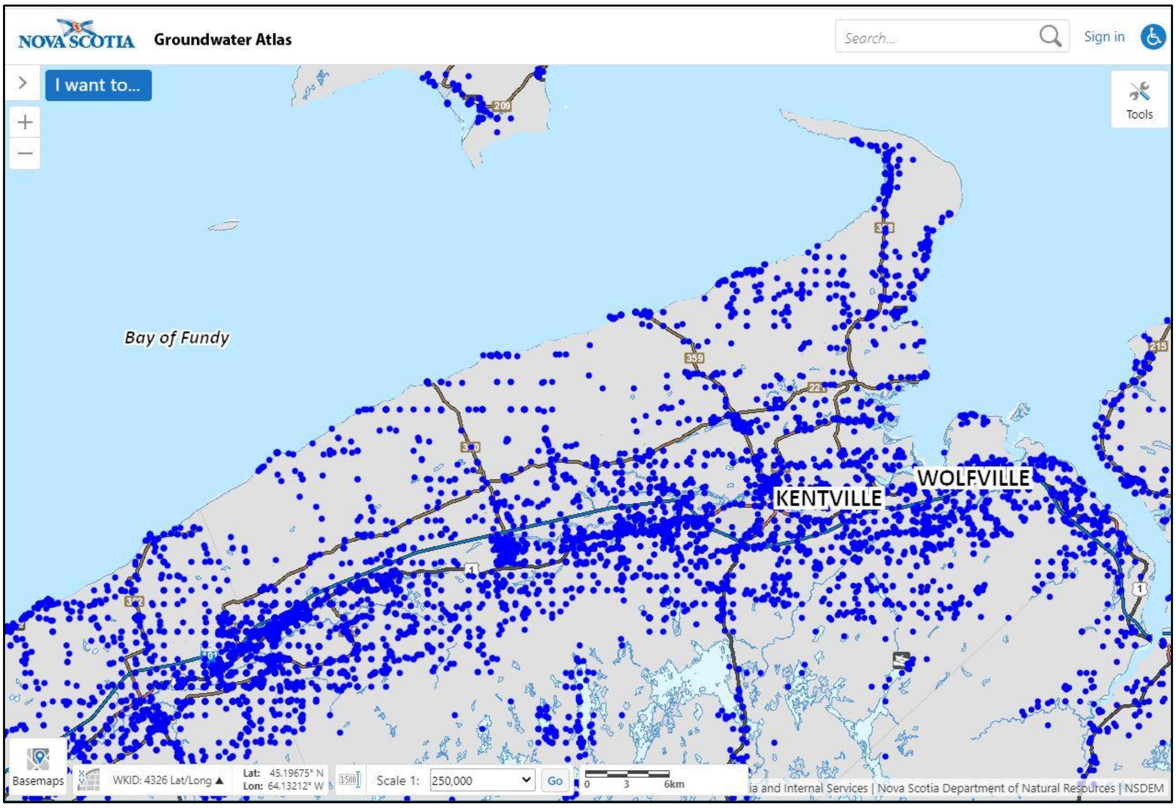

Figure Box 1-3 - Screenshot of Nova Scotia Groundwater Atlas showing well record data in an online map format, Nova Scotia, Canada.

Return to where text links to Box 1

Box 2 The Groundwater Information Network

The Groundwater Information Network (GIN)↗, shown in Figure Box 2-1, is a network of data providers cooperating to make Canada's groundwater information more interoperable online by using common protocols and standards (Figure Box 2-2). GIN was established in 2012 and currently includes well record data from eight provinces and one territory in Canada. As part of its interoperability mandate, GIN has collaborated on the development of an international data standard to facilitate the online exchange of well record data and other types of groundwater information (Brodaric et al., 2016, 2018).

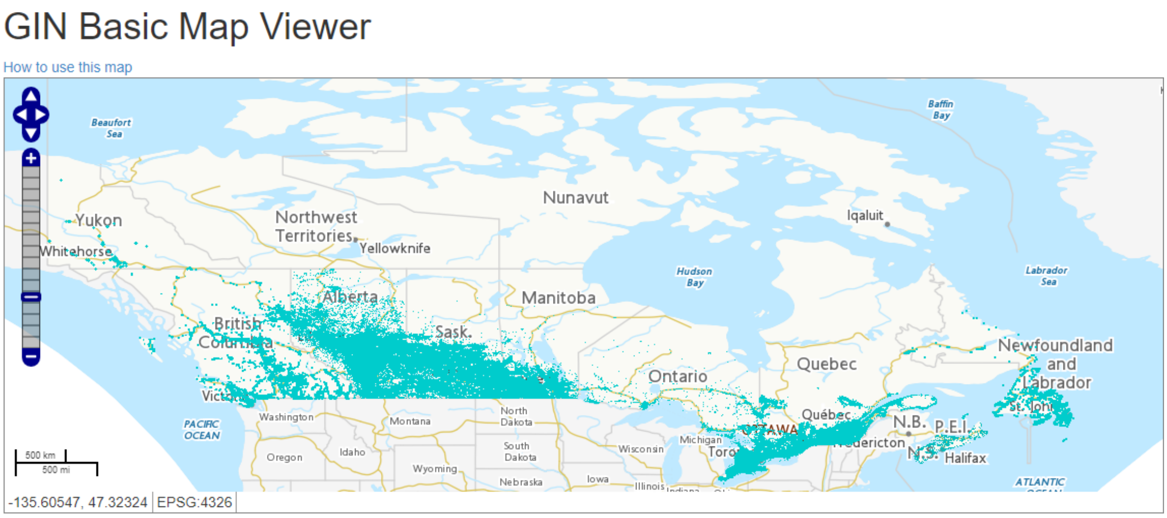

Figure Box 2-1 - Screenshot of GIN viewer showing the location of water wells in provinces and territories across Canada participating in the GIN project (GIN, 2020). Water wells are represented as teal dots on the map.

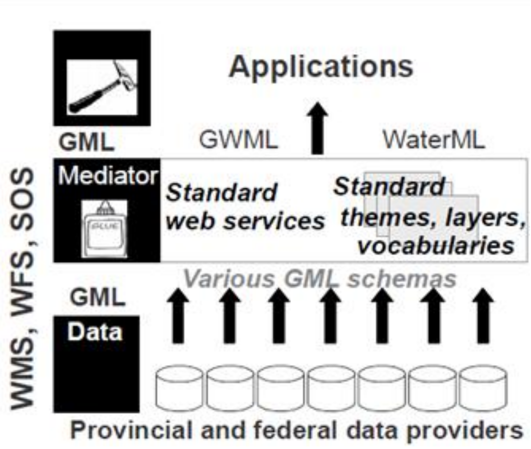

Figure Box 2-2 - GIN Architecture where requests and responses from heterogeneous data sources (web map services, web feature services, and sensor observation services) are dynamically translated by the GIN mediator and converted into a Geography Markup Language (GWML, WaterML). From Boisvert and others (2011).

Return to where the text links to Box 2↥

Box 3 Use of Well Record Data to Identify Areas of the United States Vulnerable to Seawater Intrusion

A study (Jasechko et al., 2020) to identify coastal areas of the contiguous United States where most well water elevations lie below sea level, and therefore identify areas potentially vulnerable to seawater intrusion, made extensive use of well record databases from states with coastal exposures (Figure Box 3-1). The study used static water levels (i.e., measurements made following well completion but before a pump was installed in the well) from over 50,000 wells measured since the year 2000 as recorded on well construction reports. The measurements agreed with nearby monitoring well readings, suggesting that the well records provide reliable data on groundwater elevations. The use of the well record database afforded the study authors with a high density of observations and a wide range of aquifer depths.

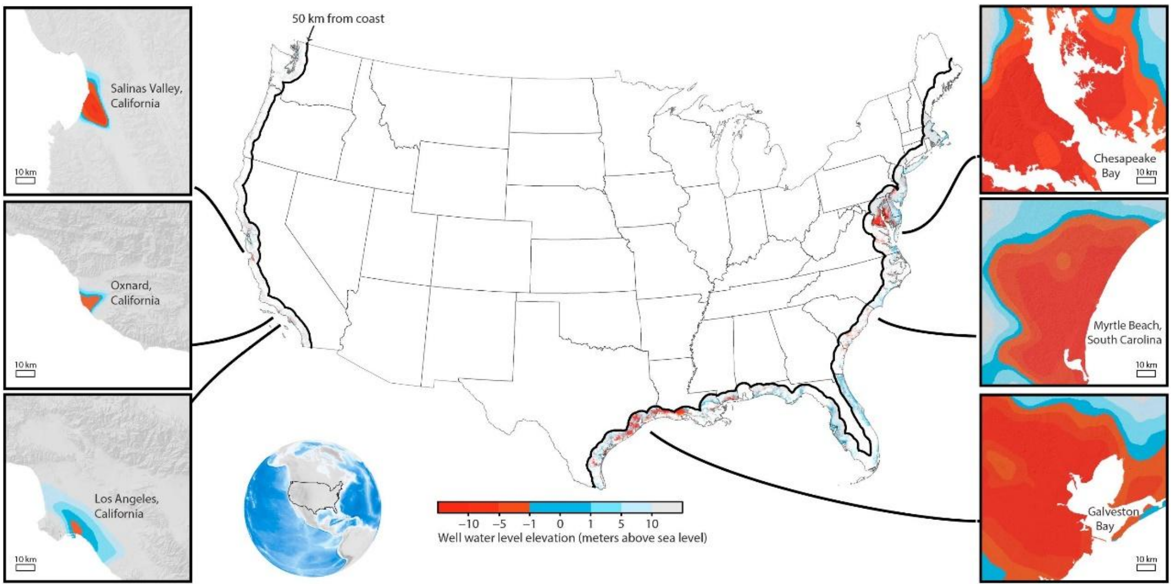

Figure Box 3-1 - Well water elevations across the contiguous United States. The center map shows unique well locations within 50 km of the coastline, with the dot color corresponding to the well water elevation measured after January 1, 2000. Interpolated water level elevations are shown in the six inset maps.

Return to where the text links to Box 3

Box 4 Use of Well Record Data to Characterize Regional Aquifer Hydraulic Conductivity

A study by Priebe and others (2017) used the Ontario Water Well Information System (well record database) to investigate spatial patterns of hydraulic conductivity. The spatial coverage of hydraulic conductivity (K) measurements for large-scale groundwater investigations is often poor due to the high cost associated with hydraulic testing and the large areas under investigation. Water well records provide a wealth of information that can be used to estimate K from specific capacity measurements that are recorded during well construction. To assess the validity of well construction specific capacity tests, these data were compared to higher quality hydraulic conductivity measurements. Results of the comparisons demonstrate that reconnaissance-level K estimates from specific-capacity tests approximate the ranges and distributions of the high-quality K values (Figure Box 4-1). The study findings indicate that specific capacity data measurements from well record databases can be used with confidence by practitioners seeking to enhance their spatial coverage of K values.

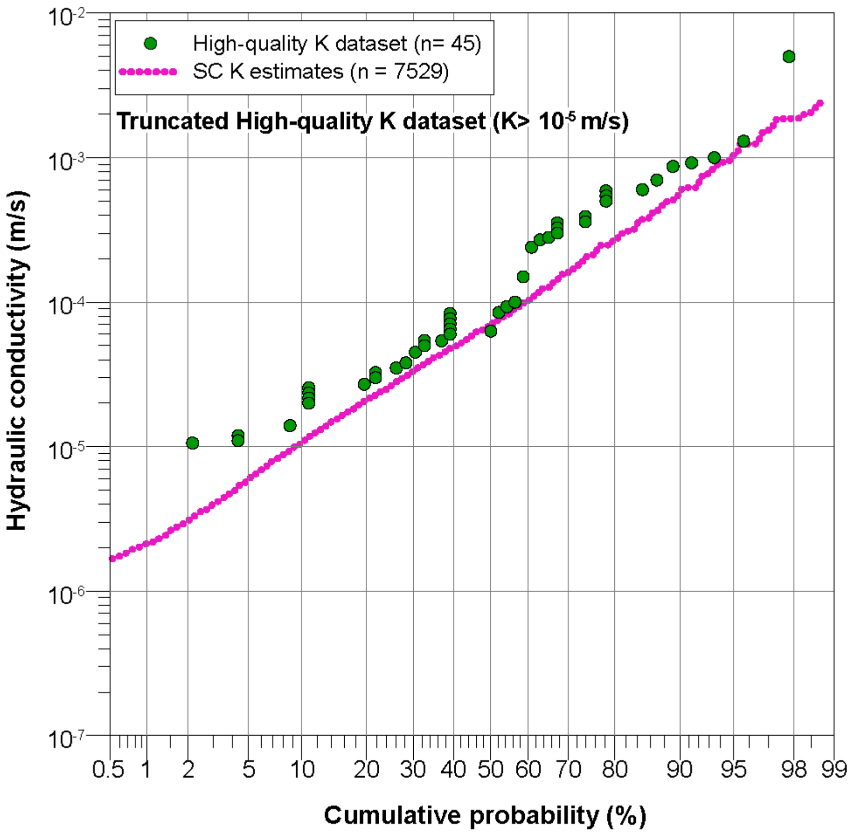

Figure Box 4-1 - The cumulative probability distribution for hydraulic conductivity estimates from specific capacity data recorded on well records (pink symbols) and the high-quality hydraulic conductivity dataset (green symbols). The high-quality hydraulic conductivity dataset was truncated below values of 10^{-5} m/s so these values are not shown on the chart.

Return to where the text links to Box 4

Box 5 Use of Well Record Data to Compare Yield Distributions

Using available well record data from Finland (Central Finland Regional Environment Centre, 2007), Norway (Morland, 1997; Geological Survey of Norway, 2008) and Sweden (Gustafson, 2002), Banks and others (2010) compared the distribution of short-term yields from crystalline bedrock types. Despite differences in lithologies, climate and tectonic history between the countries, the yields in the datasets showed a remarkably similar distribution (Figure Box 5-1). In addition, although wells drilled in crystalline bedrock can exhibit a wide range of yields, the median well yield of all three datasets was in the 600 to 700 L/h range. Based on these results, the apparent bulk transmissivity based on an observed empirical relationship between short-term specific capacity and apparent transmissivity in crystalline rocks of the upper 70 to 80 m of crystalline bedrock aquifers in this region was estimated to be about 0.56±0.3 m^2/d. An understanding of the statistical distribution of hydraulic properties of crystalline bedrock aquifers is needed to inform cost-effective drilling strategies in these types of aquifers.

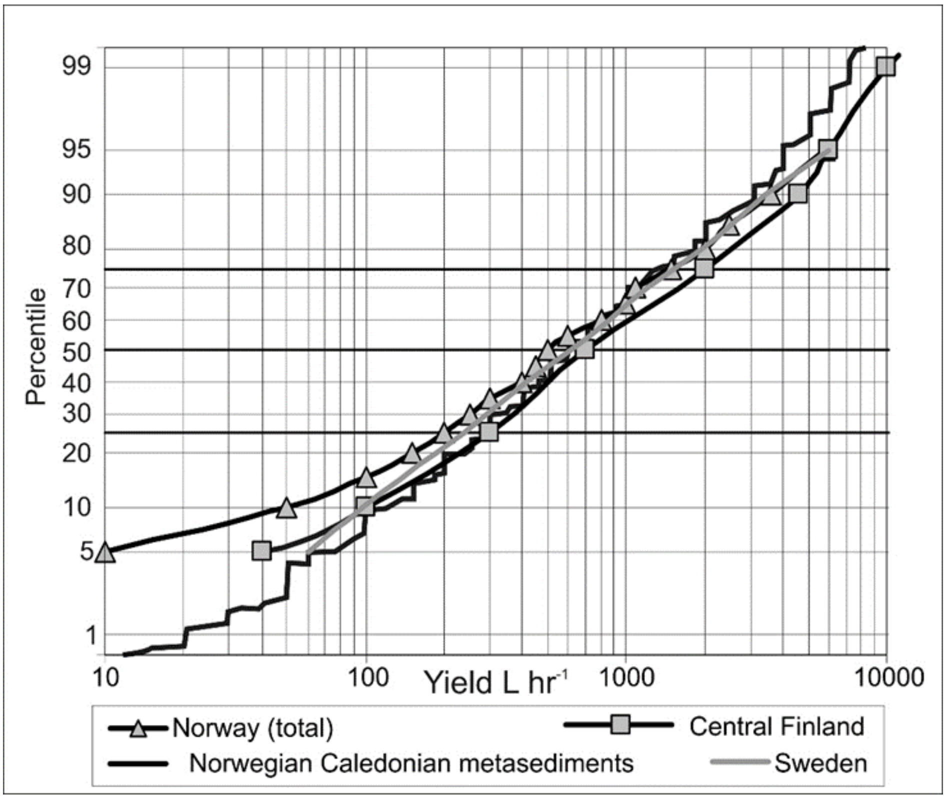

Figure Box 5-1 – Comparison of the distribution of short-term well yield in crystalline bedrock aquifers of Central Finland (n=1297), Norway (Caledonian metasediments, n=2098; all crystalline rock, n=26,811) and Sweden (n=59,000). Note the probability scale on the y-axis and the logarithmic scale on the x-axis (from Banks et al., 2010).

Return to where the text links to Box 5↥

Box 6 Use of Well Record Data to Identify Dry Wells in the Western USA

A study by Perrone and Jasechko (2017) used over two million water-well records from 1950 to 2015 in the western United States to estimate the percentage of wells that were dry during the years 2013 to 2015. The analysis of the water level from 2013 to 2015 compared to well depths was used to highlight potential groundwater management issues in the western United States. The study showed that approximately 3.3 percent of wells constructed between 1950 to 2015 had water well bottom elevations below interpolated water levels, 6.3 percent of the wells had a water level that was 0 to 5 m above the bottom of the well, and 17.5 percent of wells had a water level that was 0 to 10 m above the bottom of the water well. The analysis indicates that many domestic wells are vulnerable to declining water levels, including California's central valley, which can lead to costly or challenging adaptation scenarios (Figure Box 6-1). Domestic wells tended to be shallower, and therefore more sensitive to water level declines, compared to agricultural wells.

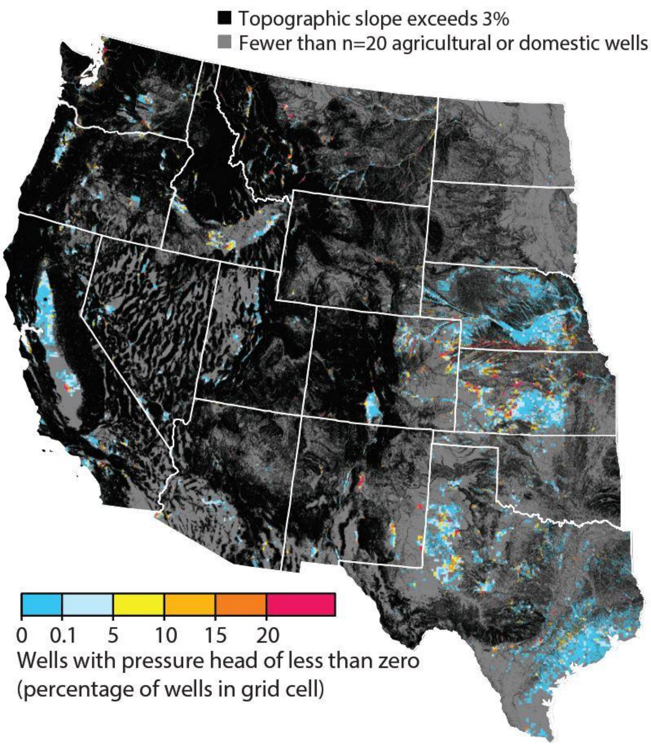

Figure Box 6-1 - The map shows the percentages of wells with estimated water tables that are deeper than the bottom of the wells, which are interpreted to be dry wells for the western United States in 2013-2015. Black shaded regions have high topographic slopes (> 3 percent) and were not analyzed. Dark gray areas mark regions with slopes of less than 3 percent, but with insufficient groundwater well data for analysis (i.e., less than 20 groundwater wells were analyzed in the study). Modern water tables (2013-2015) were determined using wells shallower than 100 m.

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Box 7 Use of Well Record Data for Identification of Surficial Aquifers in Nova Scotia, Canada

In Nova Scotia, the provincial well record database (Nova Scotia Environment, 2020) has been used extensively for research and interpretation purposes, in part due to the limited resources of the small province to collect subsurface data. A few examples include provincial scale hydrogeological characterization (Kennedy and Drage, 2009), the use of static water level information reported on well logs to identify seawater intrusion vulnerability (Kennedy, 2012), the analysis of spatial patterns of water well type (e.g., shallow drilled, dug wells, deep drilled) to identify drought vulnerability (Kennedy et al., 2017), and the spatial analysis of temporal static water level trends and groundwater quantity issues recorded on well records to identify areas of potential groundwater stress (Kennedy and Utting, 2011).

The Nova Scotia Well Logs database has also been used to map and characterize surficial aquifers. For example, well log data can be used to construct stratigraphic cross-sections as shown in Figure Box 7-1a (Kennedy and Utting, 2011) or map the potential extent of surficial (Kennedy, 2014) aquifers suitable for groundwater supply development based on a spatial analysis of well log stratigraphic information (Figure Box 7-1b).

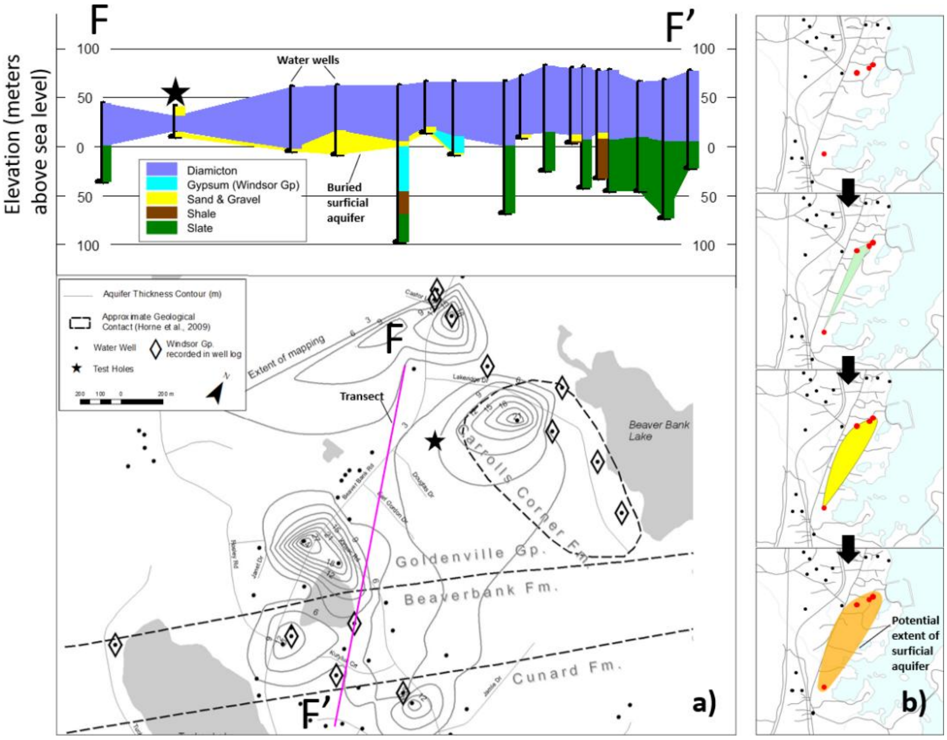


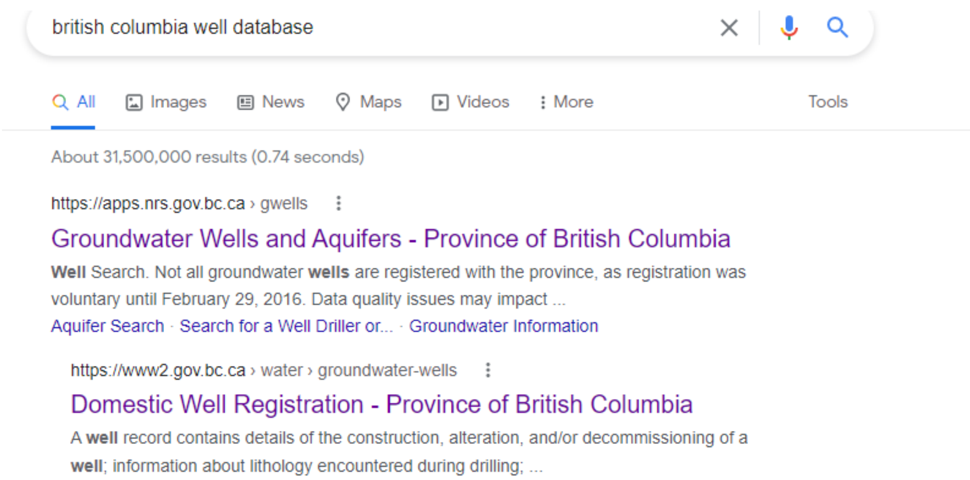
Figure Box 7-1 - a) Use of well log data to interpret geological cross-section and thickness of buried sand and gravel layer (from Kennedy and Utting, 2011); and b) GIS process to automate the delineation of the potential extent of surficial aquifers from well log data whereby wells intersecting surficial aquifer materials are grouped and then a smoothed polygon is created to envelop the points. Red dots indicate the presence of surficial aquifer materials that are more than 3 m thick as detected in well logs whereas smaller black dots indicate the absence of surficial aquifer materials (from Kennedy, 2014).

Return to where the text links to Box 7↥

12 Solutions

Solution Exercise 1

You will have to search the internet to determine if there is an online well records database for your area and, if possible, search the database to identify the type (e.g., does it include domestic wells?) and total number of well records that it contains. Start your search by entering the name of your governing unit at a specific level (e.g., country, province, state, county, district, or similar entity) followed by "water well database" until you find a promising link then follow that link. As an example, a search for "British Columbia well database" in December 2021 yielded the result shown below.



Click on the link to the webpage "Groundwater Wells and Aquifers" and then click on the link to download all wells (Well extract). By opening the downloaded file, you can determine how many records are in the database and what type of wells are included.

Return to Exercise 1

Solution Exercise 2

You will have to do research on the internet to determine whether a specific jurisdiction of interest has legislation applying to well record submission. For example, an internet search of "well construction regulations British Columbia" in December 2021 returned the following webpage.

https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/laws-rules/groundwater-protection-regulation.

In that case, by clicking on the link to "Read the Regulation in full" and scrolling to Part 10, the requirements pertaining to well construction records can be identified.

Return to Exercise 2↑

Solution Exercise 3

Hydrogeology information retrieved from a water well log may include stratigraphy encountered and lithological types, depth to bedrock, depth of water bearing zones, static water level, water yield and details of the yield test, and general water quality information (e.g., temperature, salinity, turbidity, color, odor). By navigating to the British Columbia Wells Database webpage (Exercise 1) in December 2021, one could zoom in to an area of interest, and then click on a well tag number hyperlink to bring up a webpage showing a summary of the well information. The Well Summary webpage provides various types of hydrogeology information such as lithology, well yield and depth to static water level.

Return to Exercise 3↑

Solution Exercise 4

Download data from an online well record database, open the data in a spreadsheet program, review the data to find and eliminate inconsistencies, then evaluate statistics on the 'clean' data for a few of the available fields of depth and yield. For example, the following average well depth and yield are presented for the city of 'Big Creek' by downloading the British Columbia Wells Database (Exercise 1) and filtering the 'City' field by "Big Creek", and generating averages for the 'finished well depth' and 'well yield' fields. This example uses a city with only 6 wells. Try to find a city with at least 100 wells.

well_tag_number	**city**	**finished_well_depth_ft-bgl**	**well_yield_usgpm**
3	BIG CREEK	120	5
53046	BIG CREEK	45	2
55962	BIG CREEK	47	50
111154	BIG CREEK	60	25
115888	Big Creek	79	50
115889	Big Creek	28	10
117943	Big Creek	58	40
AVERAGE:		**62**	**26**

Return to Exercise 4↑

Solution Exercise 5

A home buyer looking at a house with an existing well might want to know any of the following:

- the yield of the well (e.g., liters per minute) to determine whether the well is likely to be adequate for their water needs;
- the quality of the water reported during well installation (e.g., sulfurous, salty, clear);
- where the well is located and whether the well is properly constructed and meets codes for setbacks from sources of pollution such as septic tanks and roads; and,
- the type of aquifer and depth of the well along with thickness of overlying material in order to evaluate the potential for water quality issues and vulnerability of the water supply.

A home buyer looking at a house without an existing well might consult local well logs to find out any of the following: typical well types, depths, aquifers and water yields.

Return to Exercise 5↥

Solution Exercise 6

A domestic well owner might use a record of their water well construction to help diagnose issues with their water supply. The record could also be provided by well owners to contractors to design appropriate repairs or modifications to the well as needed.

Return to Exercise 6↥

Solution Exercise 7

Reasons that records may not be included in a well record database vary, but it is usually because of one of the following:

- records are not being submitted by water well contractors due to poor enforcement of legal requirements;
- records are not being submitted because there is no legal requirement for contractors to do so;
- records are not being submitted because there isn't an easy mechanism in place for well contractors to submit this information; and,
- the water well associated with the missing well record was constructed prior to the implementation of a framework for well record submission.

Return to Exercise 7↥

Solution Exercise 8

This is your opinion but could include the collection of additional data, such as:

- salinity;
- surveyed elevation of well head;
- casing resistance;
- approximate grain size distribution of the geologic material if it is unconsolidated;
- accurate static water level;
- accurate dynamic pumping level;
- pump depth if installed;
- specific capacity; and,
- one-hour pump test with drawdown measurements.

Return to Exercise 8↥

13 About the Author

Gavin Kennedy is a research hydrogeologist with the Geological Survey Division of the Nova Scotia Department of Natural Resources and Renewables. Nova Scotia is a Canadian Province. He is a 2002 graduate of the Earth Sciences program at the University of Waterloo, where his Master of Science research involved the development of a groundwater simulation model for the restoration of bogs that have been drained and cutover for peat products. After spending several years in groundwater consulting, Gavin joined the Geological Survey Division in 2007 and led the development of a new Hydrogeology Program. Gavin's work at the Geological Survey Division has focused on human health risks of naturally occurring contaminants and applying Geographic Information System software and geostatistical techniques to regional scale datasets, including well record data, to build knowledge and communicate groundwater science to Nova Scotians. Gavin has been involved with the research, management and publication of the province's well record database for the past 15 years. Gavin is a Fellow of Geoscientists Canada, past recipient of W.E. Buster Brown Founders Award for excellence and dedication to Nova Scotia groundwater, and is the current Atlantic region director for the International Association of Hydrogeologists - Canadian National Chapter.

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THE GROUNDWATER PROJECT

Modifications to Original Release

Changes from the Original Version to Version 2

Original Version: September 12, 2022, Version 2: March 23, 2026

General changes:

updated formatting of front matter and copyright page as well as roman numeral pagination

updated formatting of section headings which changed pagination

updated Table of Contents

Specific changes:

Page numbers refer to the Original PDF.

page ii, changed version number and date

page iii, changed number of pages to 45 because reformatted section headings included a new page for each section thus the book is longer

Section 10 updated reference format to APA (7th ed.)