



*State of Ohio
Ohio Water Resources Council
State Coordinating Committee on Ground Water*

REGULATIONS AND TECHNICAL GUIDANCE FOR SEALING UNUSED WATER WELLS AND BOREHOLES



March 2015

*John R. Kasich, Governor
Mary Taylor, Lt. Governor*

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GUIDANCE FOR SEALING UNUSED WATER
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**Ohio Water Resources Council
State Coordinating Committee on Ground Water
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(Revision of 1996 document titled “Technical Guidance for Sealing Unused Wells”)**

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State Coordinating Committee on Ground Water Member Agencies

(See Appendix 1 for contact information)

Ohio Environmental Protection Agency
Ohio Department of Natural Resources
Ohio Department of Health
Ohio Department of Agriculture
Ohio Public Utilities Commission
Ohio Department of Commerce - State Fire Marshal
Ohio Department of Transportation
United States Geological Survey
Natural Resources Conservation Service

Preface

In early 1992, the State Coordinating Committee on Ground Water (SCCGW) identified the lack of consistent standards and regulations regarding the sealing of abandoned water wells and test borings as a major issue of concern by the Committee. The SCCGW formed a subgroup in June, 1994 to develop consistent technical standards for sealing abandoned wells and test borings. Based on the standards finalized in 1996, both the Ohio Environmental Protection Agency and the Ohio Department of Health revised their rules regarding well sealing. Since the initial development of this guidance, new state regulations and research in sealing material technologies and procedures, along with practical experience in the field, have prompted an update to the guidance document. In 2013, a workgroup was formed to re-write/edit the original document. This document is the product of the workgroup.

Throughout this document are references to proprietary materials or products. These references should in no way be interpreted as endorsements for any particular brand name or manufacturer, and are used only for illustrative or comparative purposes.

This guidance does not apply to wells constructed for the purpose of injecting fluids into the subsurface (except as it may augment, not supersede, rule requirements), nor does it apply to oil and gas wells. The authority over injection wells depends on the well classification. For more information contact the Ohio Environmental Protection Agency, Division of Drinking and Ground Waters, Underground Injection Control Unit.

At the time that this guidance document was prepared, the guidance followed the applicable rules for regulated wells. However, rules can change and may have since this document was prepared. Therefore, if there are any discrepancies between an existing rule and this guidance document, follow the rule.

Introduction

Unused or abandoned water **wells**¹ or boreholes are those that are no longer in service or are in such a state of disrepair that continued use for the purposes of accessing **ground water** is unsafe or impracticable. Abandoned wells can be found almost anywhere: on farms, industrial sites, and in urban areas. Those marked by windmill towers and old hand pumps are easy to spot. Many lie hidden beneath weeds and brush. These wells are open traps waiting for unsuspecting children, hunters, and animals (Gordon, 1988). No accurate accounting of abandoned wells exists for the State of Ohio.

Each year, many wells are abandoned when homes are connected to community water supplies. Many exploratory borings are installed, data gathered, and then the borehole left as an open conduit to the aquifer. In addition, wells are often abandoned when their **yield** has diminished, or the quality of the water they supply has degraded. It has been estimated that there could be more than tens of thousands of unused wells and boreholes in Ohio. For the purposes of this document, wells refer to both wells and boreholes.

This document is intended to discuss the sealing requirements for the different types of wells and boreholes that are regulated in Ohio and provide guidance for those wells and boreholes that are not regulated. Table 1 is a list of different types of wells and boreholes with the associated rule if regulated. Any well or boring that is over ten feet in depth should follow the guidance if no regulatory authority already exists.

The number of potential contaminants that may enter these wells is unlimited. Fuel, fertilizer, solvents, sewage, animal waste, pesticides and numerous other contaminants have been introduced into ground water through unsealed abandoned wells or improperly sealed wells. If a substance can be dissolved, carried, or mixed in water, it has the potential for entering ground water through an improperly sealed abandoned water well (King, 1992). Abandoned wells also pose a physical hazard; there have been numerous accidents documented with children and pets falling into unsealed water wells.

Any well or borehole to be abandoned should be sealed to prevent vertical movement of water. The sealing method chosen should be dependent on both well construction and site **geologic/hydrogeologic conditions**. Whenever there is doubt about either the construction of the well or the site hydrogeology, the choices of sealing material and procedure should be those affording the greatest probability of providing a permanent seal.

This document also outlines the materials and methodologies that should be used to properly seal a well. It is intended to provide a comprehensive discussion of all elements involved in the well sealing process, including basic ground water principles and an introduction to well drilling and construction methods. Readers familiar with these topics can move directly to the sections dealing with well sealing procedures.

¹ All terms in bold print can be found in the glossary

Overview of the Regulations

Current regulations for private (Ohio Administrative Code (OAC) 3701-28-17) and public water wells (OAC 3745-9-10) require that boreholes not converted into wells, and wells not being used to obtain water or provide information on quality, quantity, and water level be sealed or else maintained in compliance with the respective rules.

This document is intended to cover all types of water wells and borings. The authority for enforcement lies within a few state agencies depending on the type of well. For example, the authority for enforcement for public water supplies is the Ohio Environmental Protection Agency (Ohio EPA)/Division of Drinking and Ground Waters (DDAGW) Drinking Water Program and the authority for enforcement for private wells is the Ohio Department of Health (ODH) and local health departments. Table 1 lists the different types of wells and the associated regulatory agency and legislative reference.

Table 1. Types of water wells and borings with the associated regulatory authority (if any).

Type of Water Well Being Sealed	Regulatory Agency	Applicable Regulations and Guidance
Cathodic Protection	None	None
Dewatering (non-potable well)	Ohio EPA	OAC 3745-9-10
Geophysical boreholes	None	None
Geotechnical	None	None
Geothermal – Closed loop	None	Recommendations for Geothermal Heating and Cooling Systems - Guidance for Protecting Ohio's Water Resources
Geothermal – Extraction (non-potable well)	Ohio EPA	OAC 3745-9-10
Geothermal – Return or Recharge Well (Class V)	Ohio EPA	OAC 3745-34-07 & OAC 3745-34-11
Industrial Use (non-potable well)	Ohio EPA	OAC 3745-9-10
Injection – Class V	Ohio EPA	OAC 3745-34-07 & OAC 3745-34-11
Injection - Remediation (Class V)	Ohio EPA	OAC 3745-34-07 & OAC 3745-34-11
Irrigation Use (non-potable well)	Ohio EPA	OAC 3745-9-10
Mineral Exploration Boreholes / Mine Boreholes / Mineral Exploration Test Holes	ODNR-Mineral Resources Management	Coal: OAC 1501:13-9-02 and either OAC 1501:13-4-05 or OAC 1501:13-4-14 Industrial Minerals: OAC 1501:14-4-01
Monitoring	Ohio EPA	Technical Guidance Manual for Ground Water Investigations
Piezometer	Ohio EPA	Technical Guidance Manual for Ground Water Investigations
Pressure Relief	None	None
Private Water Systems	Ohio Dept. of Health	OAC 3701-28-17
Industrial Process Water (non-potable well)	Ohio EPA	OAC 3745-9-10
Public Supply Wells	Ohio EPA	OAC 3745-9-10
Test Borings	Ohio EPA, Ohio Dept. of Health Ohio Dept. of Agriculture	OAC 3745-9-10, OAC 3701-28-17, OAC 901:10-2-03

The sealing of all abandoned wells and boreholes that penetrate an **aquifer** (see Table 1) must be properly documented in accordance with Section 1521.05 (B) of the Ohio Revised Code. A **well sealing report** (see Figure 1) must be submitted to the Ohio Department of Natural Resources (ODNR), Division of Soil and Water Resources within 30 days of the sealing. The on-line filing process is the preferred method of submitting the well sealing form (<http://soilwater.ohiodnr.gov/search-file-well-logs>). If you do not have access to a computer, you can order a paper well sealing form from the ODNR (614-265-6740).

If the well or test hole is or was part of a **private water system**, OAC Rule 3701-28-17 requires that a permit be obtained from a local health district prior to sealing. If an existing well is to be sealed when a new well is drilled, then the well sealing is included in the private water system replacement permit. The local health department is to be provided a copy of the sealing report when an abandoned well has been sealed.

The Ohio EPA regulates **public water systems** in Ohio. They also have authority for nonpotable (non-drinking) water wells, Class I, IV, and V **underground injection wells**, and **monitoring wells**. Regulations for public water system wells and **non-potable wells** require that an abandoned well be sealed in accordance with OAC 3745-9-10 and OAC 3745-9-07, with this document used as a guide. A public water system may apply to the director for a variance from these requirements in accordance with the provisions of OAC 3745-9-2. Test holes that were not converted into wells and wells not being used to obtain water or provide information on quality, quantity, and water level must be properly sealed and the sealing properly documented. The authority for enforcing well sealing rules for public water system and non-potable wells is the Ohio EPA/Division of Drinking and Ground Waters (DDAGW).

Regulations for Class V Underground Injection Control (UIC) wells require that a Class V well be sealed in a manner that prevents the movement of fluids containing contaminants that may cause an underground source of drinking water to exceed any primary drinking water standard, or may otherwise adversely affect the health of persons. Prior notification for sealing is required (OAC 3745-34-11(O)) and for permitted Class V wells a sealing plan is required. In some cases OAC 3745-9-10 and this document may be used as guidance for the proper means of sealing a well. The authority for enforcement for Class V injection wells is the Ohio EPA/DDAGW, UIC Program. Please contact the UIC program prior to sealing a Class V well.

Regulations for monitoring wells (OAC 3745-9-03) require that a monitoring well be sealed if the well is damaged or deteriorated and will not be repaired, or if the well is no longer being used. Unless an agency or program has specific requirements for sealing a monitoring well required by its rules, the sealing procedures found in Chapter 9 (Sealing Abandoned Monitoring Wells and Boreholes) of the “Ohio EPA Technical Guidance Manual for Hydrogeologic Investigations and Ground Water Monitoring” is to be used as a guide for monitoring well sealing to prevent the contamination of ground water. The authority for enforcement for monitoring wells is the Ohio EPA/DDAGW and the agency, board, or commission that required the monitoring well.

Please note that each of the OAC chapters cited in this document may use unique or uncommon terms or may have a very specific use for a familiar term. These terms are usually defined in the first section of the chapter; for example definitions for terms used for private wells can be found in OAC 3701-28-01 and terms used for Class V wells can be found in OAC 3745-34-01

Reasons to Properly Seal an Unused Well

There are many reasons for properly sealing unused wells. The most important of these include: eliminating physical hazards, preventing ground water contamination, and preventing further loss of confining pressure in confined aquifers.



Dug well in front yard of residence.

Eliminate Physical Hazard

One of the most obvious reasons to properly seal a well is the physical hazard (Figure 2). A good example of this danger was seen in the early 1990's as the nation witnessed the rescue of a small child from an unsealed abandoned water well that was less than 10 inches in diameter. It is also quite common to find animal remains in unsealed abandoned wells.

DNR 7810.12e	WATER WELL SEALING REPORT e-FORM OHIO DEPARTMENT OF NATURAL RESOURCES Division of Soil and Water Resources 2045 Morse Road, Bldg B Columbus, OH 43229-6693 Voice: (614) 265-6740 Fax: (614) 265-6767	Sealing Report No. 0
LOCATION		
County <u>GEAUGA</u>	Township <u>PARKMAN</u>	Section No. _____ Lot No. _____
Owner <u>E. J. FUDD</u>		
Address of Well Location <u>1234 NOTKNOWN RD.</u>		
City <u>ANYTOWN</u>	Zip Code <u>00000-1230</u>	
Well Location Description (120 Characters)	<u>1/2 mile south of Maindrag on west side of Notknown.</u>	
Location of Well in either:	{ State Plane <input type="checkbox"/> N <input type="checkbox"/> S <input type="checkbox"/> X _____ +/- _____ ft. Y _____ +/- _____ ft. OR Latitude/Longitude Latitude <u>41.41234</u> Longitude <u>-81.01234</u>	
Elevation of Well <u>1 0 2 2 .0 0</u> +/- _____ ft.	Datum Plane: <input type="checkbox"/> NAD27 <input checked="" type="checkbox"/> NAD83	
Source of Coordinates: <input checked="" type="checkbox"/> GPS <input type="checkbox"/> Survey <input type="checkbox"/> Other _____	Source of Elevation: <input checked="" type="checkbox"/> GPS <input type="checkbox"/> Survey <input type="checkbox"/> Other _____	
WELL IDENTIFICATION	ODNR Well Log Number <u>123456</u>	Project Well ID _____
MEASURED CONSTRUCTION DETAILS		
Date of measurements <u>08/06/2012</u>		
Depth of Well <u>106</u> ft.	Static Water Level <u>83</u> ft.	
Borehole Depth <u>106</u> ft.	Borehole Diameter _____ in.	
Casing Diameter <u>5.63</u> in.	Casing Length <u>27</u> ft.	Casing Type <u>steel</u>
SEALING PROCEDURE		
Placement:	Sealing Material	Volume/Weight Used Units Required
From <u>0</u> ft. To <u>106</u> ft.	<u>Bentonite/polymer slurry</u>	<u>115 gals/250 Lbs</u>
From _____ ft. To _____ ft.	_____	_____
From _____ ft. To _____ ft.	_____	_____
From _____ ft. To _____ ft.	_____	_____
Placement Method	<u>Pumped w/tremie pipe</u>	
Condition of Casing <u>good</u>	Was Casing Removed? <input type="checkbox"/> Yes or <input checked="" type="checkbox"/> No (check one)	
If casing Not Removed , was it Perforated? <input type="checkbox"/> Yes or <input checked="" type="checkbox"/> No (check one)	Perforations: From _____ ft. To _____ ft.	
Date Sealing Performed <u>08/08/2012</u>		
Comments/Reason for Sealing <u>VERY HIGH IRON LEVELS WHICH KEEPS SEALING OFF THE WATER</u>		
CONTRACTOR		
Name <u>ACME DRILLING COMPANY</u>	ODH Registration # <u>9876</u>	
Address <u>1234 MAIN ST.</u>		
City/State/Zip <u>SOCKERDOWNE, OH 56789</u>		
e-Signature <u>W. E. COYOTE</u>	Filed electronically on <u>08/06/2012</u>	
I hereby certify the information given is accurate and correct to the best of my knowledge.		
Completion of this form is required by section 1521.05, Ohio Revised Code - file within 30 days after completion of sealing. Distribute additional copies to: Customer, Driller and Local Health Department.		

Figure 1. Example of an official Ohio water well sealing report form.

Other than being the reason for the unfortunate creature's demise, an additional hazard is the possible bacterial contamination of the aquifer caused by the decay of the animal. There also have been cases cited where improperly sealed **geotechnical borings**, used to obtain **stratigraphic** information during highway construction, have caused potholes to occur in newly-constructed highways (Smith, 1994). Geotechnical and mineral exploration borings are often drilled on farmland or pasture land. Imagine the consequences if the farmer's prize-winning Guernsey (or other livestock, for that matter) steps into an open **borehole** and breaks a leg. These are just a few of the hazards that could result from the existence of unsealed abandoned wells of any type.

Prevent Ground Water Contamination

Another reason to properly seal a well is to prevent ground water contamination (Figure 2). There are four ways that an unsealed abandoned well could contaminate the ground water: by intermixing of waters between aquifers, by surface water entering the aquifer, by illegal disposal of contaminants down the well, and by microbial contamination from decomposition of animal bodies and waste products.

Poorly constructed wells or wells that are screened across multiple aquifers can cause intermixing of water between the aquifers. Depending on the hydrogeologic conditions, poor quality water can move upward or downward into a pristine aquifer. Ground water zones penetrated by a well may have physical or chemical qualities that are incompatible. Chemical reactions may occur that result in undesirable products such as iron sulfides and calcium sulfate (Smith, 1994).

Surface water can enter a well if the well cap has been broken or removed, or if there are holes in the **well casing** due to damage or deterioration with age. In addition, surface water can seep down along the space (called the **annular space**) between the casing and the **formation** of an improperly grouted well. This is an important consideration because most older water wells are not grouted and do not meet today's construction standards. Surface water can carry contaminants, feces, trash, debris and even dead animals into an unsealed well.

Illegal disposal of contaminants down unused wells still occurs. Open wells offer tempting disposal receptacles for liquid and solid waste. People seem naturally compelled to throw or pour unwanted material down an open hole (Smith, 1994).

Abandoned wells are often preferred havens for a host of arthropods (spiders, earwigs, and centipedes) that prefer dark, moist, calm places. Also these can become subsurface dwellings for rodents and reptiles. The bodies and waste products of these colonists add nutrients and undesirable microbes to the ground water (Smith, 1994).



Well located within 3 feet of sewage line.

Minimize Further Loss of Confining Pressure

It is important to seal a well penetrating a **confined aquifer(s)** to preserve the confined (or "pressurized") conditions (Figure 2). These confining conditions allow the water to reach a certain level in a well (called the **static level**). The static level will be higher than the depth at which the water is encountered in the aquifer; in some cases, water will flow out the top of the well because the static level is higher than the ground surface. A reduction in the confining pressure may cause water levels in neighboring wells to drop because the **hydraulic head** is no longer high enough to allow the water in these wells to maintain their original static levels. Reduced confining pressures may result from water in a deeper aquifer moving upward into formations containing no water, or into **saturated zones** of lower hydraulic head. In the case of **flowing wells**, the pressure can be reduced simply because of the constant flow of water from the aquifer onto the ground surface. Therefore, it is especially important to ensure that abandoned wells penetrating confined aquifers are properly sealed.

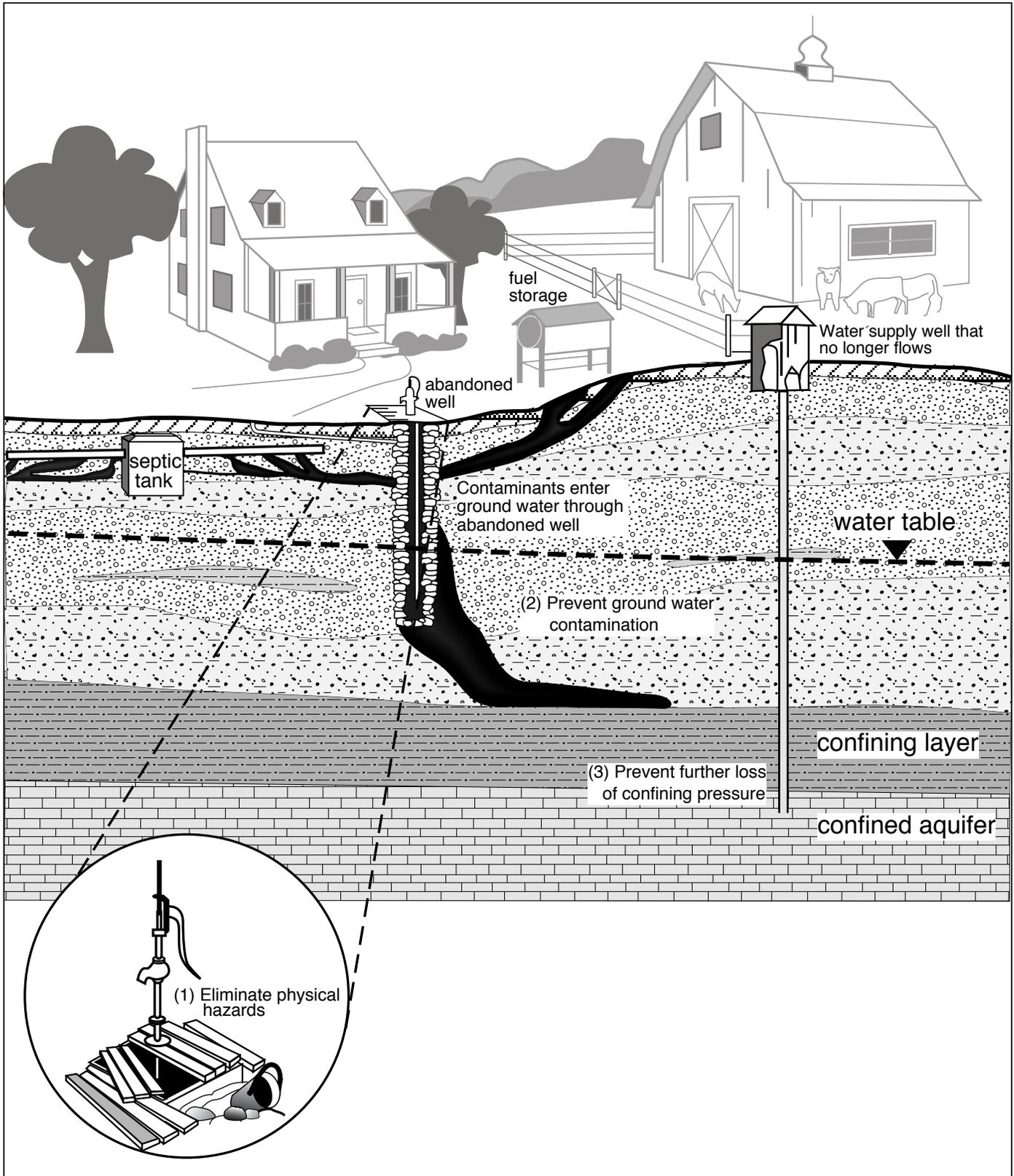


Figure 2. Reasons to properly seal an unused well. (After Glanville, 1989, and King, 1992)

Deciding Who Should Perform Well Sealing

Based on the difficulty in sealing many wells, and the equipment and knowledge involved, it is strongly recommended that well sealing be completed by an experienced registered drilling contractor. Owners of a primary or secondary property, or property rentals who want to work on their own well must be registered with the Ohio Department of Health before they seal their well and may only perform work on residences they own. At a minimum, in all sealing situations, an experienced registered drilling contractor should be consulted. Some work may also need to be supervised by a qualified hydrogeologist or qualified engineer. Under rare circumstances, state oversight or observation might be required. It should be noted that all professional contractors do not have the same experience. An experienced contractor should be able to provide a description of work to be performed and a list of references proving his/her qualifications. On sites with potential for exposure to contamination or other hazards, personnel should be trained and equipped for such conditions (Smith, 1994). No one should enter a confined space (i.e. well pit) without having the proper training and also knowing the air quality of the confined space. For more information on confined space standards and regulations see OSHA's 29 CFR 1910.146.

Once a well has been sealed improperly, it is costly to correct because the defective seal has to be drilled out. In some situations, there could be irreparable damage to the aquifer or confining layers. It is recommended that wells with one or more of the following characteristics be sealed by an experienced registered contractor only:

- drilled wells,
- flowing wells,
- wells greater than 100 feet in depth,
- wells less than 3 inches in diameter,
- wells where water is seeping from around the casing,
- wells where pumping equipment is difficult to remove,
- wells that have been damaged,
- wells which produce gas,
- wells that have been contaminated,
- monitoring wells,
- wells that may have encountered cavernous geologic conditions, and
- wells that may have encountered mine voids.

Types of Wells as Defined by Method of Construction

Wells can be described in different ways; by their method of construction, and by the type of aquifer in which they are developed. There have been three commonly used methods of well construction over the years: digging (by hand or by backhoe), driving, and drilling.

Dug Wells

A **dug well** can be defined as any well not installed by drilling rigs. They are usually large diameter (greater than 24 inches) and fairly shallow (25 feet or less), and are constructed by digging with a backhoe or by hand. Casing installed in dug wells can vary from concrete pipe and vitrified tile to cobbles and bricks. (see Figure 3 for diagrams showing two common dug well construction techniques) In some cases, dug wells are improperly used as **cisterns** for roof runoff or hauled water.

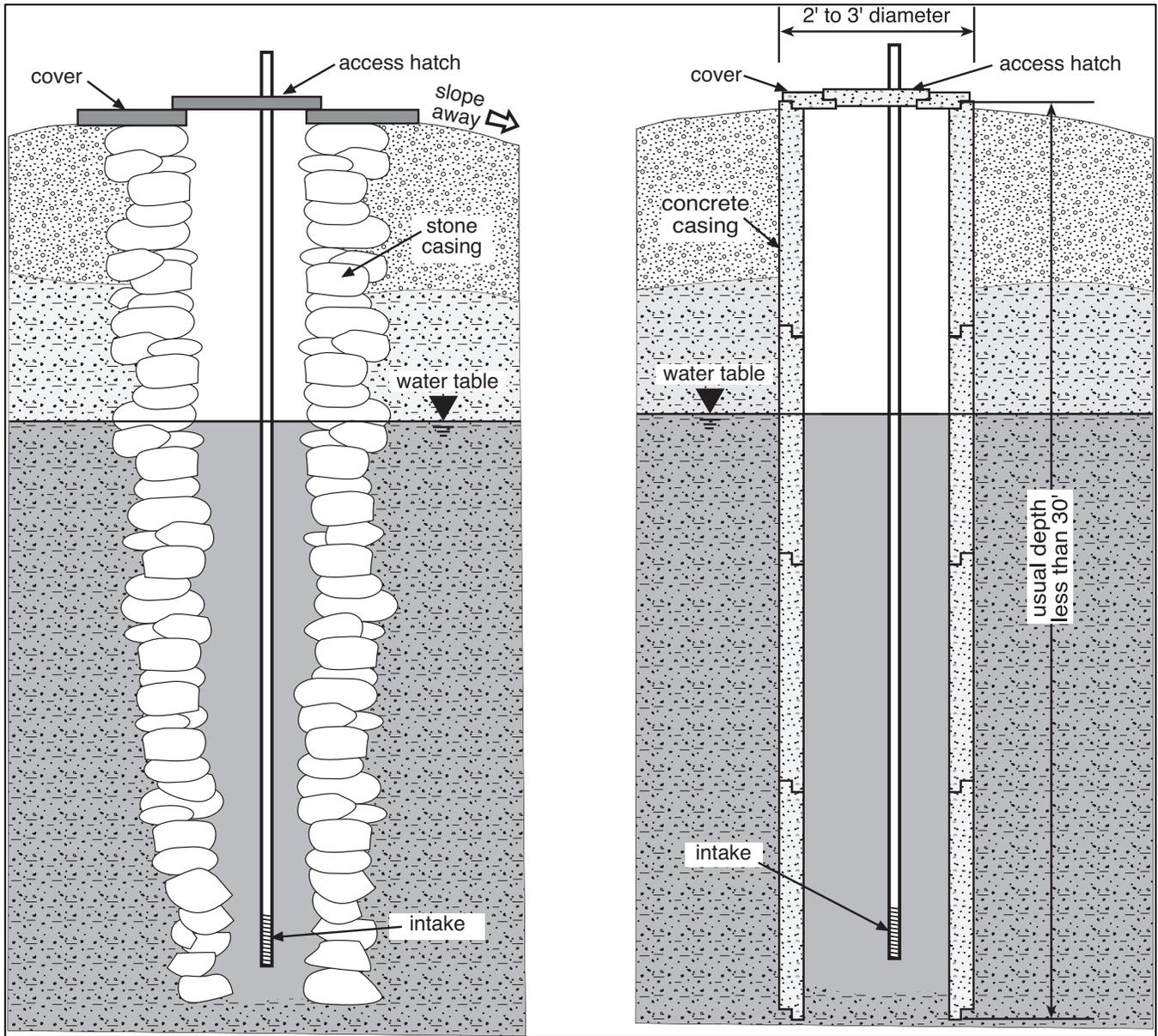


Figure 3. Typical dug well designs using either natural rock like limestone or sandstone (left), or using precast concrete (right).

Driven Wells

Driven wells are installed by pushing a pipe into the ground by hand or machine. There is no annular space around the outside of the pipe since the pipes are pushed into the ground. There are two types of driven wells: well points and Direct Push (DP). Well points are installed only in **unconsolidated** formations. Well points are typically small diameter, shallow wells used to supply water for a single household. Many of these wells are installed by the homeowners themselves. Well points consist of a **well screen** with a hardened point on the end of the screen which is hammered into place (by hand or machine) using a large weight. Sections of pipe are added to the screen in order to advance the screen to the desired depth (see Figure 4 for diagram).

DP technology devices are investigative tools that drive or push small-diameter rods and tools into the subsurface by hydraulic or percussive methods. DP can be used for a number of applications, such as soil sampling, ground water sampling, geophysical sensing, geochemical sensing, and soil gas sampling. DP technology is used in unconsolidated sediments and is most suitable for shallow depths (less than 100 feet), but may be able to go deeper depending on site conditions. Due to the small diameter of DP probeholes and wells, sealing presents special challenges. Additional information on direct push monitoring wells can be found in Chapter 15 (Use of Direct Push Technologies for Soil and Ground Water Sampling) in the Ohio EPA Technical Guidance Manual for Hydrogeologic Investigations and Ground Water Monitoring.

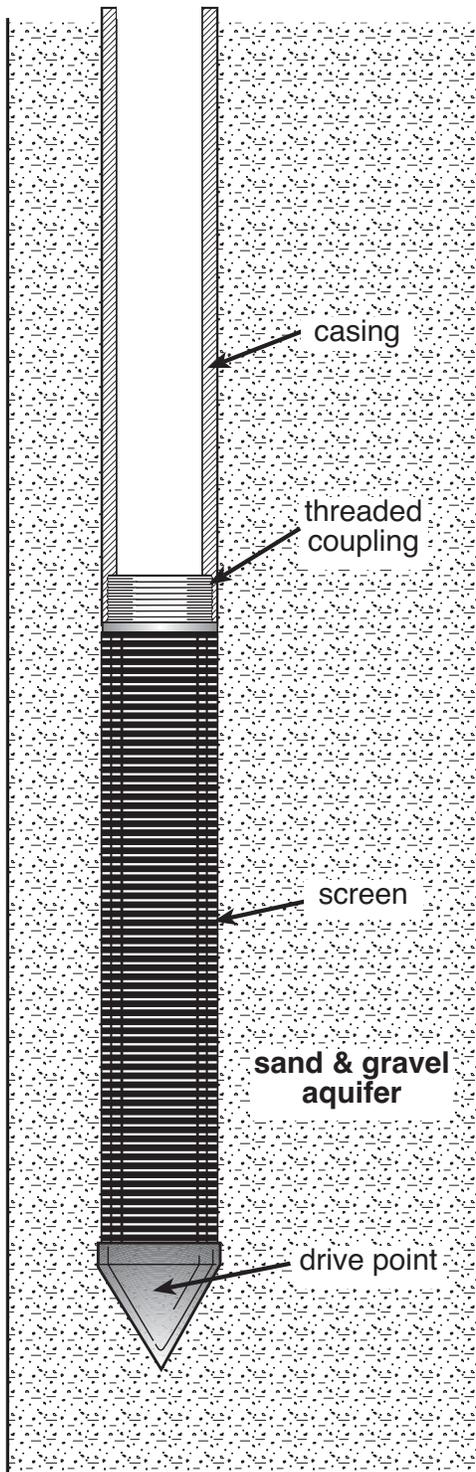


Figure 4. Driven well construction showing drive point, well screen and steel casing.

Drilled Wells

The third major category of well construction methods is that of drilled wells. Drilled wells are those that are constructed using machines designed specifically for the task of well installation. There are several drilling methods commonly used today: **auger**, cable tool, rotary or hammer rigs, and vibratory drilling.

Auger

Augers are used to construct wells in unconsolidated formations. There are three principal types of augers used for well drilling: **bucket augers, solid-stem augers, and hollow-stem augers**. The bucket auger has the largest diameter of the three types of augers, and is the most frequently used augering technique for water supply wells in Ohio. The bucket is cylindrical with hardened teeth on the bottom and has a diameter of 18" to 48". The bucket can remove 24" to 48" of material at a time. Wells drilled with a bucket auger normally range in depth from 25 to 150 feet, but in some areas they can reach 250 feet in depth (Mehmert, 2007). In Ohio, older bucket-augered wells may be cased with concrete pipe, vitrified tile, fiberglass or thermoplastic casing, and in many respects will resemble a dug well. Solid-stem and hollow-stem augers are typically used in the installation of monitoring wells.

Solid-stem augers consist of spiral flanges welded to a pipe. One length of pipe (or auger section) is called a flight; multiple auger sections are often referred to as continuous flighting. The leading auger flight has a special bit or cutter head attached that cuts a hole for the flights to follow. Flights are added as the hole is drilled deeper. **Cuttings** from the drilling process are brought to the surface by the action of the augers (Driscoll, 1986). Boreholes constructed with **solid stem augers** are typically used for geotechnical, or, less commonly, environmental purposes, rather than water supply wells.

Hollow-stem augers are similar to solid stem augers in design, except that **drill rods** can pass through the auger sections. The leading drill rod has a pilot assembly attached to drill slightly ahead of the lead auger flight (see Figure 5). The outside diameter of these augers can range from 4 1/4" to 18", with corresponding inside diameters of 2 1/4" to 12 1/4". Because the

flights are hollow, they can be used as temporary casing to hold the hole open while the permanent casing is installed or to collect soil samples before the casing is installed. As the well is being installed, the augers are removed. Wells drilled with hollow stem augers have been used to construct water supply wells, but they are more often used to construct monitoring wells.

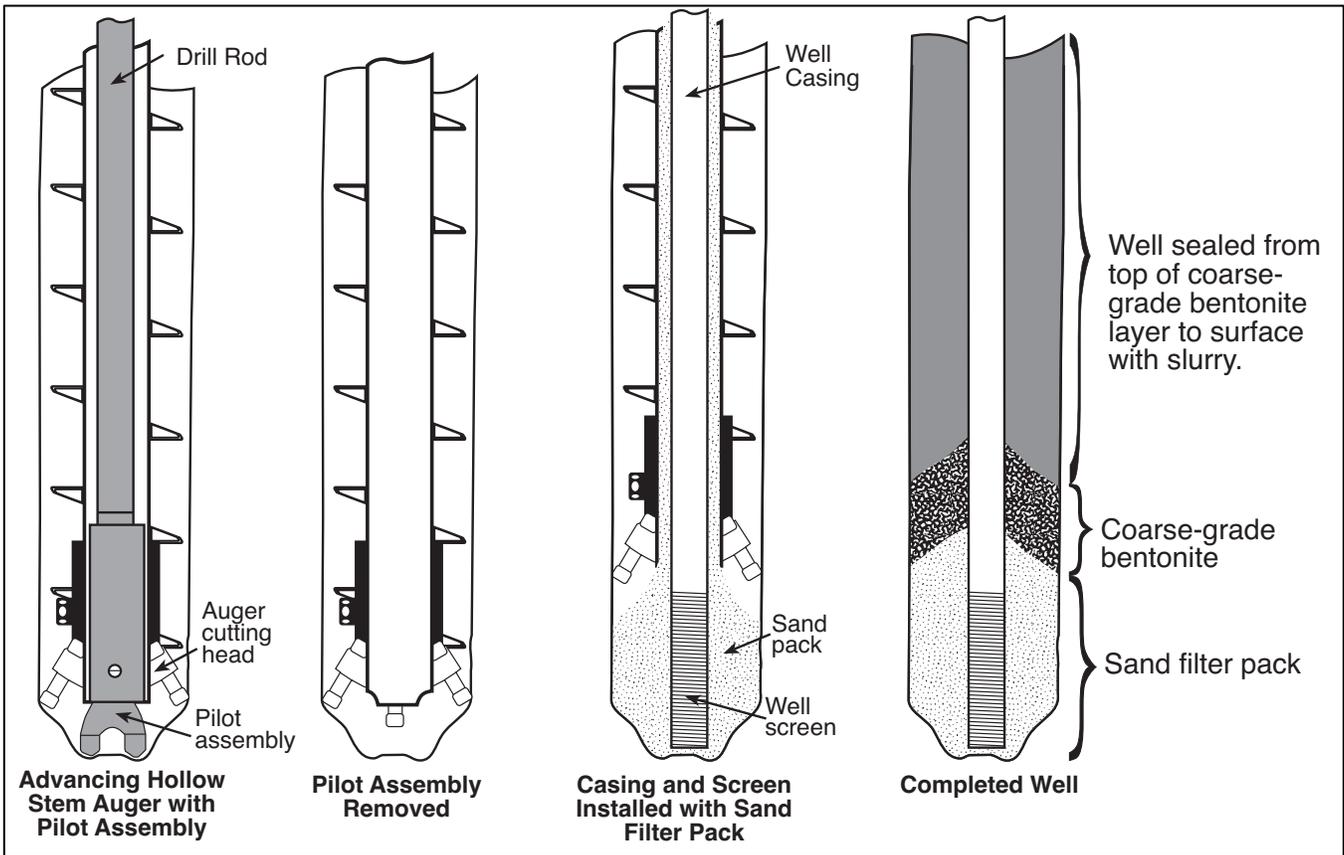


Figure 5. Well construction using hollow stem augers. (Modified from Hackett, 1987)

Cable Tool

Cable tool rigs operate by repeatedly lifting and dropping a string of **drill tools** into the hole. The **drill bit** at the bottom of the drill tools breaks or crushes the formation and when this material is mixed with water, it forms a slurry. When the penetration rate becomes unacceptable, the bit and tools are pulled from the hole and the slurry is removed by **bailing**. In unconsolidated formations, casing is driven into the hole behind the drill bit so that the hole will stay open. When the desired depth has been reached, the casing can be pulled back to expose a screen, if one is to be installed. Otherwise, the casing is driven until a solid rock formation is encountered, and the casing is set a few feet into the bedrock. In some situations an outer casing may have been used. (see Figure 6 for diagrams of properly constructed, cable tool-drilled wells).

Rotary

Rotary rigs use one of two methods to rotate the drill bit: a table drive or top head drive. The rotation of the table or top head is transferred to the drill rods, which in turn rotate the bit. Mud rotary rigs use a roller cone bit at the end of the drill rods. The drill cuttings are circulated out of the hole with water or **drilling mud**. When the appropriate depth has been reached, the drill rods are withdrawn from the hole. The casing and screen (if needed) can then be set in the open borehole. Since it is necessary to drill an oversized borehole with this type of drilling method, the diameter of the borehole will be at least three inches greater

than the outside diameter of the well casing. The annular space is sealed to prevent contamination from the surface, and to hold the casing in place in the borehole.

Air rotary drilling rigs operate in basically the same way as mud rotary. However, instead of using drilling mud to clean the cuttings out of the borehole, a combination of compressed air and water is used. Air rotary rigs also run roller cone bits, but, in addition, they have the capability to run a down-the-hole hammer. The down-the-hole hammer is used for **consolidated** formations only. Compressed air is forced down the drill rods to operate the piston-like action of the hammer bit. The hammer pulverizes the material being drilled through. The air, in combination with water or foam, lifts the cuttings out of the hole. Hole sizes can range from 4 1/8" to 30" (Ingersoll-Rand Co., 1988). Usually a well will be drilled with mud through unconsolidated formations to the bedrock formation, if that is the aquifer. After the casing is set and grouted into place, the well can continue to be drilled with a combination of air and water until the desired depth is reached. Both methods of rotary drilling are frequently used in Ohio to construct water supply wells. Figure 7 shows a typical rotary-drilled well construction.

Another method of rotary drilling is reverse rotary. Reverse rotary drilling is most often used to construct large diameter (24 inches or greater) water supply wells. Reverse rotary rigs are similar to air or mud rotaries in design, but are larger in size. The bit is only rotated by **table drive** because the top head drive does not develop enough torque to turn the size of the bit required to drill large diameter wells. The major difference between the reverse rotary and the other rotary methods described here is the pattern of fluid circulation. With reverse rotary, the drilling fluid is added to the borehole through the annular space, then the fluid and cuttings are removed from the hole by suction up through the drill rods. The fluid and cuttings are deposited into a mud pit, where the cuttings settle out and the fluid is recirculated. The resulting large-diameter borehole allows easy installation of **filter pack** and well screens, which are necessary to properly develop high capacity wells in unconsolidated formations. Reverse rotary drilling can also be used in most consolidated formations. A considerable quantity of make-up water must be available at all times when drilling in permeable sand and gravel formations. Also, reverse rotary drilling is not commonly used when the static water level is less than 10 feet below ground surface (Mehmert, 2007).

Vibratory

Vibratory drilling (referred to as sonic or roto-sonic drilling) involves the use of a resonance source through the drill rods to advance a core barrel to the desired depth. In overburden, the vibratory action causes the surrounding soil particles to fluidize, thereby allowing effortless penetration. In rock, the drill bit causes fractures at the rock face, creating rock dust and small rock particles, which facilitates advancement of the drill bit. In many instances the drilling and coring of rock and earth can be accomplished without the use of any drilling fluid. The resonance through the rods pushes the cuttings into the side wall of the hole and into the center of the core barrel. Once the core barrel has been advanced, casing can then be advanced down to the depth of the core barrel. The core barrel is retrieved and the sample is removed. After the core is removed, the core barrel is re-inserted into the well and advanced ahead of the casing. This drilling method allows the borehole to be cased after the coring tool has been advanced to the next sample interval. This method produces a minimal amount of cuttings, uses no drilling mud, and can produce a continuous core. Drilling in dense bedrock formations could be difficult.

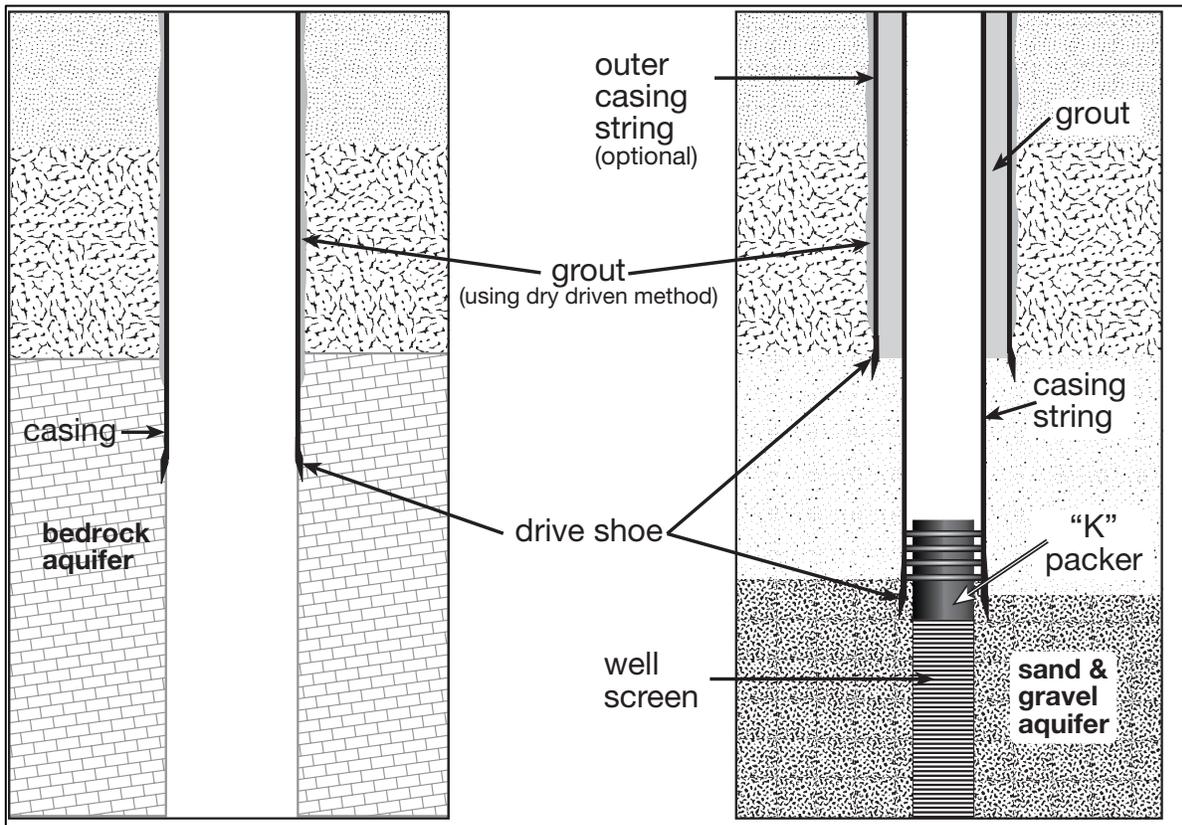


Figure 6. Cable tool-drilled wells showing water well completion in bedrock (left) and in sand and gravel (right).

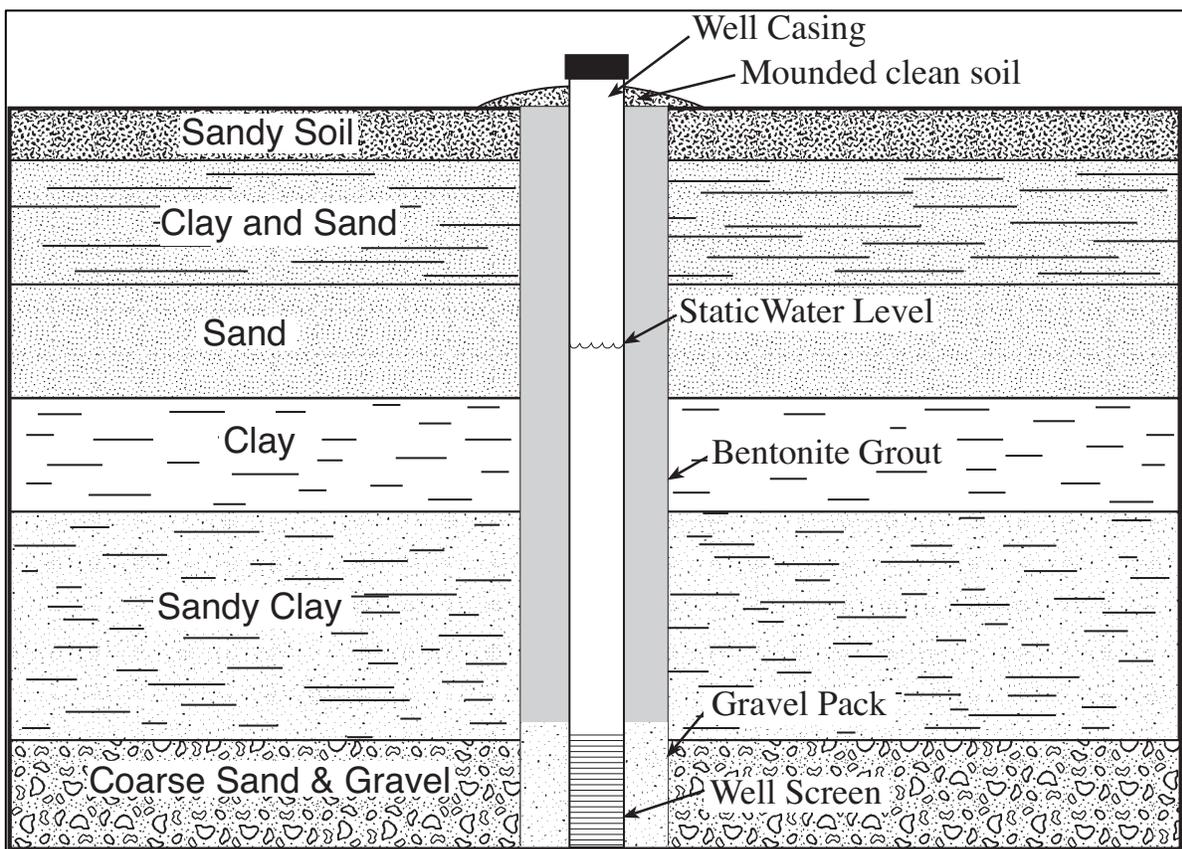


Figure 7. Rotary-drilled well with screen, developed in a sand and gravel aquifer.

Types of Wells as Defined by Aquifer Characteristics

Wells can be described by the types of aquifers in which they are developed. An aquifer is a geologic formation, group of formations, or part of a formation that is capable of yielding water to a well or spring. Figure 8 shows the distribution statewide of expected well yields from aquifers (this map is very general and should not be used to determine well yields on a site-specific basis). These yields, of course, are directly related to the types of geologic formations that comprise the aquifers. For example, aquifers that consist of shales, or interbedded limestone and shale, typically yield less than five gallons per minute to a well.

Geologic formations are classified as either consolidated or unconsolidated. Consolidated formations are those that are lithified, that is, hardened into rock. A borehole penetrating a consolidated formation would be able to stay open indefinitely without benefit of casing. Consolidated aquifers in Ohio generally consist of sandstone, limestone, or shale. The most productive consolidated aquifer is cavernous limestone. Sealing wells set in fractured and cavernous rock present special problems due to loss of **grout** material.

Unconsolidated formations are usually soft and loose (there are some exceptions). Wells penetrating unconsolidated formations must be cased, otherwise the borehole walls will collapse. Unconsolidated aquifers in Ohio consist of silt, sand, gravel, or any combination of the three. Many of the state's most prolific wells are developed in sand and gravel aquifers.

Consolidated and unconsolidated aquifers can also be confined or unconfined. Unconfined aquifers are aquifers in which there are no **confining layers** between the zone of saturation and the surface (see Figure 9 for example). They are often referred to as water table aquifers. The upper surface of an unconfined aquifer is in direct contact with the atmosphere through open **pores** of the material above. Therefore, the static level in a well penetrating an unconfined aquifer will be the same as the level of the water table. Confined aquifers are overlain by a confining bed (see Figure 9 also). The confining bed has a significantly lower **permeability** than the aquifer. When a confined aquifer is penetrated by a well, the water will rise above the base of the confining unit to an elevation at which it is in balance with the **atmospheric pressure**. If this elevation is greater than the top of the well, the water will flow from the well (commonly called an artesian well). The term artesian well, however, includes any well developed in a confined aquifer where the water level rises above the top of the aquifer, not just those that are flowing. Wells completed in confined aquifers can present special challenges when it comes time to seal them.

Wells screened across several aquifers will require more care in sealing. Wells screened in a single aquifer but penetrating several aquifers will need careful consideration in choosing an appropriate sealing method. These wells must be sealed in a manner that prevents mixing of water between the aquifers.

These scenarios and others will be addressed in the section titled **Procedures for Sealing the Well**.

Preparation for Sealing

Well Information

Information concerning the geology and physical condition of the well, such as total depth, formations encountered, and diameter is important in determining the sealing method. Geologic conditions vary throughout the state and different methods of sealing are needed to meet these varying conditions. Well construction details are needed to determine the type and amount of materials needed to seal the well.

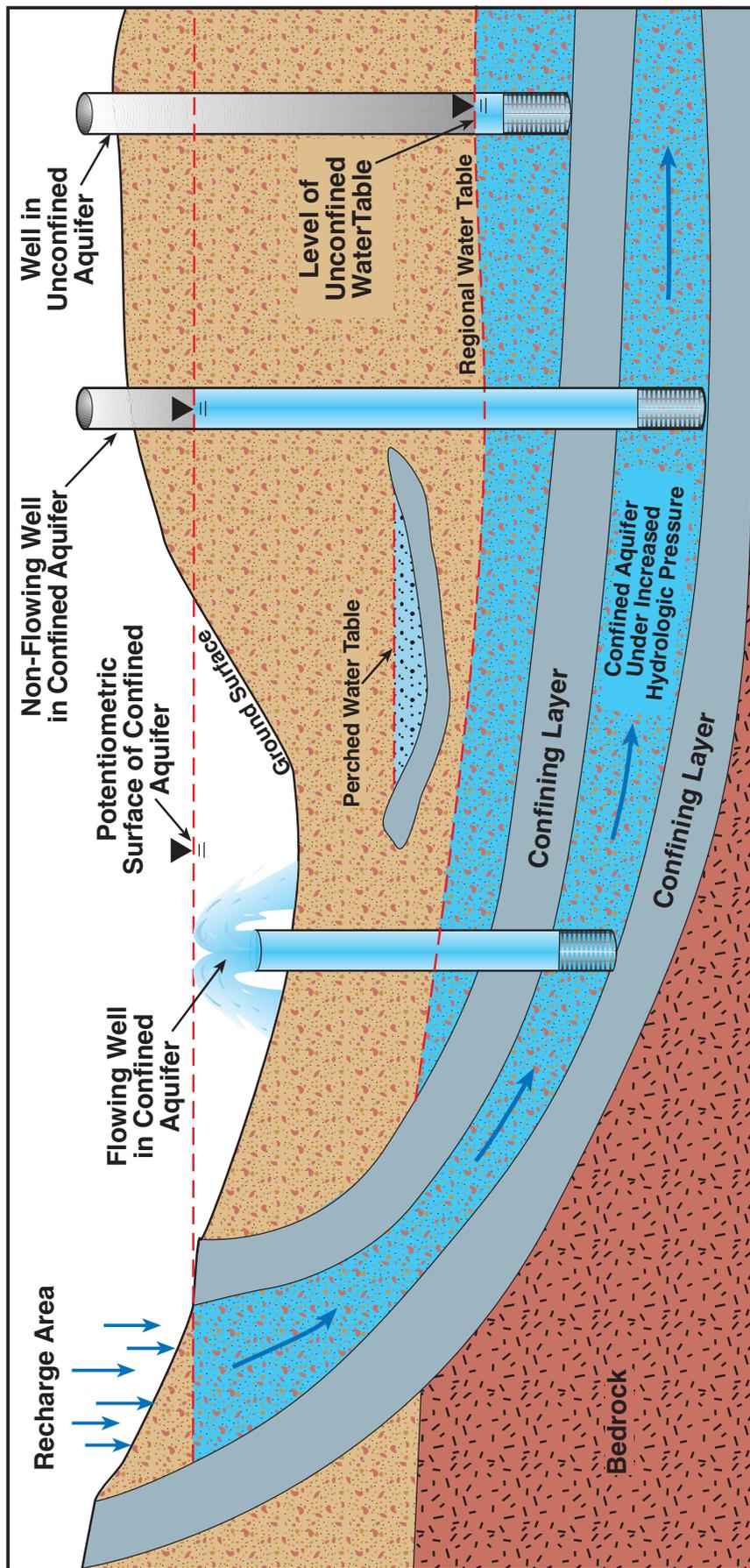


Figure 9. Confined and unconfined aquifers. (After U. S. Department of the Interior, 1977)

The best source of information is the 'Well Log and Drilling Report' that was completed by the driller at the time of construction. These reports contain well construction information and a record of formations encountered during well installation. Figure 10 is an example of a well log and drilling report. An accurate well log and drilling report will enable a drilling contractor to select the most appropriate sealing method for that well. These reports have been filed since 1947 with the Ohio Department of Natural Resources, Division of Soil and Water Resources and, within the last 25-30 years, with each local health district. Copies of public water supply well records may be kept at the appropriate Ohio EPA District Office. To obtain a copy of a well log and drilling report, it is necessary to know the county in which the well was drilled, the township within that county, the street address, the name of the property owner at the time the well was drilled, and the approximate year in which the well was drilled. The water well record database can be searched on-line at <http://soilwater.ohiodnr.gov/search-file-well-logs> or a Division of Soil and Water Resources employee can do a file search with the information that is available. Occasionally, a well log and drilling report may not be on file, either because the well was drilled before the filing law went into effect (1947) or because, for some reason, the log was not sent to the Division. To have the Division of Soil and Water Resources search for a specific well log and drilling report, call 614-265-6740 or e-mail at dswc@dnr.state.oh.us.

Logs for nearby wells should be reviewed if a well log and drilling report cannot be located. Often, wells on adjacent properties will be of similar depth and construction. Review of well logs may indicate one of several conditions that may require special sealing techniques. These conditions may include:

- **karst and paleokarst,**
- flowing or **artesian** conditions, and
- underground mine shafts or rooms.

These conditions may necessitate changing the method selected for dealing with the casing, revising plans for grout selection and selecting different equipment. Review of information available about the local aquifer or aquifers may be needed. Potential sources of information regarding geologic and ground water conditions, siting restrictions and water and waste water infrastructure locations are included in Table 2.

Table 2. Sources of information available during a pre-design review*.

Area of Concern	Potential Sources of Information
Karst geology	ODNR-DGS, ODNR-DSWR
Coarse sand and gravel deposits	ODNR-DGS, ODNR-DSWR, USGS-OWSC
Flowing or artesian conditions	ODNR-DSWR, USGS-OWSC
Ground water contamination	Ohio EPA-DDAGW; Ohio EPA-DERR; BUSTR
Other local ground water conditions	ODNR-DGS, ODNR-DSWR, Ohio EPA-DDAGW, USGS-OWSC, Local health districts and departments
Active and abandoned underground mines	ODNR-DMRM
Mining activity	ODNR-DMRM

*A list of the abbreviations used in this table can be found in Appendix 4.

If a well is free of obstructions (including old pumps), then the total depth and depth to water may be easily determined with a weighted measuring tape or rope. Local drilling contractors will also be familiar with the general geologic conditions in the area.

WELL LOG AND DRILLING REPORT

DNR 7802.05e

Ohio Department of Natural Resources
Division of Water, 2045 Morse Road, Columbus, Ohio 43229-6605
Voice (614) 265-6740 Fax (614) 265-6767

Well Log Number

0

Page **1** of **1** for this record.

WELL LOCATION	CONSTRUCTION DETAILS																																																		
County <u>STARK</u> Township <u>JACKSON</u> R. D. RUNNER Owner/Builder 12345 RINGS ROAD Address of Well Location City <u>CANTON</u> Zip Code +4 <u>44718</u> Permit No. <u>N/A</u> Section; <u>27</u> and/or Lot No. Use of Well <u>AGRIC/IRRIG</u> Coordinates of Well (Use only one of the below coordinate systems) State Plane Coordinates N <input type="checkbox"/> X _____ +/- _____ ft. S <input type="checkbox"/> Y _____ +/- _____ ft. Latitude, Longitude Coordinates Latitude: <u>40.81234</u> Longitude: <u>-81.41234</u> Elevation of Well in feet: <u>1107</u> +/- _____ ft. Datum Plane: <input type="checkbox"/> NAD27 <input checked="" type="checkbox"/> NAD83 Elevation Source <u>GPS</u> Source of Coordinates: <u>GPS</u> Well location written description:	Drilling Method: <u>ROTARY</u> BOREHOLE/CASING (Measured from ground surface) 1 { Borehole Diameter <u>9.000</u> inches Depth <u>84.0</u> ft. Casing Diameter <u>5.000</u> in. Length <u>85</u> ft. Thickness <u>0.2650</u> in. 2 { Borehole Diameter <u>5.000</u> inches Depth <u>175.0</u> ft. Casing Diameter _____ in. Length _____ ft. Thickness _____ in. Casing Height Above Ground _____ 1.0 ft. Type { 1: <u>PVC</u> 2: _____ Joints { 1: <u>O-RING</u> 2: _____ SCREEN Diameter _____ in. Slot Size _____ in. Screen Length _____ ft. Type _____ Material _____ Set Between _____ ft. and _____ ft. GRAVEL PACK (Filter Pack) Vol/Wt. Used _____ Material/Size _____ Method of Installation _____ Depth: Placed From: _____ ft. To: _____ ft. GROUT Material <u>Bentonite/polymer slurry</u> Vol/Wt. Used <u>600 lbs./275 gallons</u> Method of Installation <u>Pumped w/tremie pipe</u> Depth: Placed From: <u>84.0</u> ft. To: <u>0.0</u> ft.																																																		
Comments on water quality/quantity and well construction: HARDNESS: 10 GPG IRON: 2 PPM PH 7.8 TDS: 319 PPM	DRILLING LOG* FORMATIONS INCLUDE DEPTH(S) AT WHICH WATER IS ENCOUNTERED. <table border="1" style="width: 100%; border-collapse: collapse; margin-top: 5px;"> <thead> <tr> <th style="width: 20%;">Color</th> <th style="width: 20%;">Texture</th> <th style="width: 40%;">Formation</th> <th style="width: 10%;">From</th> <th style="width: 10%;">To</th> </tr> </thead> <tbody> <tr> <td>BROWN</td> <td></td> <td>SANDGRAVELBOULDERS</td> <td>0.0</td> <td>20.0</td> </tr> <tr> <td>GRAY</td> <td></td> <td>SANDGRAVELBOULDERS</td> <td>20.0</td> <td>51.0</td> </tr> <tr> <td>GRAY</td> <td></td> <td>SAND AND GRAVEL</td> <td>51.0</td> <td>78.0</td> </tr> <tr> <td>GRAY</td> <td></td> <td>SHALE</td> <td>78.0</td> <td>82.0</td> </tr> <tr> <td>GRAY</td> <td></td> <td>SANDSTONE</td> <td>82.0</td> <td>107.0</td> </tr> <tr> <td>GRAY</td> <td>SANDY</td> <td>SANDSTONE AND SHALE</td> <td>107.0</td> <td>140.0</td> </tr> <tr> <td>GRAY</td> <td></td> <td>SANDSTONE</td> <td>140.0</td> <td>175.0</td> </tr> <tr> <td></td> <td></td> <td>WATER AT</td> <td>100.0</td> <td>107.0</td> </tr> <tr> <td></td> <td></td> <td>WATER AT</td> <td>140.0</td> <td>175.0</td> </tr> </tbody> </table>	Color	Texture	Formation	From	To	BROWN		SANDGRAVELBOULDERS	0.0	20.0	GRAY		SANDGRAVELBOULDERS	20.0	51.0	GRAY		SAND AND GRAVEL	51.0	78.0	GRAY		SHALE	78.0	82.0	GRAY		SANDSTONE	82.0	107.0	GRAY	SANDY	SANDSTONE AND SHALE	107.0	140.0	GRAY		SANDSTONE	140.0	175.0			WATER AT	100.0	107.0			WATER AT	140.0	175.0
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WELL TEST * Pre-Pumping Static Level <u>27.0</u> ft. Date <u>02/18/2013</u> Measured from <u>GROUND LEVEL</u> Pumping test method <u>AIR</u> Test Rate <u>20</u> gpm Duration of Test <u>0.5</u> hrs. Feet of Drawdown <u>40.0</u> ft. Sustainable Yield <u>20</u> gpm *(Attach a copy of the pumping test record, per section 1521.05, ORC) Is Copy Attached? <input type="checkbox"/> Yes <input checked="" type="checkbox"/> No Flowing Well? <input type="checkbox"/> Yes <input checked="" type="checkbox"/> No																																																			
PUMP/PITLESS Type of pump <u>SUBMERSIBLE</u> Capacity <u>10</u> gpm Pump set at <u>140</u> ft. Pitless Type <u>AQUA SEAL</u> Pump installed by <u>ACME DRILLING COMPANY</u> I hereby certify the information given is accurate and correct to the best of my knowledge. Drilling Firm <u>ACME DRILLING COMPANY</u> Address <u>1234 MAIN ST.</u> City, State, Zip <u>SOCKERDOWN, OH 56789</u> Signed <u>W. E. COYOTE</u> Date <u>02/26/2013</u> (Filed electronically by ID # _____) ODH Registration Number <u>3456</u>	Aquifer Type (Formation producing the most water.) <u>SANDSTONE</u> Date of Well Completion <u>02/23/2013</u> Total Depth of Well <u>175.0</u> ft.																																																		

Completion of this form is required by section 1521.05, Ohio Revised Code - file within 30 days after completion of drilling.
Distribute copies of this record to Customer and Local Health Department.

Figure 10. Example of an official Ohio well log and drilling report form.

Well Inspection

Well casing is usually constructed of polyvinyl chloride (PVC) plastic or steel (in drilled wells), or concrete pipe, vitrified tile, brick, or cobbles (in dug wells). Although concrete pipe, vitrified tile, brick, and cobbles are not approved casing materials for private water systems, older wells were constructed with these materials. The length and the condition of the casing should be examined. A determination should be made if a **well screen** was used in the well and if so, the approximate depth. In many older wells, it was common practice to cut slots with a torch in the bottom two or three feet of casing to produce a home-made screen. These types of "screens" are highly inefficient and susceptible to corrosion and plugging. If there is no well log or other information about the construction of the well, or if the well casing is in poor condition, removing the casing may damage the aquifer or confining layer.

Methods for examining the condition of a well include borehole video cameras, casing-depth indicators, and geophysical logging equipment such as calipers and gamma-ray probes. These tools are commonly used in the maintenance of public supply wells and in scientific investigations. Geophysical logging equipment such as calipers and gamma-ray probes are expensive and most wells will not need such detailed investigations. If necessary, local drilling contractors should be able to locate firms possessing this equipment.

Water Quality

The existing water quality is important to know so that the most appropriate material is used to seal the well. Sulfates, pH, iron, chlorides, and calcium concentrations are important to know when determining which grout to use. These factors are discussed in the Sealing Materials section.

Access to Well

Accessibility of the well is important in determining how the well can be sealed. Access to the well and well site will be important if drill rigs or pump hoist vehicles are to be used in preparing for sealing the well.

Past Land Uses

Prior to sealing a well there should be a review of information about the property, surrounding properties and past land uses. The review will help identify local conditions that may dictate the methods used to seal the well. These conditions may include:

- contaminated ground water,
- underground mine shafts or rooms, or
- areas previously used for surface mining.

These conditions may necessitate changing the method selected for dealing with the casing, revising plans for grout selection and selecting different equipment. This should include a review of public records to identify contaminated zones in soil and ground water, past practices and other hazards that may complicate the process of sealing the well. Potential sources of information regarding geologic and ground water conditions, siting restrictions and water and waste water infrastructure locations are included in Table 2.

Procedure Planning

No single method and material are suitable for all situations and site-specific conditions may require modifications to normal operations. To ensure that the well owner and driller are prepared, a work plan summarizing what is known about the well and the details for sealing it should be prepared prior to sealing a well.

The plan should include:

- the reason for sealing the well,
- copies of any permits required for well sealing or site access,
- a summary of information concerning the physical condition of the well, including the results of any well inspections,
- information about special requirements for accessing the well,
- information about local water quality, special environmental and geologic conditions,
- the method(s) and materials for sealing the well,
- an estimate of the volume of sealing material needed (for more on calculating the volume of the void being sealed see Table 8),
- special equipment requirements including an estimate of the amount of water that may need to be brought to the site,
- the final site restoration requirements, and
- a health and safety plan.

Sealing Materials

There are a variety of materials that can be used for well sealing including grouts, clay, and other inert materials. Grout materials used for sealing abandoned water wells must have certain properties to make them desirable for use.

The ideal grout should:

- be of low permeability to resist flow of water,
- be capable of bonding to both the well casing (if present) and borehole wall to provide a tight seal,
- be chemically inert or nonreactive with formation materials or constituents of the ground water with which the grout may come in contact,
- be readily available at a reasonable cost, and
- be safe to handle.

For pumpable grouts, the grout should:

- be easily mixed,
- be of a consistency that will allow the grout to be pumped and remain in a pumpable state for an adequate period of time,
- be capable of placement into the well through a 1-inch diameter pipe,
- be self-leveling in the well,
- have minimal penetration into permeable zones, and
- be capable of being easily cleaned from mixing and pumping equipment.

Pourable grouts should be easy to place by gravity through standing water.

Grout materials currently approved for use in water wells are comprised of either **cement**, **concrete**, **bentonite**, and /or bentonite-cement mixtures. Table 3 lists advantages and disadvantages of cement and bentonite grouts.

The permeability of the grout should be no greater than 1×10^{-7} centimeters per second to retard fluid movement and adequately seal a well or borehole.

Cement-Based Grouts

Cement Properties

All cement placed into the wellbore should be Portland cement that is manufactured to meet the standards of API "10 A Specification for Cements and Materials for Well Cementing" or ASTM "C150/C150M Standard Specification for Portland Cement". Portland cement is the main ingredient in cement-based grouts such as neat cement or concrete. Cement is a mixture of lime, iron, silica, alumina, and magnesia. The raw materials are combined and heated to produce cement clinker. The clinker is ground up and mixed with a small amount of gypsum or anhydrite to control setting time.

When Portland cement is mixed with water (producing neat cement), several chemical reactions occur. Heat is generated as the mixture cures and changes from a slurry to a solid. This is referred to as the heat of hydration and results in a temperature increase at the cement's interface with the formation of the well casing, if any remains in the hole (Troxell et al., 1968; Portland Cement Association, 1979). The amount of heat given off is dependent upon several factors such as cement composition, cement additives, and surrounding temperatures. Excessive heat of hydration may adversely affect the structural properties of PVC well casing left in the borehole (Molz and Kurt, 1979; Johnson et al., 1980).

The setting of cement is controlled by temperature, pressure, water loss, water quality, and other factors (Smith, 1976). Warm water used for slurry preparation and warmer air temperature will cause faster setting than cold water and cooler air temperature. Cement in the borehole will tend to set faster at the bottom since the weight of the cement column will increase hydrostatic pressure on the cement at the bottom. Water expelled from the cement into permeable zones will also result in an increased rate of setting. Standard Portland cement will reach its initial set in about 4 hours at a 50°F curing temperature. Table 4 shows the total curing times for various cement grouts.

Table 3. Grout Properties for Sealing

	ADVANTAGES	DISADVANTAGES
Cement-based Grouts	Suitable permeability	Shrinkage & settling
	Easily mixed & pumped	Long curing time
	Hard-positive seal	High fluid loss to formation
	Supports casing	Heat of hydration
	Suitable for most formations	Can be affected by water quality
	Proven effective over decades of field use	Equipment clean-up essential
	Properties can be altered with additives	
Bentonite-based Grouts	Suitable permeability with high solids grouts	Less working time
	Non-shrinking & self-healing	Subject to wash out in moving water (voids)
	No heat of hydration	Subject to failure from contaminated/poor quality water
	Low density	Low structural strength
	Less setting time than cement	
	Ease of placement	
Cement-Bentonite Grouts	Suitable permeability	Shrinkage and settling
	Easily mixed and pumped	Long curing time
	Hard positive seal	Low compressive strength
	Suitable for most formations	
	Low heat of hydration	
	Lower density reduces shrinkage and settling	

Cement Types

Several types of cement are manufactured to accommodate various chemical and physical conditions which may be encountered. ASTM Specification C150 is the standard used by cement manufacturers. The different types of cement and their appropriate uses are described in Table 4.

Table 4. Grout uses, curing times and mix ratios *

Sealant Type	Use	Curing Time (hrs)	Mix Ratios
Cement Type I	General purpose cement suitable where special properties are not required.	24	94 lbs cement, 5.2 gallons of water. **
Cement Type II	Moderate sulfate resistance. Lower heat of hydration than Type I. Recommended for use where sulfate levels in ground water are between 150 and 1500 parts per million (ppm).	24	94 lbs cement, 5.2 gallons of water. **
Cement Type III	High-early-strength. Ground to finer particle size which increases surface area and provides faster curing rate (approximately 1/4 of the time it takes for Type I to cure).	12	94 lbs cement, 6.3 to 7 gallons of water. **
Cement Type IV	Low heat of hydration cement designed for applications where the rate and amount of heat generated by the cement must be kept to a minimum. Develops strength at a slower rate than Type I.	24	94 lbs cement, 5.2 gallons of water. **
Cement Type V	Sulfate-resistant cement for use where ground water has a high sulfate content. Recommended for use where sulfate levels in ground water exceed 1500 ppm.	24	94 lbs cement, 5.2 gallons of water. **
Cement/Bentonite Mix	Suitable for sealing where a hard positive seal and low heat of hydration are required.	24-36	94 lbs. Cement: 50 lbs Bentonite Grout: 31 Gal. water
Bentonite	Suitable for general purpose sealing. Easily placed where low density and low heat of hydration are required.	2-4	50 lbs Bentonite Grout: 27 Gal. water**
Bentonite chips	Suitable for general purpose sealing where a hard positive seal and a low heat of hydration are required. Used where accessibility for placement allows.	1***	n/a not mixed
Bentonite pellets	Suitable for general purpose sealing where a hard positive seal and a low heat of hydration are required. Used where accessibility for placement allows.	1***	n/a not mixed

* Typical 20% high solids bentonite grout mix ratio shown; see manufacturers' recommendations for exact mixing ratios.

** Based on American Petroleum Institute (API) and Portland Cement Association recommendations

*** If an adequate amount of water for hydration is present

Neat Cement Grout

Neat cement slurry is comprised of Portland cement and fresh water, with no aggregate present. Field experience has shown it to be effective for sealing off formations when properly placed. It can be mixed using a wide variety of methods. Generally, lower pressures are developed while pumping neat cement grouts. The main disadvantages with neat cement are shrinkage upon curing, possible formation of a **microannulus** around the casing, and, in some cases, mixing according to manufacturer's specifications, which can result in a thick mixture that is difficult to pump. Neat cement should not be used when the borehole diameter or annular space exceeds 6 inches.

The amount of shrinkage or settling, and compressive strength, of neat cement are dependent upon the proportion of water to cement in the slurry (Coleman and Corrigan, 1941; Halliburton, 2000). As the water to cement ratio increases, the compressive strength of the neat cement will decrease and shrinkage will increase. Laboratory studies and field experience have demonstrated that settling of cement particles will occur, resulting in a drop in the grout level (Coleman and Corrigan, 1941; Kurt, 1983). The top of the hardened neat cement grout mass will generally be a few feet below the slurry level due to this settling. Field observations show that the amount of settling will usually be 5 to 10 percent of the total grouted depth if the neat cement is mixed at 5 to 6 gallons of water per sack. Table 4 shows the curing times for various cement grouts.

At weights greater than 16 lbs./gal, pumping of the slurry becomes difficult due to higher **viscosity** and pumping pressure. **Density** measurements of the slurry using a **mud balance** are recommended to assure proper water-to-cement ratios.

Under certain conditions it may be necessary for a consulting engineer or the regulatory agency to specify an increase in the water-to-cement ratio. There are also numerous specialized commercial cement products available such as expanding, self-healing cements. Factors such as the cement type, addition of additives, and quality of ground water will affect the cement performance and should be considered when planning the grouting operation. Any variations from these required mix ratios should be discussed with the regulatory agency.

Concrete Grout

Concrete grout for sealing wells and boreholes consists of Portland cement, sand, and water. The proper mix ratio is 94 pounds of cement mixed with an equal amount of sand, with no more than 6 gallons of water to result in a density of 17.5 pounds per gallon. The addition of sand to a neat cement slurry results in less shrinkage and tighter bonding to the casing and borehole. The sand in the slurry will also aid in bridging pores in permeable formations. Sand particles range in size from 0.0625 mm (or 1/16 mm) to 2 mm in diameter. In the United States, sand is commonly divided into five sub-categories based on size: very fine sand (1/16 – 1/8 mm diameter), fine sand (1/8 mm – 1/4 mm), medium sand (1/4 mm – 1/2 mm), coarse sand (1/2 mm – 1 mm), and very coarse sand (1 mm – 2 mm). To help improve the flow of the concrete into small fractures and gaps in wells and boreholes, the use of finer, more uniform sand should be considered to be mixed into concrete. Concrete grout should be used only under specific sealing circumstances, such as when the borehole or annular space diameter is greater than 6 inches, for sealing flowing wells, sealing water wells with natural gas or methane present, and sealing wells with cavernous zones. Concrete should be handled only by experienced registered drilling contractors due to the exacting requirements for its successful installation. It is advisable to consult with the appropriate regulatory agency to make sure the use of concrete is appropriate or allowed.

In most cases concrete grout should be pumped down a tremie pipe when water is present in the borehole. Placing concrete grout through greater than a few feet of water will cause separation of the slurry – the sand may drop out of suspension - which may result in placement problems. If concrete grout is used on a

routine basis, it should be pumped through a metallic grout pipe because it is highly abrasive to plastic pipe. The sand in the concrete slurry can also cause excessive pump wear. Concrete grouts may be placed by gravity where minimal water is present in the borehole and the diameter is larger than 4 inches.

Commercially Packaged Concrete Sack Mixes

Commercially packaged concrete sack mixes such as “Quikrete®” or “Sakrete®” may be used in some limited situations for small jobs such as shallow, dry boreholes. There are many commercially packaged concrete products available and the choices for sealing should be carefully evaluated based on design characteristics of the specific products. Many of these already meet ASTM Standard C150. They must also meet any of the other appropriate ASTM standards the job may require.

When using commercially packaged concrete sack mixes only prepare the amount of material able to be used within a 15 minute period. Since these products tend to set or harden quickly, mixing more than can be placed into the borehole within this period will complicate proper grout placement. The concrete needs to be fluid enough to properly seal the entire borehole. Commercially packaged cement or concrete products should be mixed with the proper amount of water prior to placement. Dry packaged cement or concrete products should never be placed into a well or borehole and then hydrated in the hole. One 50 pound sack of commercially packaged concrete will only fill about 2.5 feet in a 6 inch borehole.

Cement Additives

There are hundreds of additive products available for a wide variety of cement and concrete applications. The suitability of an additive for sealing a well or borehole should be evaluated based on the requirements of the individual job. Some additives are typically used in combination with other additives, while some should not be used together. Always review the product use labels thoroughly for compatibility.

Admixtures are classified according to function. There are five distinct classes of admixtures: air-entraining, water-reducing, retarding, accelerating, and plasticizers or super-plasticizers (Portland Cement Association, 2014). Super-plasticizers are also known as high-range water reducers. All other varieties of admixtures fall into the specialty category whose functions include corrosion inhibition, shrinkage reduction, alkali-silica reactivity reduction, workability enhancement, bonding, damp proofing, and coloring. (Portland Cement Association, 2014). ASTM Standard C494 specifies the requirements for seven chemical admixture types.

- Type A: Water-reducing admixtures
- Type B: Retarding admixtures
- Type C: Accelerating admixtures
- Type D: Water-reducing and retarding admixtures
- Type E: Water-reducing and accelerating admixtures
- Type F: Water-reducing, high range admixtures
- Type G: Water-reducing, high range, and retarding admixtures

ASTM Standard C494-98 does not currently contain specifications for shrinkage-reducing and mid-range water reducing admixtures.

Accelerators may be added to cement to decrease its setting time when attempting to stop flows in and around casings. These admixtures allow the cement to set before it is washed out of the hole. Calcium chloride is the most common and readily available accelerator. It is generally used at between 2 and 4 percent by weight of cement. Accelerators should be used with caution since miscalculations or equipment breakdown can result in a cemented grout pump or hose. Other additives such as set-retarders, weight-reducing agents, weighting agents including barite and hematite, circulation-loss control agents, and water-reducing agents are available for cements and may be used for water well sealing when conditions warrant.

Cement shrinkage can be complex and happens in a variety of ways including plastic shrinkage, thermal shrinkage, autogenous shrinkage, and drying shrinkage. Specific admixtures to control shrinkage typically affect only the specific types of shrinkage they are designed for. High-range water reducers reduce water content by 12 to 30 percent and can be added to concrete with a low-to-normal slump and water-cement ratio to make high-slump flowing concrete. Adding bentonite to a cement mixture increases the amount of water that can be absorbed by the mixture. This both lowers the density and increases the mass of the mixture. The lower density reduces the slurry loss to the formation which in turn reduces shrinkage and settling. The increased mass lowers the heat of hydration. The addition of bentonite increases the set time and decreases the strength of the cement while improving the pumpability of the mixture. This allows for easier placement and increased flexibility when compared to neat cement.

Table 5. Examples of cement and concrete additives

Admixture Class	Examples of Admixture Compound	Function	Potential Issues
Accelerator	<ul style="list-style-type: none"> - Calcium chloride - Calcium nitrate - Sodium nitrate 	Decrease setting time, 2 and 4 percent by weight of cement. Useful for modifying the properties of concrete in cold weather.	Miscalculations can result in rapid setting that may damage equipment.
Retarder	<ul style="list-style-type: none"> -Sucrose -Sodium gluconate -Glucose -Citric acid -Tartaric acid -Sodium citrate 	Cement setting times can be more controlled and adjusted accordingly.	High concentrations may decrease the effectiveness of cellulose-based fluid-loss additives (Halliburton, 2014).
Water-reducing admixture aka Plasticizers.	<ul style="list-style-type: none"> Lignosulfonate Sugars/Sugar Acids (molasses, corn syrup, and gluconate) -Melamine Sulfonate Formaldehyde Condensate (MSFC) -Naphthalene Sulfonate Formaldehyde Condensate (NSFC) -Polycarboxylate Ether 	<ul style="list-style-type: none"> -Reduces the required water content for a concrete mixture by about 5 to 10 percent. -Higher strength concrete can be produced without increasing the amount of cement. -More stable over a wider range of temperatures 	Limited setting times depending on the product and dosage rate, followed by a rapid loss in workability.
Plasticizer and Super plasticizer aka high-range water reducers	<ul style="list-style-type: none"> -Lignosulfonate -sulfonated naphthalene formaldehyde condensate, -sulfonated melamine formaldehyde condensate -acetone formaldehyde condensate -Polycarboxylate ethers. 	<ul style="list-style-type: none"> -Reduce water content by 12 to 30 percent and can be added to concrete with a low-to-normal slump and water-cement ratio to make high-slump flowing concrete - Super plasticizers used to increase workability more than is practical with traditional plasticizers. 	Limited setting times depending on the product and dosage rate, followed by a rapid loss in workability.

Admixture Class	Examples of Admixture Compound	Function	Potential Issues
Specialty Admixtures:			
Shrinkage-reducing admixtures	-Poly(ethylene glycol-co-propylene glycol monobutyl ether -Oxirane, methyl-, polymer with oxirane, monobutyl ether	Used to control drying shrinkage and minimize cracking.	-Different combinations of cementitious materials, aggregates, water and chemical admixtures can result in concretes with differing amounts of shrinkage. -Admixture is a potentially combustible material.
Alkali-silica reactivity inhibitors	Lithium-based	Control durability problems associated with alkali-silica reactivity due to certain siliceous mineral aggregates that react with soluble alkalis.	Can accelerate the initial setting time of concrete.
Corrosion inhibitors	Non-chloride-containing admixtures	Used as a defensive strategy for concrete structures, such as marine facilities, highway bridges, and parking garages, that will be exposed to high concentrations of chloride.	Possible decrease in compressive strength.
Circulation-loss control agents	Gilsonite (trademark name) Uintaitite or uintahite form of natural asphalt mined in underground shafts and resembles shiny black obsidian	Inert plugging particulates which seal off high permeability thief zones or bridge off natural fractures. - Provide higher strength than heavier additives with high water requirements. (Halliburton, 2014)	Can also cause the additive to separate to the top of thin slurries and slurries containing dispersants. Adding 2% or more bentonite to the slurry will help prevent separation. (Halliburton, 2014)
Other Additives			
Weighting agents	Hematite (Fe ₂ O ₃) - most commonly used Ilmenite (FeO TiO ₂) Hausmannite (Mn ₃ O ₄) Barite (BaSO ₄)	Used to increase slurry density for control of highly pressured wells.	Barite is not normally used in cementing as a weighting agent because of its high surface area and high water demand.
Weight-reducing agents	Expanded Perlite	Used to reduce the weight as water is added with its addition. Can be used to achieve a slurry weight as low as 12.0ppg.	Without bentonite the perlite separates and floats to the upper part of the slurry. Bentonite in concentrations of 2–4% is added to prevent segregation of particles and slurry.

Bentonite-Based Grouts

Sodium bentonite is used for grouting because it expands when wet, absorbing as much as several times its dry mass in water. The property of swelling on contact with water makes sodium bentonite useful as a sealant, since it provides a self-sealing, low permeability barrier to seal off the annulus of a water well, or to plug old wells. Similar uses include making slurry walls, waterproofing of below-grade walls, and forming other impermeable barriers. Calcium bentonite does not absorb as much water as sodium bentonite and provides a lesser-quality sealant.

Other industrial or commercial uses of bentonite include: drilling fluids, decolorizing oils, clarifying wine, liquor and beer, cat litter, dermatologic formulas, pelleting aids, anti-caking agents, flow agents, binders for livestock and poultry feeds, and digestive aids. Only sodium bentonite products specifically designed for use in well sealing should be used when sealing a water well.

Clay Mineral Properties

Clay minerals are the principal ingredient of all bentonite-based grouts and drilling muds. They may be characterized as naturally-occurring substances which exhibit colloidal-like properties (remain in suspension in water for a long period of time) and varying degrees of **plasticity** when wet (Bates, 1969).

The common characteristic associated with clay minerals is the very small particle size that has a very high surface area-to-mass ratio. Negative electrical charges on the particle surface result in the interaction of clays with other particles and water. Hydration occurs with incorporation of the water molecule into and around the lattice structure of the clay mineral, during the shearing process of mixing the water and bentonite. This explains the ability of certain clays to swell many times their original volume when **hydrated**.

The variety of bentonite commonly used in grouting materials and drilling muds is one in which the clay mineral is predominantly sodium-rich montmorillonite. Mined at relatively few locations, the majority of the high-grade sodium bentonite is obtained in Wyoming, Montana, and South Dakota (Gray and Darley, 1981). These clays are characterized by their ability to absorb large quantities of water and swell 10 to 12 times in volume. When placed in water, the bentonite particles tend to remain in suspension for an indefinite period of time. The resulting slurry has a low density and high viscosity. Bentonites that have calcium as the predominant exchangeable ion are less desirable as sealing materials because they have significantly lower swelling ability (Gaber and Fisher, 1988).

Properties of Bentonite Grout

Three important physical properties of a grout are: 1) density, 2) **gel strength**, and 3) viscosity. A review of these properties will aid in understanding what makes a good bentonite grout.

Density is defined as the weight per unit volume of a fluid and is commonly expressed in pounds per gallon. The terms weight and density, although technically distinct, are frequently used interchangeably in the drilling industry. The density of grout determines how much pressure is exerted on the formation when the fluid is at rest and is a direct indicator of the amount of clay solids present. The higher the density, the more solids are suspended in solution. A dense grout is needed to keep a borehole from collapsing. Density is measured using a mud balance. A mud balance measures a specific volume of grout slurry in pounds per gallon. The densities of various sealing materials can be seen in Table 6. It is important to choose a grout that has at least 20% solids and has a permeability less than 1×10^{-7} cm/sec.

A density measurement should be taken before grout placement and a grout sample should also be collected after the grout appears at the surface. To obtain the best seal the grout discharged from the well should have a density equal to that of the grout before it was pumped. Therefore, the grout must be pumped into the well until dilution is minimal. When conducting density tests it is important to make sure air is not trapped within the grout, as this will affect the measurements.

Gel strength is a measure of internal structural strength. It is an indication of a fluid's ability to support suspended particles when the fluid is at rest. Gel strength is caused by the physical alignment of positive and negative charges on the surface of the clay particles in solution. Gel strength is responsible for the quasi-solid (plastic) form of a clay/water mixture. It is not necessary to test the gel strength but it is important to follow the manufactures' recommendations for mixing.

Viscosity is a measure of a fluid's resistance to flow. The higher the viscosity of a fluid, the more difficult it becomes to pump. The viscosity of bentonite-based grouts is dependent upon a number of factors including: 1) the density, 2) the size and shape of the clay particles, and 3) the charge interaction between the particles (Peterson and Rothauge, 2007). It is not necessary to test the viscosity of the grout but is important to follow the manufactures' recommendations for mixing.

The quality of the water in the well and geologic formation must also be considered when using bentonite based grouts. Bentonite grout slurries should not be used for sealing a well or borehole when the total dissolved solids content of the water in the hole exceeds 1,500 milligrams per liter (mg/l) , unless the dissolved iron is less than 15 mg/l, chloride is less than 500 mg/l and calcium is less than 500 mg/l. The presence of highly mineralized water may prevent the full hydration of the bentonite slurry and lead to incomplete sealing of the well or borehole. Coarse grade or pelletized bentonite should not be used as a sealing material when the total dissolved solids content of water in the well or borehole exceeds 1,500 mg/l.

Make-up water for pumpable grouts should have total dissolved solids of less than 1,500 ppm and total hardness of less than 500 ppm. It is important to treat make up water with soda ash to achieve a target pH between 8 and 9, to insure the proper hydration and suspension of the bentonite grout. Soda ash will first tie up the hardness before it affects the pH of the make-up water.

Table 6. Grout Slurry Densities

Product	Water Ratio	Minimum Density lbs/gal	Volume cu. ft./sack (or batch)
Neat Cement	6.0 gal./sack of cement	15.0	1.28
	5.2 gal. recommended/sack of cement	15.6	1.18
Neat Cement & CaCl (accelerator)	6.0 gal./sack of cement CaCl - 2 to 4 lbs. sack of cement	15.0	1.28
Concrete Grout	1 sack of cement and an equal volume of sand per 6 gallon water maximum	17.5	2.0
Bentonite 30% WT*	14 gal/50# bag	9.8	2.27
Bentonite 20% WT	24 gal/50# bag	9.3	3.61
Cement/Bentonite mix 41% WT	24 gal/94# bag cement and 50# bag bentonite	11.0	4.14
Cement/Bentonite mix 57% WT	9 gal/94# bag of cement and 5# bentonite	13.8	1.7

*Percentage of product by weight

Bentonite Grout Products

The bentonite-based grouts widely used for sealing can be grouped into four classifications reflecting the degree of processing and the particle size of the bentonite. The four classes are: 1) powdered bentonite, 2) granular bentonite, 3) coarse grade bentonite, and 4) pelletized bentonite. All bentonite grout products should be American National Standards Institute (ANSI) NSF 60 certified. Each class of bentonite requires

a different handling and placement method. Manufacturers recommend that mixing and placement methods should be assessed with regard to ground water quality, the depth to the water table, the required depth of grout placement, and other pertinent geological information.

Bentonite products are designed to be easy to mix, pump, place, and clean up. Some products require the use of chemical additives when mixing to control the development of viscosity and gel strength thus increasing the work time. Difficulties in pumping and placement may be encountered if proper mixing guidelines are not followed or if working times are extended. Generally, bentonite grouts require higher pumping pressures than neat cement grouts (Gaber and Fisher, 1988). It also is important to know the environment into which the bentonite will be placed.

Powdered Bentonite/Clay Grout

Powdered bentonite is commonly used in environmental and geothermal applications. Powdered bentonite/clay products available are similar in texture, appearance, and packaging to the high-yield drilling mud-grade bentonite. Use of feed-grade bentonite is not allowed. Powdered bentonite grouts are finely ground single bag, single step grouts designed to have adequate work time to allow placement and to achieve a flexible, low permeability seal with between 20% and 30% concentration by weight solids. While these grouts can be mixed and placed with most available pumping equipment, paddle mixers and positive displacement or progressive cavity pumps work best for placing these viscous materials. Powdered bentonite grouts can be adapted by varying the amount of water added to the mix to change the available work time and pumping viscosity. Local regulations may not allow such changes in mix ratio.

Failure to meet manufacturer's density requirements or placement of the grout on top of a lower density material (e.g., drilling mud or water) may result in a settling of the grout material to the bottom of the well. These grouts can be used to displace lower density materials if placed by a tremie pipe. Proper use of these products requires placement of the material the entire length of the borehole starting at the bottom of the borehole. A bentonite pellet or neat cement cap a few feet thick is also recommended near the surface to complete the grout seal.

Granular Bentonite Slurries

Granular bentonites are generally manufactured from high-yield, non-drilling-grade bentonite. The bentonite is processed to provide coarse granular particles in the 8 to 20 nominal **mesh size ranges**. The larger particles possess lower surface area-to-mass ratios than the finely ground, powdered bentonite. This results in considerably less dust while mixing and slower water absorption and delayed hydration and expansion when compared to a finely ground bentonite. See Table 7 for bentonite grout particle sizes.

Table 7. Bentonite grout particle sizes

Product	Nominal Size	Actual Size
Powdered Bentonite Grouts	200 mesh (.0029")	80 – 325 mesh (.0070" - .0017")
Granular Bentonite Grouts	8 mesh (.0937"), 20 mesh (.0331"),	8 – 40 mesh (.0937" - .0165") 10 – 30 mesh (.0787" - .0232")
Coarse Grade Bentonite (Chips)	3/8" medium, 3/4" coarse	-3/8" + 1/4" -3/4" + 3/8"
Pelletized Bentonite (Pellets)	1/4" 3/8" 1/2"	1/4" 3/8" 1/2"

One advantage of the granular bentonite slurry is that the delay in swelling of the bentonite particles allows preparation of a slurry possessing a lower viscosity for a short period of time (15 minutes or less). If mixing and pumping are done efficiently, the granular bentonite slurries allow placement of a high density grout in a low viscosity state. The hydration and expansion process is then completed in the well or borehole. Granular bentonite must be prepared with no less than 20 percent bentonite content by weight. This results in a set grout which exhibits desired permeability and gel strength characteristics.

These products rely on the addition of a polymer to suppress hydration and delay swelling of the bentonite particles. These additives can be added either by the manufacturer for a single step mix or added to the mix in the field. All additives should be ANSI NSF 60 certified. The use of such products requires particular attention to the manufacturer's mixing recommendations. Mixing requires the use of blade or paddle-type mixers or grout mixers with recirculation; centrifugal pumps are not recommended for mixing or pumping granular bentonite slurries. Placement of the grout must be accomplished before swelling of the bentonite occurs. If expansion occurs prematurely the slurry cannot be pumped and the batch is wasted.

Coarse Grade Bentonite

Coarse grade bentonite, also referred to as crushed or chip bentonite, is processed by the manufacturer to provide a large particle size and density. The bentonite particles typically are available in nominal sizes of 3/8 to 3/4 inch and are intended to fall through a column of water. When placed properly, the coarse grade bentonite provides a flexible high density, low permeability, down-hole seal. Be aware that the ODH and Ohio EPA well standards may limit the placement of this product.

Due to the size of the coarse grade bentonite products, care should be taken in their use and adequate time allotted for slow placement. Since the material cannot be pumped, placement requires pouring from the surface and care should be taken with the rate of placement. The settling rate for coarse bentonite chips is 1 foot per second; adequate time must be allotted for the product to settle into position. Placement may be accompanied by tamping to insure that bridging has not occurred. The product must be poured slowly, and the pouring rate should not exceed the manufacturer's specifications. If the borehole was just drilled and needs to be sealed, clean the borehole of all the drilling fluids before sealing. Do not pour coarse grade bentonite through drilling muds.



Bentonite chips. (Coarse grade bentonite)

Prior to using this material, it should be sieved through 1/4-inch mesh screen to remove any fines which have accumulated in the bag during shipment. These fines, if not removed, will clump if they hit water and increase chances of bridging. It is also recommended that water be poured on top of any coarse grade bentonite above the water table to induce hydration.

Pelletized Bentonite

The pelletized bentonite products are compressed pellets with nominal sizes of 1/4, 3/8 and 1/2-inch. As with coarse grade bentonite, pelletized bentonite provides a dense and flexible seal. It can be poured directly into the well through standing water. The pellets come in a coated version to slow down hydration. Precautions similar to those for the use of coarse grade bentonite are required to avoid bridging.

Other Fill Materials

Other materials are available for sealing wells with specific construction methods or in unique geologic conditions. These include gravel, sand, and clay. Gravel includes siliceous, well-rounded particles that range from fine (2 millimeter [mm]) to coarse (76 mm) in size. Sand should also be siliceous and well-rounded particles that range from very fine (.05 mm) to very coarse (2 mm) in size. Clay includes particles that are less than .002 mm in size and may include kaolinite, chlorite, illite and smectite-based clays. All fill materials considered for well sealing should be sized to the well being sealed, meaning that the material should have particle-size diameters small enough not to cause bridging (Gordon, 1988). Any fill materials used for well sealing must be clean and free of sticks, leaves, or other foreign matter. Additionally, the material should be free of any toxic chemical residues that could cause contamination of ground water.

Clays mined from glacial deposits or from underclays in the coal-bearing regions of the state may be used for sealing some wells. The ability of these clays to serve as an effective sealing agent was evaluated by Carlton (1975). These clays should be evaluated to ensure that the clay-size particle content exceeds 40%, the remaining particle sizes should vary to ensure good compaction and minimize porosity in the sealing materials. Clays with a mixed clay mineralogy will provide the best seal. Native clays do not seal as effectively as commercially prepared bentonite products and may not be used as a sealing material or fill material in some types of wells (Carlton, 1975) Native clays can bridge in deeper, smaller diameter wells.

Clays should be wetted to help disperse the particles and improve compaction. The material must contain sufficient moisture to easily form by hand into a moist, somewhat soft, ball without developing any cracks (NRCS, 2010). Clays should be placed in lifts no more than 1 foot thick and be firmly compacted in the borehole before placement of the next lift. Clays must be layered with concrete, coarse grade or pelletized bentonite to ensure a uniform, impermeable seal of the borehole.

Alternative fill materials may be used in wells that have very large volumes in the borehole, such as dug or bucket auger wells, where it may not be economically feasible to recommend complete filling with a bentonite or cement material. Most wells in this category are large in diameter and, therefore, present a physical hazard if they are not properly sealed. This type of well must be filled with load-bearing materials (Gordon, 1988). Large diameter, shallow dug wells can be filled with clean gravel adjacent to the water producing zones, and the remainder of the borehole filled with clean clay to a depth specified in ODH or Ohio EPA rules.

There are other geologic conditions where alternative fill materials may be placed in a portion or portions of the borehole during the sealing process. These include wells completed in fractured bedrock or extremely coarse gravel where there may be excessive loss of sealing materials during and after placement. In such instances, gravel can be used to bridge fractures or fill areas of large voids in the water-producing zone before sealants are emplaced (Gordon, 1988). ODH rules permit the placement of clean gravel adjacent to known water bearing zones to help reduce well sealing costs where well log data is available to ensure proper depth placement of these materials.

Procedures for Sealing the Well

General Sealing Procedures

It is highly recommended that wells and boreholes be sealed by an experienced registered water systems contractor. Private water system wells must be sealed by a private water systems contractor registered with ODH. If the well to be sealed is regulated by a state agency, the applicable rules should be followed.

1. Remove obstructions from the well

The first step in the well sealing process is to remove all obstructions from the well. These obstructions can include pumps and related equipment, such as drop pipes, **pitless adaptors** or **pitless units**, and

suction lines. Pumps that are stuck and cannot be pulled should be pushed to the bottom of the hole, if possible. Other obstructions may consist of trash, animal remains, and debris such as large rocks or pieces of wood. If there is a possibility that the well has been contaminated, which could be evidenced by the presence of items such as empty pesticide containers, fertilizer bags, or a strong odor, the well owner should inform the appropriate agency (see Appendix 1) before sealing begins. Cap off the water supply line either in the house or near the well, ideally as close to the well as possible.

2. Evaluate the condition of the casing

After the obstructions have been removed from the well, the next step is to decide what to do with the casing and any liner pipe that may be present. Remove any liner pipe that is not permanently attached to the casing. Whether or not the casing is left intact will depend on the type of casing, its condition, and the type of well being sealed. Under normal situations, leaving the casing in place is recommended. If the annular seal is determined to be adequate, then the casing may be left in place unless other site conditions warrant removal or perforation of the casing. If there is a suspected breach in the annular seal, a dye trace may be conducted to determine the integrity of the annular seal.

When the following conditions exist an evaluation should be made to determine if the casing should be removed:

- there is water flowing from around the outside of the well casing (this condition can occur in flowing wells), or
- the well is located in an area of known contamination, or
- there is gravel packing connecting two or more hydraulic zones, or
- voids are known to exist between the casing and the formation, or
- there is a gravel pack (type of filter pack) between the two casings of a double-cased well, or
- the well is located in an area of known ground water contamination and one of the above conditions exists.

Methods for removing the casing include overdrilling, pulling, or drilling out the casing. Overdrilling is not commonly used by the water well industry to remove casing. It is more commonly used to remove casings from wells used for environmental monitoring and remediation. Overdrilling a well requires the contractor to drill a larger diameter borehole around the existing well. The depth of the overdrilled borehole will depend on the construction of the well and local hydrogeologic conditions. After overdrilling, the casing can then be pulled from the ground. When the old casing is removed efforts should be made to prevent collapse of the native materials into the open borehole.

Drilling out the casing may be possible for shallow, small diameter wells when the casing is made of PVC or Teflon. This method of removing the casing uses a solid stem or rotary bit to drill vertically through the casing, destroying the casing as the drilling progresses. This method of removing casing presents risks to the drilling equipment, including excessive wear on drill bits, which may add to the costs of sealing the well. These added costs and the environmental benefit gained by removing the casing using this method should be considered before deciding to drill out the casing.

In rare cases, ripping or perforating a casing should be performed. Perforating or ripping should always be done by an experienced registered drilling contractor that has the specialized tools, including **packers** and high pressure equipment, needed for this work. Ripping or perforating the casing may be considered if the annular seal is not in good condition and trying to remove the casing can do harm to the aquifer, a confining unit or will create additional pathways for contamination to reach the aquifer.

3. Calculate the amount of sealing and fill material needed

The materials to be used in sealing the well and their method of placement will be determined by the well construction, geologic conditions and applicable rules. In most situations (except for shallow wells), the method that provides the easiest placement and best seal is pressure grouting with a neat cement or bentonite slurry. As discussed in the Sealing Materials section of this document, local water

quality should be taken into account before a sealing product and technique are chosen. Water used in well sealing may be treated as needed to ensure the grout is properly mixed.

The amount of grout required to seal a well can be estimated in three ways:

- a) On-line grout volume calculator: Many of the bentonite manufacturing companies have calculators for estimating the amount of grout needed to seal a well available on their websites. Also, ODH has developed a downloadable spreadsheet for making a grout volume estimate. Links to these calculators are listed below. Table 8 provides volumes of different well sealing materials required to seal a 100-foot deep well.

ODH worksheet - <http://www.odh.ohio.gov/en/odhprograms/eh/water/PWSForms/LHDFForms.aspx>

Wyoben - <http://www.wyoben.com/>

Cetco - <http://drillingproducts.cetco.com/>

Baroid - <http://www.baroididp.com/>

- b) Quick estimate method: The hole diameter (in inches) multiplied by itself then divided by 24.5 will give the approximate grout volume in gallons per foot. [Hole Diameter (inches) x Hole Diameter (inches)/24.5 = Hole Volume (Gal/ft)]

$$\begin{aligned} \text{Approximate grout volume per unit} & & & = \frac{d^2}{24.5} \\ \text{length of borehole (gallons/foot)} & & & \end{aligned}$$

(Where d = diameter of borehole in inches.)

- c) Exact calculation method: The hole radius (in inches) multiplied by itself and then multiplied by π (3.1415). Divide this result by 1728 to find the hole volume in cubic feet per inch of hole. Then multiply this number by 12 to get the cubic feet per foot of hole. Multiply this number by 7.48 to get the volume in gallons per foot of hole. [Hole radius (inches) x Hole radius (inches)][3.1415]/1728 = Hole Volume (cubic ft/in) x 12 in/ft = hole volume (cubic ft/ft). Hole Volume (cubic ft/ft) x 7.48 gal./cu. ft = Hole Volume (Gal/ft).]

$$\begin{aligned} \text{Grout volume per unit} & & & = (\pi r^2 / 1728 \text{ in}^3/\text{ft}^3) \times 12 \text{ in/ft} \times 7.48 \text{ gal/ft}^3 \\ \text{length of borehole (gallons/foot)} & & & \end{aligned}$$

(Where: r = Hole radius in inches.)

Table 8. Comparing volumes of different well sealing materials required to seal a 100-foot deep well*

Hole Diameter (Inches)	Gallons Per Foot	Gallons to be Plugged in 100' Well	Minimum Bags Required to Plug a 100 foot Well		Hole Volume Cu Ft/Ft Depth	Feet filled by one bag of Coarse Grade Bentonite (3/8"-3/4")	Bags of Bentonite Pellets or Chunks to Fill a 100' Well	Cu Ft of #8 Aggregate to Fill a 100' Well
			Bentonite Slurry	Neat Cement				
2	0.17	17	1	2	0.022	31.3	4	2.2
3	0.38	38	2	4	0.049	14.3	7	4.9
4	0.67	67	3	7	0.087	7.9	13	8.7
5	1.00	100	5	11	0.136	5.1	20	13.6
6	1.51	151	7	16	0.196	3.5	29	19.6
7	2.05	205	10	22	0.267	2.6	39	26.7
8	2.7	270	13	28	0.349	2.0	51	34.9
9	3.4	340	16	35	0.442	1.6	64	44.2
10	4.2	420	19	44	0.545	1.3	79	54.5
11	5.0	500	23	52	0.66	1.1	95	66.0
12	6.0	600	27	62	0.785	0.9	113	78.5
15	9.5	950	43	98	1.227	0.6	177	122.7
18	13.6	1360	61	140	1.767	0.4	255	176.7
20	16.8	1680	75	173	2.181	0.3	315	218.1
25	26.0	2600	117	267	3.409	0.2	491	340.9
30	38.0	3800	170	390	4.909	0.1	707	490.9
60	152.0	15200	679	1559	20.322	0.04	2500	2032.2

*-Provisions should be made to have up to 20% additional material available should inconsistencies in well diameter be encountered while sealing.

4. Placement of the sealing and fill material

There are four recommended procedures for sealing a well. They include:

a. Pressure grouting bentonite or cement slurries

Pressure grouting involves pumping the cement or bentonite slurry down a plastic pipe (called a tremie pipe) lowered to the bottom of the borehole or well (see Figure 11). As the slurry is pumped, the pipe is pulled back at a rate that keeps the end of the pipe submerged in the slurry as each batch is mixed and pumped. The slurry is denser than water and will displace any water in the well and force it up in the borehole. When the slurry that reaches the surface is the same density as the slurry being pumped through the tremie, the well has been properly sealed. Time should be allowed for settling to occur and the sealing material to achieve its final volume before the final steps in the sealing procedure are completed. The actual volume of sealing material used should be compared to the



Pressure grouting – early stage.

calculated volume to either confirm adequate sealing material has been used or to identify potential problems. (See Table 4 for approximate times)

b. Wet pouring cement or concrete slurries

Cement and concrete grouts may be gravity poured into a dry hole where no water is present in the well or borehole. In low-yielding wells, it may be possible to pump the well dry and then pour the cement or concrete before too much water re-enters the well, thus diluting the concrete or cement. In higher-yielding wells, it is very unlikely that the well can be dewatered or stay dewatered long enough for the cement or concrete to be poured into the well.

c. Dry pouring coarse grade or pelletized bentonite

When sealing wells with coarse grade bentonite products, precautions must be taken to ensure that the sealing material does not bridge. Coarse grade bentonite products can be used in wells up to 200 feet deep. Pelletized bentonite products can be used in wells up to 100 feet deep. If the well is less than 4 inches in diameter and over 100 feet deep, dry pouring is not allowed. All coarse grade products used in wells less than 24" in diameter should be poured over a wire mesh screen to eliminate the fine bentonite powder that could cause **bridging**. These products should be slowly poured at a rate no faster than 3 minutes per 50 pound bag (see Figure 12). The pouring process should be halted occasionally in order to lower a weighted measuring tape into the well until it reaches the top of the sealing products to confirm that bridging has not occurred. Adequate time for settling of the coarse grade bentonite needs to be allowed before measurements are taken. A tamping device can be used to break any bridges that form. The total volume of products used to fill the well should be no less than 80% of the estimated amount needed for sealing. Where the borehole or well is dry, the bentonite must be periodically hydrated with water in accordance with the manufacturer's requirements.



Pouring coarse grade bentonite over mesh screen to filter out fine particles.

d. Dry pouring sand, gravel or **fire clay**

Where the borehole conditions and geologic formations are known through an accurate well log, the well was recently completed or a downhole camera inspection was performed, materials other than bentonite or cement may be used. In some cases clean gravel may be placed from the bottom of the well to the top of the aquifer or to twenty-five feet below ground surface, whichever is encountered first. For some wells sand or fire clay may also be used to accomplish sealing. If the depth to the aquifer is unknown, then the entire borehole shall be filled with cement, concrete, or bentonite. Well sealing must always ensure that no mixing of water between aquifers will occur. For more information on the appropriate use of clean gravel, sand or fire clay see the Specific Well Sealing Procedures section of this document and consult the rules applicable to the well or the appropriate regulatory agency.

5. Grout material set-up

After the grout and other sealing materials have been placed into the well, dry hole or test hole, the sealing material shall be left a minimum of twelve hours to assess whether any settling of the sealing

material has occurred. If settling has occurred, then additional grout shall be placed into the remaining void space.

6. Surface completion

When the installation of sealing material has been completed, any remaining casing must be cut off to a depth of at least two or three feet below ground level, depending on the type of well or borehole being sealed. The remaining hole should be filled with clean soil or clean clay and the finished ground surface mounded to ensure that surface water will drain away from the area. Variations of this procedure may occur depending on future use of the property and the location of the well, for example, within a building or pumphouse. Consult appropriate regulatory agency for assistance.



Cutting off the casing.

7. Recordkeeping and filing

The final step in the well sealing process is submitting a well sealing report to the Ohio Department of Natural Resources, Division of Soil and Water Resources and to the local health district or the appropriate Ohio EPA District Office depending on the use of the well (see Figure 1). This form can be filled out on-line by going to <http://soilandwater.ohiodnr.gov/search-file-well-logs> or a blank form can be obtained from the ODNR - Division of Soil and Water Resources upon request.

Specific Well Sealing Procedures

It should be noted that where there are existing regulations for sealing a well or borehole, the procedures spelled out in the regulations should be followed. This guidance document should be followed if no regulations are available. If conditions indicate that sealing methods other than those spelled out in the regulations may be needed to properly seal the well or borehole contact the appropriate regulatory agency.

Sealing Dug Wells

The procedure for sealing dug wells differs somewhat from the general procedures described earlier in this guidance (see Figure 13 for details). Once any obstructions, loose debris, drop pipes, and pump are removed, the casing wall or liner material (i.e. stone, brick, concrete, tile, etc.) should be left intact except for the upper three to five feet depending on the type of well and the depth of the static water level. The area should be excavated at least six inches beyond the original borehole. If the well contains water, it should be pumped dry, if possible.

The well or borehole can be filled with clean clay, cement grout, coarse grade bentonite chips or concrete. The well or borehole can be filled with gravel adjacent to the water-producing zone. A layer of bentonite or cement grout at least one foot thick must be placed in the abandoned well. This layer will either be placed at the elevation of the static water level or from 15 to 14 feet below the natural ground surface, depending on the appropriate rules. If dry-poured bentonite is used it must be hydrated with five gallons of water per fifty pounds of bentonite. The remainder of the well must be filled with concrete, coarse grade or pelletized bentonite, fire clay, clay, or cuttings. To provide structural strength and minimize permeability, an equal part mixture of gravel and bentonite chips could be used. Some wells will also need to have a minimum one foot thick layer of coarse grade or pelletized bentonite or concrete grout placed at the elevation to which the casing has been removed. Settling may occur over time requiring additional fill to maintain drainage away from the well.

If the well owner wants to keep the well because of historical significance, the well owner should contact either the Ohio Department of Health or the Ohio EPA to determine the appropriate safety measures to reduce physical hazards and protect the aquifer.

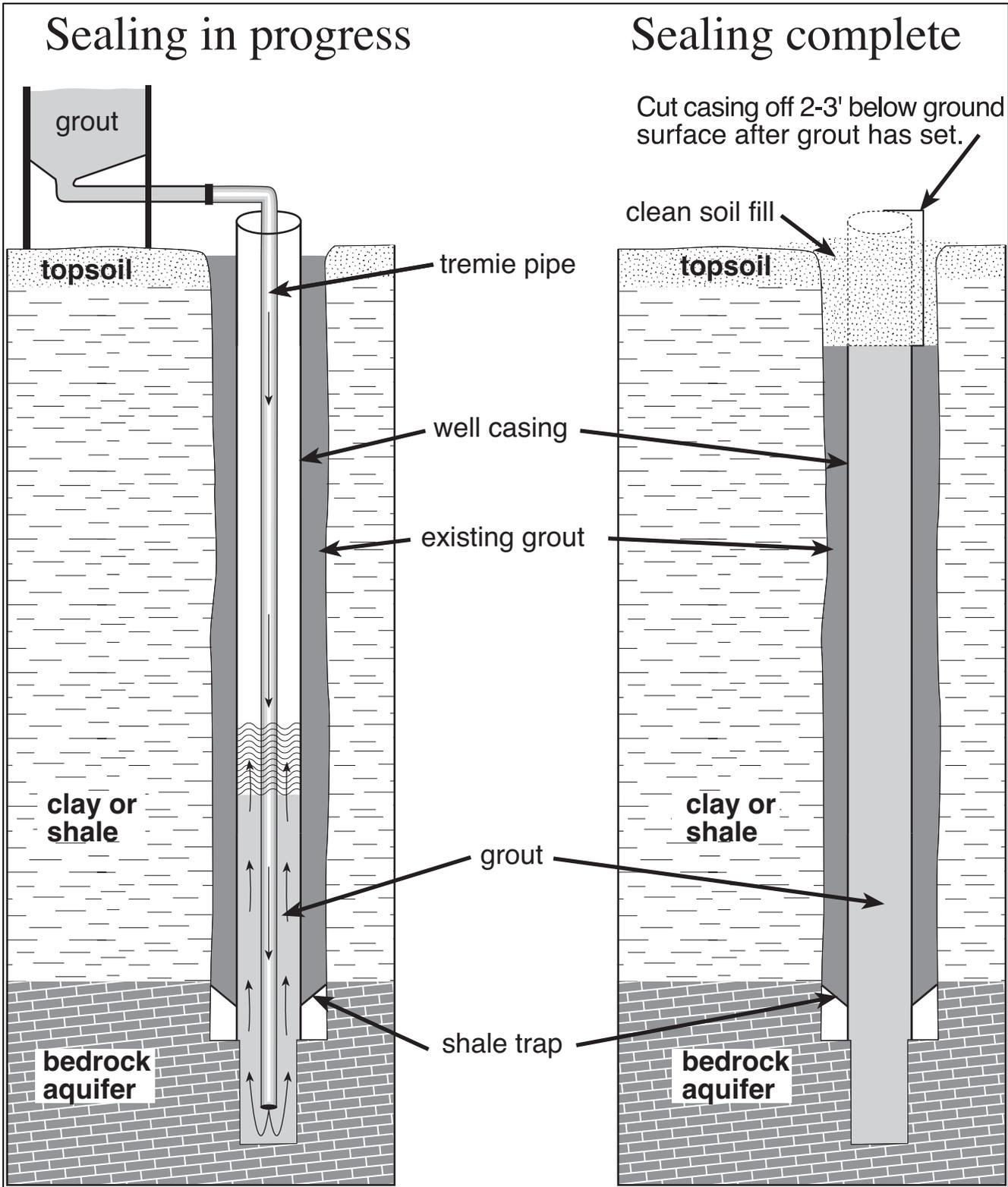


Figure 11. Grouting a bedrock well using the tremie pipe method.

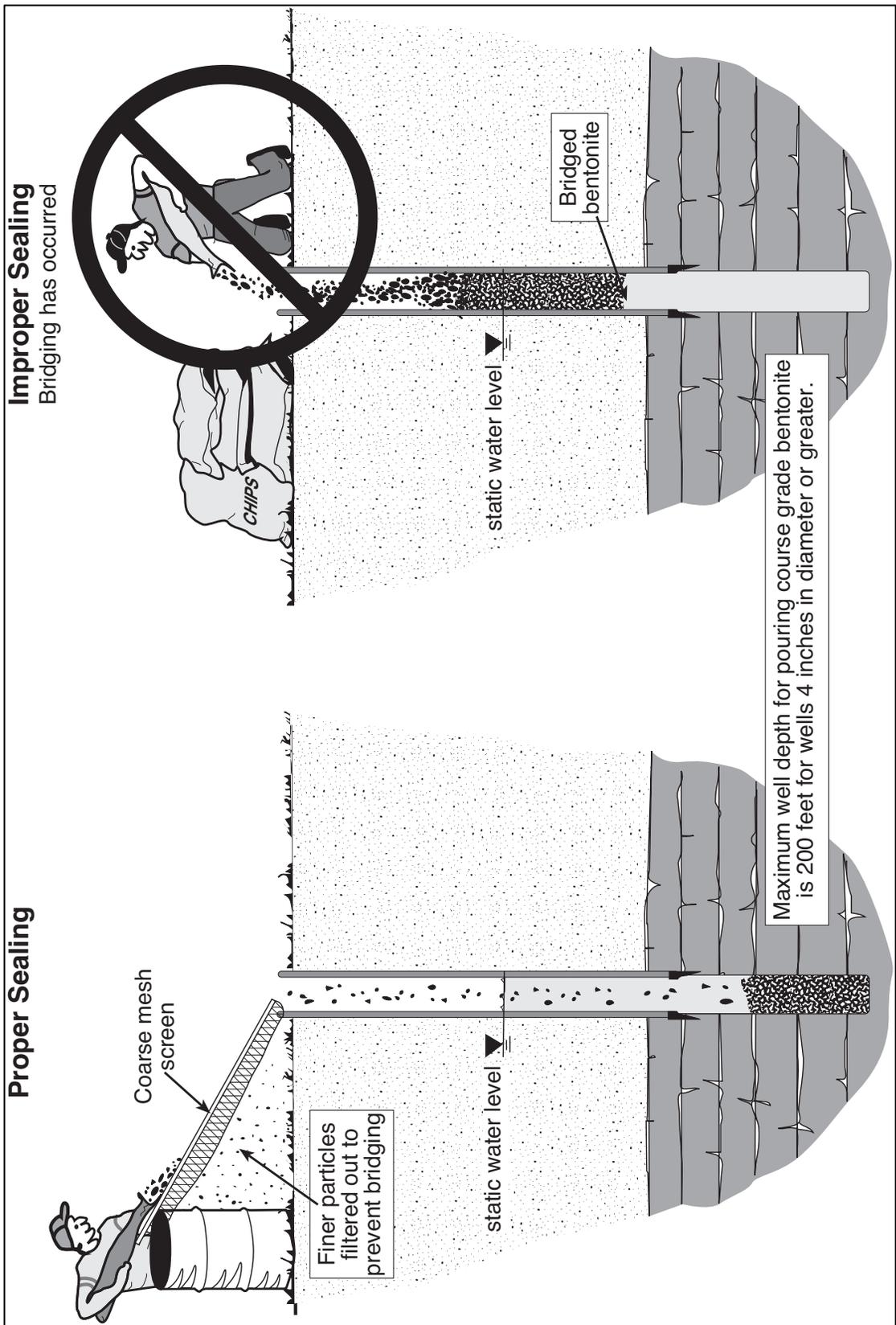


Figure 12. Sealing wells with coarse grade bentonite products showing the correct pouring method on the left and the incorrect pouring method on the right. (Modified from Wisconsin Department of Natural Resources, 1993)

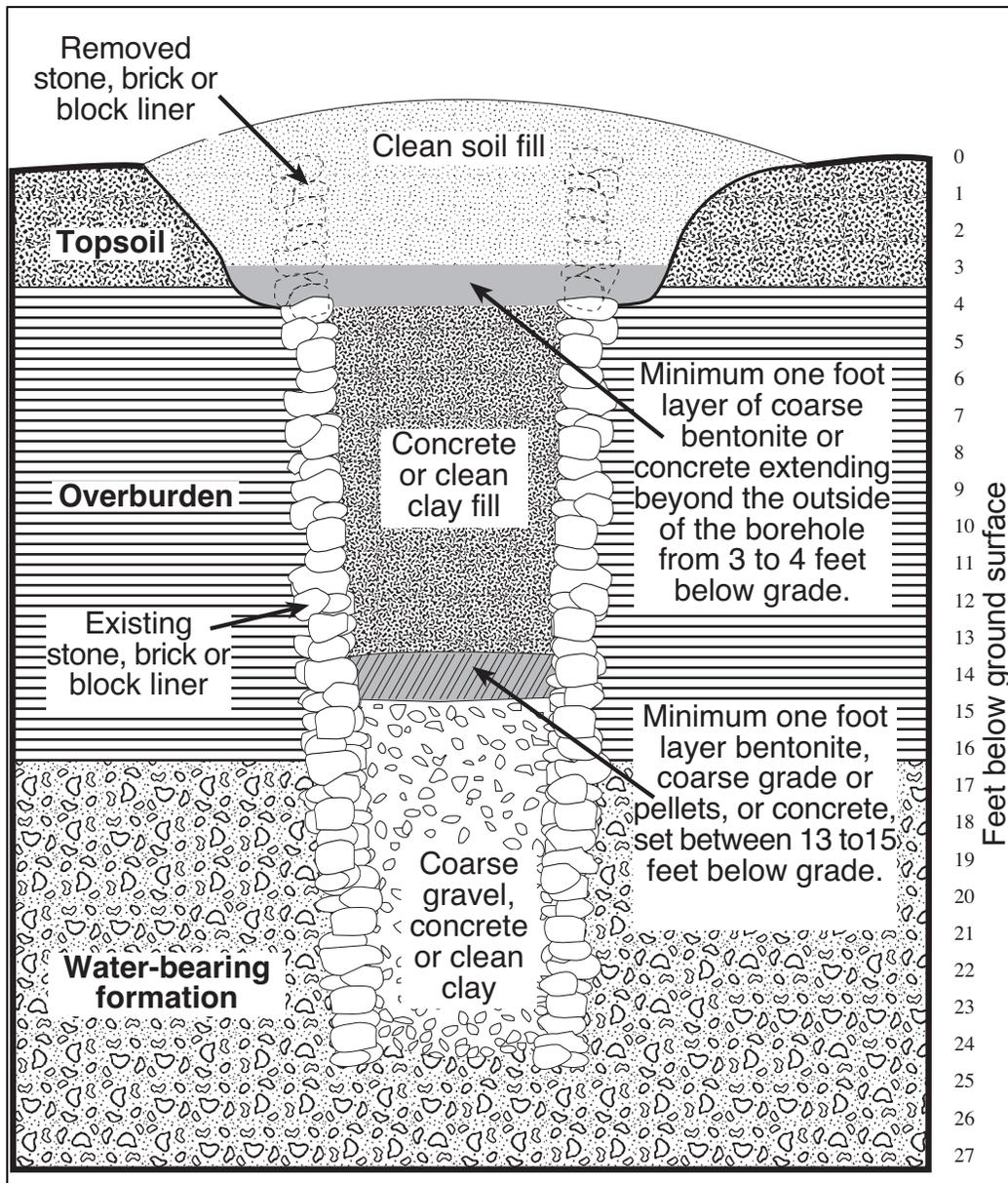


Figure 13. Cross section of a properly sealed dug well.

Sealing Bucket Auger Wells

The procedure for sealing bucket augered wells also differs from the general procedures described earlier in this guidance and also differs based on the rules applicable to sealing the well.

For wells regulated by ODH, all obstructions, loose debris, drop pipes, and pump are removed and all well casing, liner pipe and gravel pack to a depth of fifteen feet from the natural ground surface must be removed. The well can then be filled with concrete, coarse grade or pelletized bentonite, fire clay, clay, or cuttings to within fifteen feet of the natural ground surface. To provide structural strength and minimize permeability, an equal part mixture of gravel and bentonite chips could be used. The remaining borehole can then be filled with concrete, or at least a two foot layer should be placed from 13 to 15 feet below ground surface and the remainder of the borehole filled with clean clay or native fill material as appropriate for the site. The surface should be graded to ensure drainage away from the well (see Figure 14). Settling may occur over time which may require addition fill to maintain drainage away from the well.

For wells regulated by Ohio EPA, all obstructions, loose debris, drop pipes, and pump must be removed and the casing or liner material should be left intact except for the upper four or five feet depending on the depth of the static water level. The area should be excavated at least six inches beyond the original borehole. If the well contains water, it should be pumped dry, if possible. The well or borehole can be filled with clean clay or cement grout; the well or borehole may be filled with gravel adjacent to the water-producing zone. A layer of bentonite or cement grout at least one foot thick must be placed in the abandoned well at the elevation of the static water level. If dry-poured bentonite is used it must be hydrated with five gallons of water per fifty pounds of bentonite. The remainder of the well must be filled with clean clay and the surface should be graded to ensure drainage away from the well. Settling may occur over time which may require additional fill to maintain drainage away from the well.

The caisson of a **Ranney collector well** should be sealed in a similar method as stated in the above paragraph for bucket augered wells. The ports for the horizontal laterals should be sealed shut which usually involves installing a steel plate over the port opening. Attempting to install fill material in the laterals is not required. The caisson above land surface and any building attached to the caisson should be dismantled and removed. The land surface should be mounded to allow for settling.

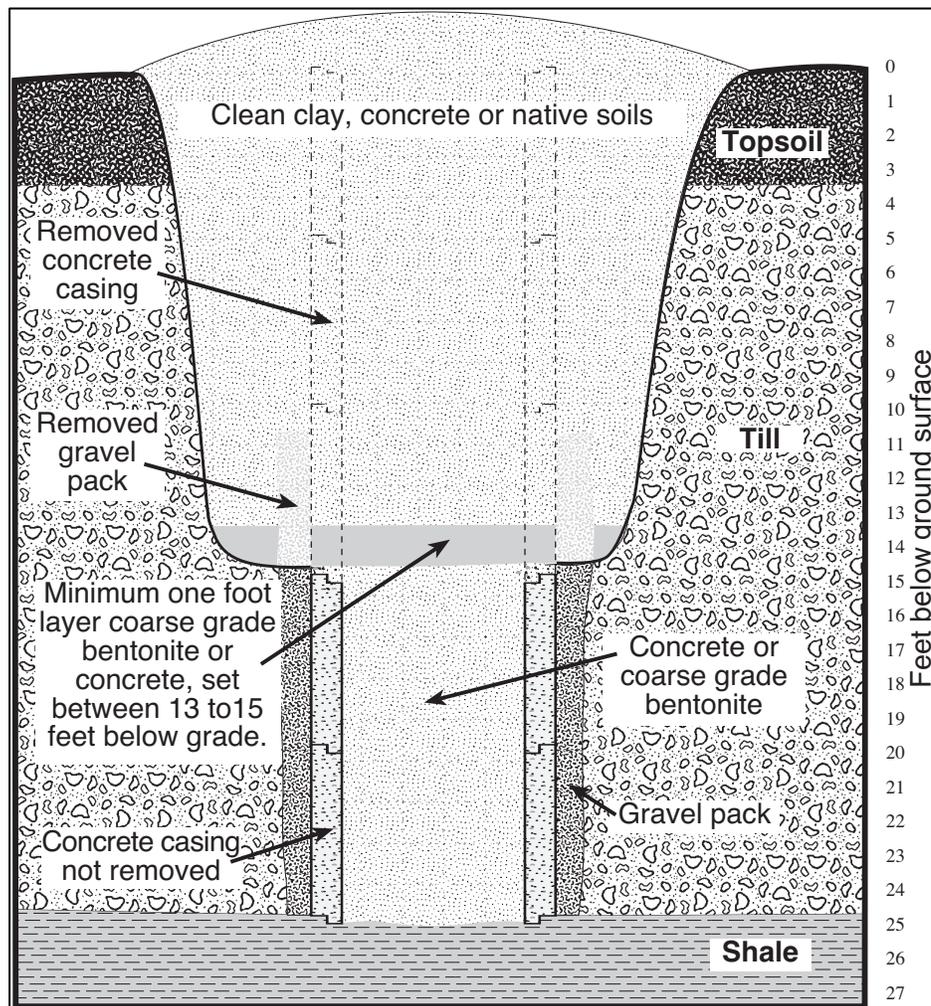


Figure 14. Cross section of a properly sealed bucket auger well per ODH rules.

Sealing Driven or Small Diameter (2 inches or less) Wells

Small diameter wells or boreholes (≤ 2 inches) may present special challenges. A small diameter ($3/4$ inch) grout pipe can be used; however, high pumping pressures or less viscous materials may be necessary

(ASTM D5299). Grouting machines are available for use with small diameter wells. A grouting machine reduces problems of bridging and incomplete seals associated with adding materials from the ground surface. The two most common small-diameter well types are drive points for domestic water supply and environmental wells and boreholes.

Sealing Water Supply Wells

After inspection and removal of any obstructions, casing removal should be attempted. The borehole must then be filled with coarse grade or pelletized bentonite, bentonite slurry, or cement slurry to ground surface. If the casing was not removed, it should be cut off two or three feet below the ground surface and filled with grout. If the casing was removed, the sealing should occur immediately before the borehole can collapse. The area excavated around the well should be filled with clean soil and mounded at ground surface to ensure drainage of surface water away from the well. For wells located in basements or in slabs, the top should be finished with a level concrete pour.

Sealing Environmental Wells and Boreholes

When sealing monitoring wells and boreholes no single method and material are suitable for all situations. Site-specific characteristics may merit modifications or procedures not discussed in this document. Additional information can be found in the references listed in the “Ohio EPA Technical Guidance Manual for Hydrogeologic Investigations and Ground Water Monitoring”.

Inspect the well and remove any obstacles (i.e., pumps, pressure lines, other debris, etc.) that may interfere with the placement and performance of the sealing material. If necessary, a camera survey can help to identify the depth and construction of the well if this information is not known. The outer protective casing should be removed. Inspection of the well and annular seal are not necessary for sealing of exploratory boreholes.

When the annular seal is inadequate, the filter pack connects two or more water bearing zones, water is flowing from around the outside of the casing, or when construction details are not known, the casing, screen, annular seal and filter pack should be removed. The casing and well screen can be removed by pulling or bumping the casing, overdrilling around the casing using a hollow stem auger, or drilling out the well using a solid stem auger or rotary bit. Aller et al. (1991) and ASTM 5299-99 provide a discussion on various removal techniques.

If overdrilling is chosen, the borehole should be overdrilled using a bit with a diameter at least 1.5 times greater than the original diameter of the borehole. Drilling should be slightly deeper than the original depth to assure complete removal. To achieve an effective seal, the borehole should be cleared of any excess mud filtercake. In some instances, such as when safety-related issues arise or when dealing with large diameter wells, casing removal can be difficult. Since the primary purpose of sealing is to eliminate vertical fluid movement, it is recommended that the casing and screen be removed and the boring be overdrilled to remove the annular seal and filter pack. However, monitoring wells can be sealed in-place when the construction details are known, the annular seal is intact, and the filter pack does not cross more than one ground water zone.

If circumstances prevent complete removal of casing and screen, then the following procedure can be used (based on Renz, 1989):

- The well can be filled with clean (ANSI/NSF 613) disinfected sand to one foot above the screen in the event that the screened area is adjacent to a highly permeable formation.
- One foot of bentonite chips/pellets can be placed above the screen in a manner that prevents bridging, such as through a tremie pipe or by tamping after installation. Chips are recommended below the water table because they will sink, whereas pellets will often float on the water table.
- The chips/pellets should be hydrated, if placed above the water table.

- To allow the sealant to permeate and be effective, the casing should be perforated to one foot above the bentonite seal either by splitting it vertically (synthetic casing) or by making horizontal cuts every two feet with a retractable blade (steel casing).

If no casing was ever installed, the borehole can be either pressure grouted from bottom to top with neat cement, bentonite or a cement/bentonite mix, or be sealed by slowly pouring coarse grade or pelletized bentonite. If pouring is conducted, the bentonite should be poured over a screened trough to filter out the fine bentonite before it enters the borehole. If the borehole is mostly dry, water should be added to hydrate the bentonite. The upper two to three feet of the borehole can be filled in with native soils or finished to match the surrounding surface (i.e. blacktop parking area).

Where evidence of microbiological growth is present, a monitoring well may need to be disinfected. Before disinfecting the monitoring well, the effect on water quality monitoring results in the proximity of the well to be sealed should be evaluated. Wells should be disinfected by slowly wetting the circumference of the well/borehole with the disinfection solution starting from the bottom of the well and working upwards using a tremie pipe to assure that all sides are wetted by the solution. The solution should be well-mixed within the well/borehole and purged before sealing with grout. Contact of disinfectant with bentonite should be avoided.

The disinfectant should:

- Have a concentration in the water column of approximately fifty milligrams per liter (mg/L) total chlorine, but no more than 100 mg/L.
- Have standard ANSI/NSF 60 certification. Standard ANSI/NSF 60 refers to "Standard ANSI/NSF 60, Drinking Water Treatment Chemicals - Health Effects", February 9, 2001, Document Number NSF/ANSI 60-2001 (NSF Web Site).

The borehole should be pressure grouted using a tremie pipe as the drilling stem is removed. The sealant should be applied in one continuous procedure to prevent segregation, dilution, and bridging (Aller et al., 1991). The pipe should be submerged in the sealant to prevent air pockets from forming. The borehole should be sealed from the bottom up to the frost line - approximately two to three feet from the surface. The overflowing grout should be regularly evaluated as it reaches the surface. The density of the grout should be monitored as discussed in the Properties of Grout section of the document to ensure an adequate seal is achieved.

When sealing wells that have two or more saturated zones or in flowing wells, it may be necessary to use a packer assembly. An inflatable packer can be placed at the top of the producing water zone to stop or restrict flow. The borehole can be sealed by pressure grouting from the bottom of the hole to the top of the packer. The packer can then be deflated and the grouting process continued. If dry sealant is introduced by gravity pouring, care must be taken that bridging does not occur. This can be accomplished by slowly adding the grout and stopping periodically (e.g., every five feet) to measure, tamp the grout and add water to hydrate. The amount of added water should be in accordance with manufacturer specifications. Coarse grade or bentonite pellets should be poured over a wire mesh to remove fines.

The grout plug should be inspected 24 hours after installation to check for settling; grout should be added if needed. If the well is sealed in-place, the casing should be cut off approximately three feet below ground level and a PVC or stainless steel cap should be placed over the sealed well. Monitoring wells sealed in-place should be marked with a piece of metal to allow for location by a metal detector or magnetometer (Aller et al., 1991).

The area above the plug should be finished in a manner that is compatible with the site. For example, its top can be covered with soil, mounded at ground surface to ensure drainage of surface water away from the well, and planted if vegetation is desired. If the area is to be surfaced, then the final seal can be completed with cement, concrete, or blacktop.

For additional information see Chapter 9 Sealing Abandoned Monitoring Wells and Boreholes, from “Ohio EPA Technical Guidance Manual for Hydrogeologic Investigations and Ground Water Monitoring”. Additional information covering special requirements for small diameter wells, wells penetrating multiple aquifers and confined aquifers can be found in other sections of this document.

Sealing Wells Drilled Through Multiple Aquifers

If the well penetrates multiple aquifers but is open only to one, or penetrates multiple aquifers and is screened across multiple zones, it is recommended that the well be pressure grouted from the bottom of the well to ground surface with bentonite or cement slurry. The casing should be pulled if there is any uncertainty as to the integrity of the annular grout seal. If there is detailed information available on the depth and thickness of each aquifer penetrated and the casing will be removed, it may be possible to place clean sand and/or gravel within each aquifer zone, and place an impermeable sealing material, such as neat cement or bentonite products, between each aquifer corresponding to the confining unit present (see Figure 15 for details). Then the well should be sealed from the top of the uppermost aquifer or from a depth of 25 feet to within two or three feet of the land surface with neat cement or bentonite products. The remainder of the well must be filled with clean clay and the surface should be graded to ensure drainage away from the well. Settling may occur over time which may require additional fill to maintain drainage away from the well.

Sealing Wells Drilled Through Confined Aquifers

Wells drilled through confined aquifers can be difficult to seal because water can be flowing out the top of the casing. This guidance strongly recommends that an experienced registered drilling contractor be consulted in all sealing situations, but it is especially important when dealing with these types of wells. To successfully seal a flowing well, the weight of the sealing materials must exceed the pressure of the water flowing out of the well, and the sealing materials must bond to the borehole or casing so that water cannot continue to flow to the surface. The grouting operation needs to occur quickly and uniformly to ensure that the weight of the grout is able to hold the water in the formation and provide an effective seal.

If the well is not flowing, clean sand and/or gravel may be placed from the bottom of the well to the top of the producing zone or to twenty-five feet below the ground surface, whichever is encountered first. This should be followed by pressure grouting with cement or bentonite slurry, or by slowly pouring in coarse grade bentonite products or pelletized bentonite, from twenty-five feet to ground surface. Any coarse grade bentonite products used should be periodically hydrated, if necessary, and tamped to prevent bridging. If the well is over 200 feet deep, pouring of coarse grade bentonite is not permissible. Pressure grouting should be performed.

If the well is flowing from within the casing only (Figure 16a), an attempt should be made to determine the hydraulic head. If the hydraulic head is low enough to permit casing extension, extend the casing high enough to keep the well from flowing (Figure 16b). Pressure grout with concrete or cement from the bottom of the well to the ground surface. If the flow has been completely stopped by the casing extension, and if the depth of the well is less than 200 feet, coarse grade bentonite products may be poured into the wells. If the well is less than 100 feet deep, pelletized bentonite may be used. The well should be grouted to ground surface. The casing can then be cut off two to three feet below ground surface, and the remaining excavation filled with clean soil and mounded.

If the hydraulic head is too high to permit casing extension, the well can be sealed by attempting to stop the flow, or by other methods that will allow sealing while the well is flowing. To control the flow, a packer should be placed above the producing formation (Figure 17b). Then the well can be pressure grouted with cement from the bottom of the well to the bottom of the packer. The sealing materials must be allowed to set to gain sufficient strength to withstand the hydraulic head pressures before the packer is deflated. The packer can then be deflated and brought to the surface provided no additional flow occurs. Continue pressure grouting to the surface (Figure 17c).

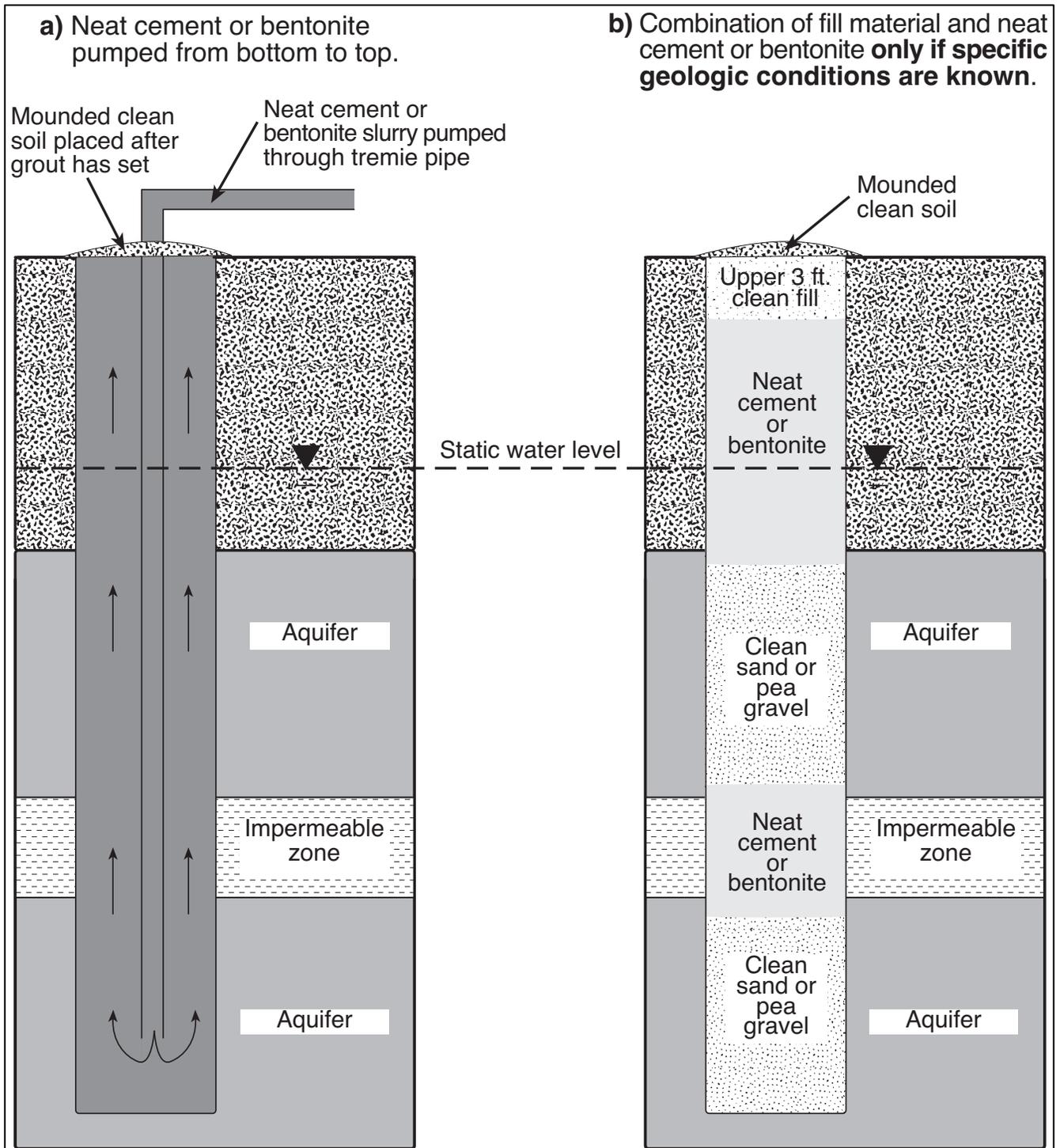


Figure 15. Methods for sealing wells penetrating multiple aquifer. a) Pressure grouting from bottom to land surface. b) Installing permeable material in aquifer zones and neat cement or bentonite in impermeable zones and above the uppermost aquifer.

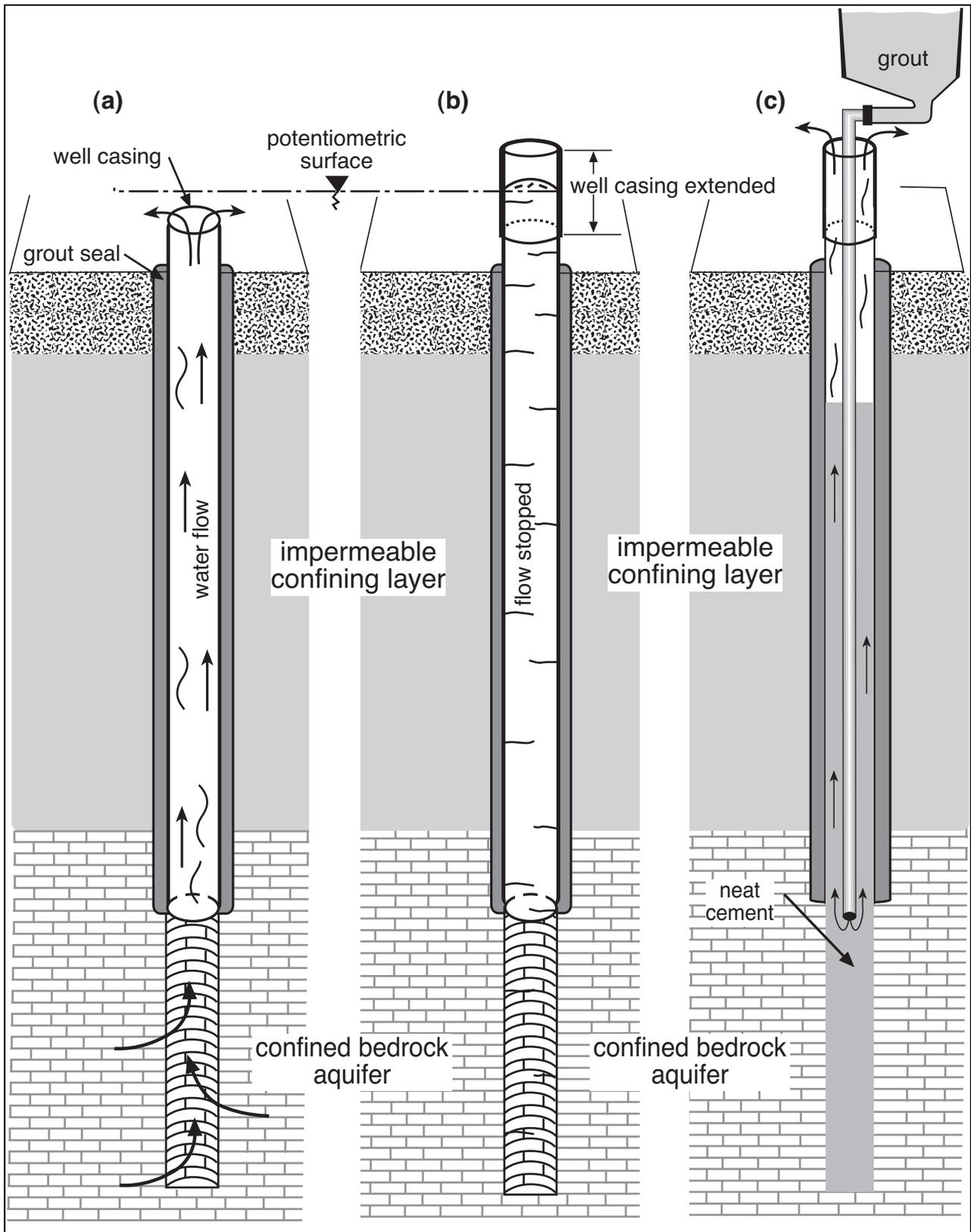


Figure 16. Reducing or stopping flow of well by casing extension. a) Water is flowing out the top of the casing. b) Casing has been extended to stop the flow of water out the top of the casing. c) Pressure grouting of the well with cement. (After Wisconsin regulations, 1994)

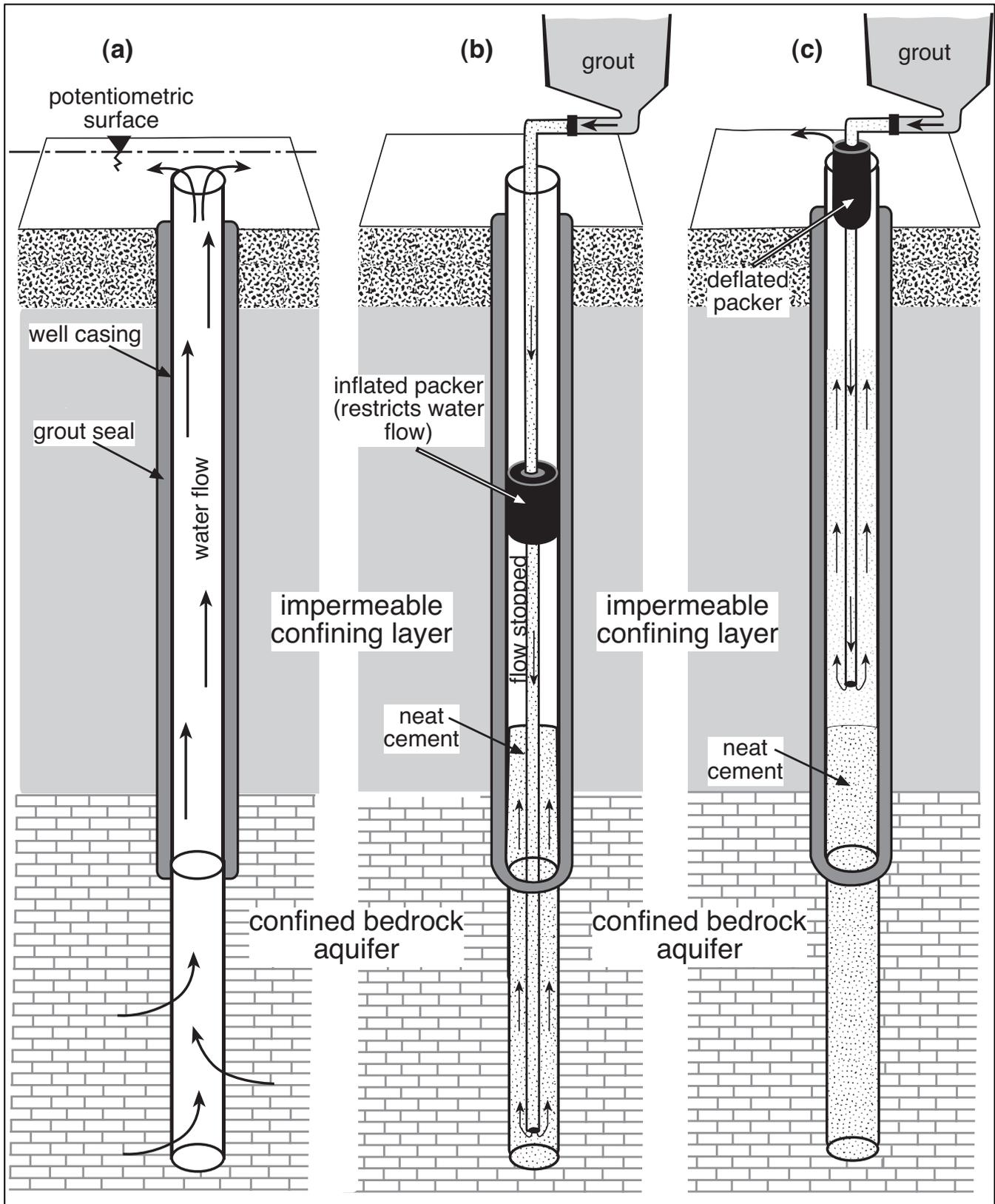


Figure 17. Using an inflatable packer to restrict flow. a) Water is flowing out the top of the casing. b) A packer has been inserted into the well and inflated to stop the flow of water out the top of the casing. The first stage of pressure grouting with cement is occurring. c) Pressure grouting with cement of the well to the land surface. (After Wisconsin regulations, 1994)

It may also be possible to stop the flow by placing a shut-in device on top of the well. A tremie tube can be inserted through the shut-in device and the well pressure grouted with cement from the bottom of the well to the ground surface.

Another alternative for slowing or stopping the flow is to pour disinfected gravel into the well (Figure 18a and b). Gravel may be placed from the bottom of the well to within 5-10 feet of the bottom of the casing in an attempt to reduce the flow to a point where it becomes possible to use pressure grouting equipment to seal the well (Figure 18c). Once the cement grout has set, any remaining casing can be cut off two to three feet below the ground surface. The resulting hole can then be filled with clean soil and mounded at ground surface. In some cases, it may be necessary to use a combination of these techniques to seal a flowing well.

If the well is flowing from within the casing and around the outside of the casing, and if the casing can be removed by overdrilling, then the well should be pressure grouted continuously from bottom to top with cement. Grout placement should be done while the casing is being removed. If the casing cannot be removed, drive or drill a large diameter casing around the flowing well. If the flow cannot be stopped and the annular space is open, tremie lines should be run along the outside of the existing casing and down through the middle of the casing, so that the well bore and the annular space can be continuously and simultaneously pressure grouted from the bottom of the well to the ground surface. It is important to have more than enough grout on hand to conduct a continuous pour in order to overcome hydrostatic pressures.

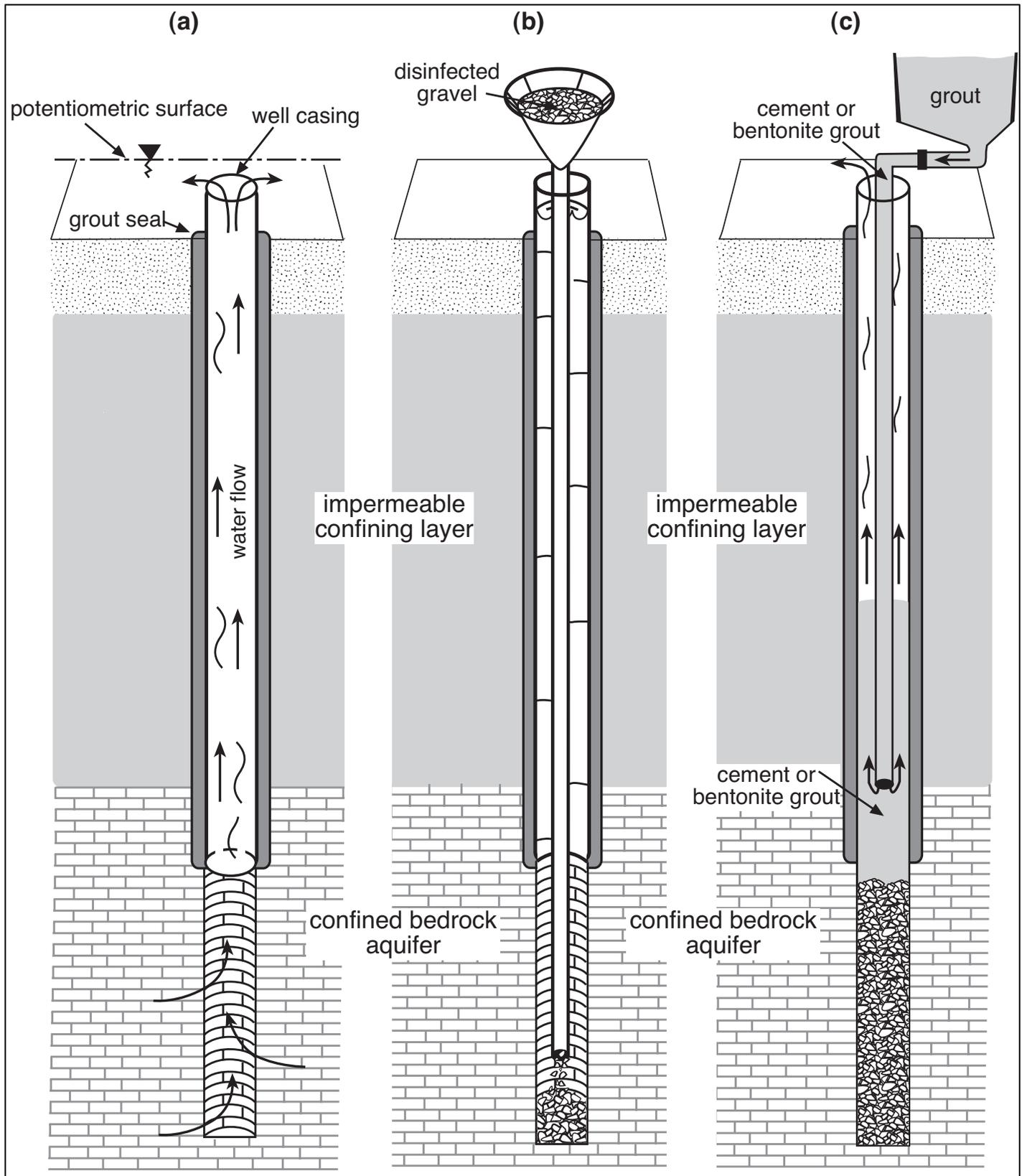


Figure 18. Pouring disinfected gravel into well to reduce flow. a) Water is flowing out the top of the casing. b) Gravel is being poured into the well to stop the flow of water out the top of the casing. c) Pressure grouting with cement or bentonite of the well to the land surface. (After Wisconsin regulations, 1994)

Sealing Wells Drilled Through Fractured or Cavernous Formations or Mine Voids

It is important when sealing a well open to or cased through fractured or cavernous formation or voids left by mining to try to determine the depth(s) at which the fractures or voids occur and their thickness. The well log may not provide sufficient information to determine these values. Downhole video cameras and geophysical logging such as calipers logs are the best to accurately determine the location and size of subsurface voids.

If the borehole is drilled past the void, the borehole can be pressure grouted with cement up to the bottom of the void. Allow time for the cement to set. Measure the depth of the borehole and then determine the depth to the top of the void. Install at least two, and preferably three, **shale traps** on a casing that will then be installed to the bottom of the well or into the cement-filled portion of the borehole (Figure 19a). The shale traps should be stacked on top of each other and aligned two to three feet above the top of the void. If multiple voids or large fracture zones occur, there are two different ways to address them. If there is a need to isolate the different zones, shale traps could be placed above each of the void zones. A tremie tube would have to be inserted at the same time that the casing is inserted so the tremie tube is just above the lowermost set of shale traps. The lowermost zone is sealed first. Then the tremie tube is pulled up above the next set of shale traps and pressure grouting continues. If the multiple void zones are not water-bearing or there is little concern of water moving from one void to the next, one set of shale traps should be placed above the uppermost void. Pressure grout with cement around the outside of the recently installed casing filling up the annular space from the shale traps to the land surface (Figure 19a). Then pressure grout inside the casing from bottom to top (Figure 19b).

If the cavernous or fractured zone is less than a few feet in thickness, the well or borehole can be filled with coarse gravel to the top of the void, and then pressure grouted with cement from the top of that zone to the ground surface (Figure 19c). Installing a few feet of coarse grade bentonite above the gravel would help minimize the flow of cement slurry through the gravel and into the void.

To complete the sealing process, the casing should be cut off two to three feet below the ground surface and the remaining hole filled with clean soil and mound the area to ensure drainage away from the well.

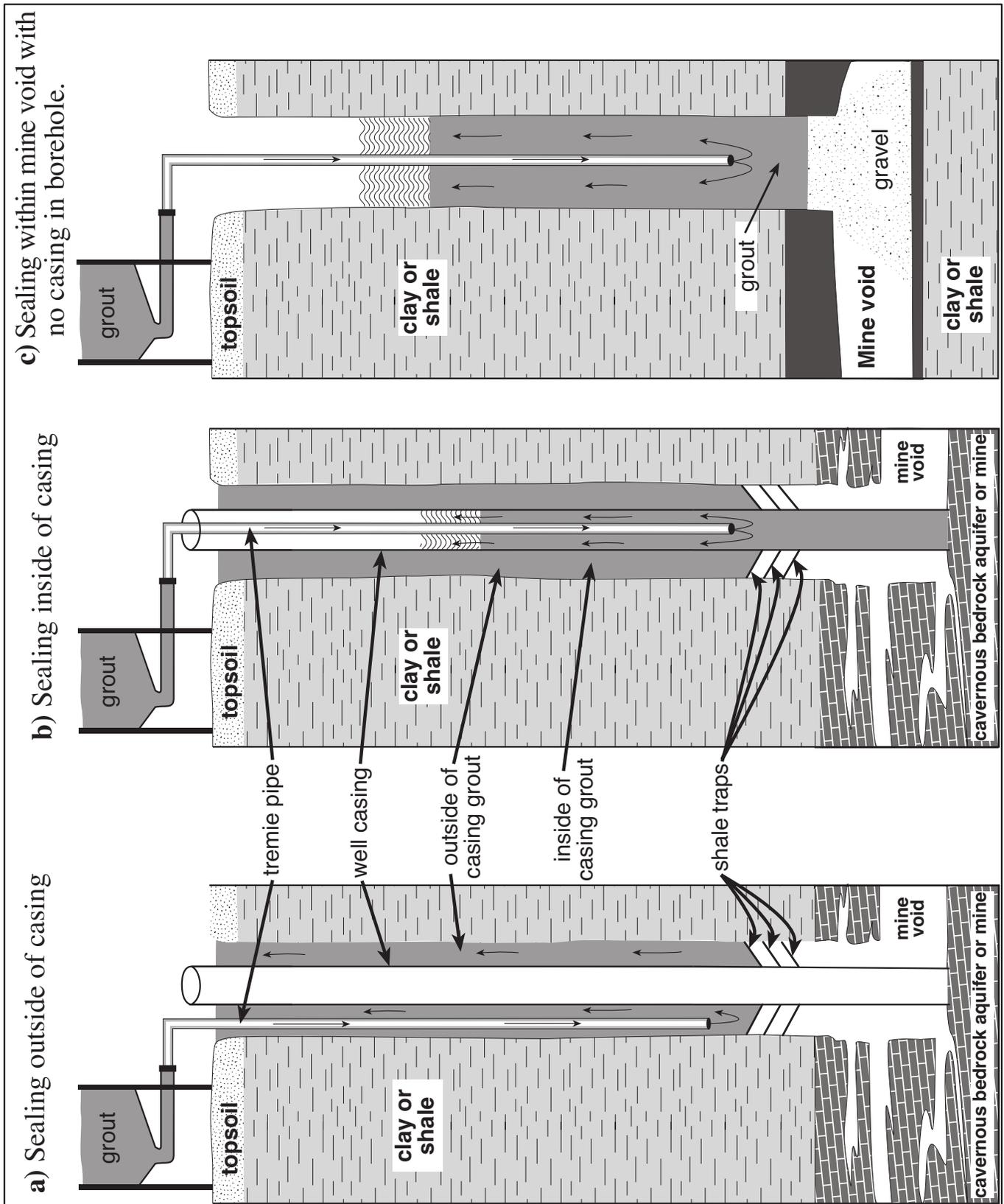


Figure 19. Sealing procedures for wells penetrating fractured or cavernous formations. a) Casing has been installed to the bottom of the borehole with three shale traps installed a few feet above the top of the void(s). Pressure grouting is occurring in the annular space. b) Pressure grouting inside the casing is occurring. c) The void has been filled with gravel up into the borehole and pressure grouting of the borehole is in process.

Conclusion

Unsealed or improperly sealed abandoned wells present a very real threat to the quality of ground water in Ohio. With possibly tens of thousands of unused and abandoned wells scattered across the state, steps must be taken to guarantee the future quality of the state's ground water resources.

The guidelines outlined in this document are the result of a genuine need for information on how to seal abandoned wells properly. While these guidelines are not intended to cover every possible scenario, they can certainly serve as a reference for basic methodologies to be followed in commonly encountered situations. It is strongly recommended that a well owner consult an experienced registered drilling contractor when preparing to seal a well. This is the best way to ensure that the well will be sealed in a manner appropriate for that type of well under those specific geologic conditions.

At the time that this guidance document was prepared, the guidance followed the applicable rules for regulated wells. However, rules can change and may have since this document was prepared. Therefore, if there are any discrepancies between an existing rule and this guidance document, follow the rule. In addition, there are differences between agency rules and it is important to follow the correct rules when sealing a well. A summary of all the well sealing procedures discussed in this section can be found in Table 9.

The final step in all of these well sealing procedures is to file a well sealing report with the Ohio Department of Natural Resources, Division of Soil and Water Resources.

Table 9. Summary of recommended well sealing materials and procedures.

WELL TYPE	MATERIALS										METHOD OF INSTALLATION	
	Clean Fill		Concrete	Neat Cement	Cement-Bentonite mix	Coarse grade Bentonite ²		Bentonite Slurry	Bentonite Granular			
	Gravel and/or Sand	Clay				Chips	Pellets					
Unknown construction	No	No	No	Yes	Yes	No	No	Yes	No	No	Slurry must be pressure grouted from bottom to top.	
Dug Well	Yes ¹	Yes	Yes	No	Yes	Yes	Yes	No	Yes ⁹	Material may be poured into well. A 2-foot layer of concrete, cement, or bentonite is required at 13-15 feet below land surface.		
Bucket Auger	Yes ¹	Yes	Yes	No	Yes	Yes	Yes	No	Yes ⁹	Material may be poured into well. A 2-foot layer of concrete, cement, or bentonite is required at 13-15 feet below land surface.		
Driven	No	No	No	Yes	Yes	Yes ²	Yes ²	Yes	No	Slurry must be pressure grouted; coarse-grade bentonite must be slow poured.		
Small Diameter (<2 in)	No	No	No	Yes	Yes	Yes ²	Yes ²	Yes	No	Slurry must be pressure grouted; coarse grade bentonite must be slow-poured.		
Wells into a single aquifer	Yes ³	No	No	Yes	Yes	Yes ²	Yes ²	Yes	Yes ¹⁰	Gravel may be poured, slurry must be pressure grouted; coarse-grade bentonite must be slow-poured.		
Wells through multiple aquifers	Yes ¹	No	No	Yes	Yes	Yes	Yes	Yes	No	Install clean fill in aquifer zone(s) only and cement or bentonite in confining zones and above uppermost aquifer to the surface.		
Wells into flowing artesian aquifers	Yes ⁴	No	Yes	Yes ⁶	Yes ⁶	Yes ⁶	Yes ⁶	Yes ⁶	No	Use gravel to stop or greatly reduce the flow. If flow cannot be stopped, pump concrete into well.		
Wells into fractured/cavernous aquifers	Yes ¹¹	No	Yes	Yes ⁷	Yes ⁷	Yes ⁷	Yes ⁷	Yes ⁷	No	Use gravel to bridge fractured/cavernous zone only. Slurry must be pressure grouted.		
Wells into mine voids	Yes ⁵	No	Yes	Yes ⁸	Yes ⁸	Yes ⁸	Yes ⁸	Yes ⁸	No	Use large gravel in mine void area.		

1. In aquifer zone only
2. Coarse grade bentonite must be poured slowly over a wire mesh screen and into the well at a rate no faster than 3 minutes per 50 pound bag. Requires periodic tamping
3. To top of aquifer. The rest of the well should be filled to the surface with cement or bentonite
4. To slow the flow to allow grouting to proceed
5. In mine void area only
6. If flowing conditions have been stopped
7. From top of fractured/cavernous zone to the land surface
8. From top of mine void to the land surface
9. Use for 1-foot layer at the 3-4 foot level below grade
10. Dry hole and less than 25 feet deep. Must be periodically hydrated.
11. Can be used to fill fractured or cavernous zones

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Glossary

Annular space - the space between the well casing and the borehole wall.

Aquifer - a geological formation, part of a formation, or group of formations that is capable of yielding a significant amount of water to a well or spring.

Artesian – a well condition when a confining layer overlies the aquifer, which causes the water level in the well to rise above the top of the aquifer. If the confining pressures are great enough, the water level could rise above the land surface, creating a flowing artesian well.

Atmospheric pressure - the pressure on the earth's surface caused by the weight of the earth's atmosphere.

Auger - is a drilling device, or drill bit, that usually includes a rotating helical screw blade called a "*flighting*" to act as a screw conveyor to remove the drilled out material. The rotation of the blade causes the material to move out of the hole being drilled.

Bailing - the use of a bucket, or rigid tube or pipe with a valve to remove fluid volumes or debris and cuttings from a well.

Bentonite - a plastic, colloidal clay composed predominantly of sodium montmorillonite which has an extensive ability to absorb water and swell in volume.

Borehole - a hole in the earth made by a drill; the uncased drill hole from the surface to the bottom of the well.

Bridging - the action of sealing material to get stuck in the well or borehole before it gets to the bottom, which creates open voids. Fine particles can bridge at the static water level due to surface tension of the water. Any sealing material can bridge when it is poured too quickly.

Bucket auger - a cylindrical bucket that has auger-type cutting blades on the bottom. The bucket fills up as the auger is turned and pushed into the ground.

Cement - complex, finely-ground kiln-fired calcium silicate which, when mixed with water, forms a slurry which will harden in the borehole to form an effective seal.

Cistern - a large receptacle used for storing water, especially an underground tank in which rainwater is collected.

Concrete - a mixture of neat cement, an aggregate, and water.

Confining layer - a body of impermeable or distinctly less permeable material stratigraphically adjacent to one or more aquifers.

Confined aquifer - an aquifer bounded above and below by beds of distinctly lower permeability than that of the aquifer itself and which contains groundwater under pressure greater than that of the atmosphere. This term is synonymous with the term "artesian aquifer."

Consolidated - lithified geologic materials. In Ohio, these materials constitute formations such as sandstone, limestone, and shale.

Cuttings - chips removed from the borehole by a bit in the process of well drilling.

Density - the mass or quantity of a substance per unit of volume, usually expressed in grams per cubic centimeter or pounds per gallon.

Drill rod - the extension rods used to attach the bit to the drilling rig to enable the penetration into the earth.

Drilling bit - a device used on the end of a drilling stem or rod for the purpose of penetrating earth formations. Drilling bits are usually made of a hardened material so as to last an extended period of time.

Drilling mud - a special mixture of clay, water, and chemical additives pumped down hole through the drill pipe and drill bit. The mud is used to lubricate and cool the bit and to float cuttings to the surface for removal.

Drilling tools - general term associated with all equipment used in the drilling process. Tools, bits, rods, stems, etc.

Dug well - a well excavated into a generally shallow, unconsolidated aquifer in which the side walls may be supported by material other than standard weight steel casing.

Filter pack - siliceous, well-rounded, clean, and uniform sand or gravel that is placed between the borehole wall and the well screen to prevent formation material from entering through the screen.

Fire clay - a term applied to a range of refractory clays used in the manufacture of ceramics, especially fire brick. Fire clay is made up of natural argillaceous materials, mostly kaolinite group clays, along with fine-grained micas and quartz, and may also contain organic matter and sulfur compounds.

Flowing well - a water well in which ground water normally flows over the top of the well casing

Formation - a body of consolidated or unconsolidated rock characterized by a degree of lithologic homogeneity which is prevailing, but not necessarily, tabular and is mappable on the earth's surface or traceable in the subsurface.

Gel strength - a measure of internal structural strength. It is an indication of a fluid's ability to support suspended particles when the fluid is at rest. Gel strength is caused by the physical alignment of positive and negative charges on the surface of the clay particles in solution.

Geologic conditions - the distribution, types, and structural features of earth materials present in any given area.

Geotechnical boring - borings installed to determine the geological and engineering properties of subsurface soils.

Geothermal Extraction Well – a well that is used to extract water from an aquifer for the intended use of heating or cooling a building

Geothermal Return Well – a well completed in an aquifer that is used to pump water into after the water is used to heat or cool a building. The water temperature is the only change that has occurred to the water. This type of well is classified as a Class V injection well and is regulated by the Ohio EPA.

Ground water - any water below the surface of the earth in a zone of saturation.

Grout - as used in these guidelines, grout is a fluid mixture of water and cement or water and bentonite that is of a consistency to be pumped through a small-diameter pipe.

Hollow-stem auger - the auger flights are welded onto larger diameter pipe with a cutting head mounted at the bottom. A plug is inserted into the hollow center of the cutter head to prevent soil from coming up inside the auger.

Hydrated - the incorporation of water into the chemical composition of mineral.

Hydraulic head - the height of the free surface of a body of water above a given subsurface point; a reflection of the ground water level plus the pressure head.

- Hydrogeologic conditions** - the occurrence, distribution, and quality of subsurface water within consolidated and/or unconsolidated earth materials in a given area.
- Karst** - landscape formed from the dissolution of soluble rocks such as limestone. Sinkholes are a common karst feature.
- Mesh** - one of the openings in a screen or sieve. The value of the mesh is usually given as the number of openings per linear inch.
- Microannulus** - for the purpose of this guidance document the term means the space between the sealing material and the casing and/or the formation. This is caused by the shrinkage of the sealing material.
- Monitoring well** - any excavation that is drilled, cored, bored, washed, driven, dug, jetted, or otherwise constructed for the purpose of extracting groundwater for physical, chemical, or biological testing, or for the purpose of determining the quantity or static level of ground water on a continuing basis.
- Mud balance** - a scale that measures a specific volume of grout slurry (density) and is expressed in pounds per gallon.
- Non-potable well** - any well that is used for the provision of water other than for human consumption. Non-potable wells include, but are not limited to, wells used to provide water for irrigation, non-contact cooling water, water for use in commercial and industrial processes, and water for use in dedicated open-loop geothermal heating and cooling systems. (Private water system and public water system wells are potable wells.)
- Packer** - a rubber or inflatable device used to temporarily or permanently seal off a portion of the borehole, annular space or well casing
- Paleokarst** - a karstified rock or area that has been buried by later sediments. Most of the voids or caves have been filled by the later sediments.
- Permeability** - the capacity of a porous rock, sediment, or soil for transmitting fluid; a measure of the relative ease of fluid flow across a pressure gradient often expressed in centimeters per second or feet per day.
- Piezometer** – generally a small-diameter non-pumping well used to measure the elevation of the water table or potentiometric surface
- Pitless adaptor** - a device or an assembly of parts which permits water to pass through the casing or extension thereof; provides access to the well and to the parts of the water system within the well; and provides for the transportation of the water and the protection of the well and water therein from surface or near surface contaminants.
- Pitless unit** - an assembly which extends the upper end of casing to above grade and prevents the entrance of contaminants into the well, to conduct water from the well, to protect water from freezing or extremes of temperature and to allow access to the well and components of the pumping equipment.
- Plasticity** - the capability of being deformed permanently without rupture.
- Pore** - a tiny opening, usually microscopic, in consolidated or unconsolidated materials.
- Potentiometric surface** - a hypothetical surface representing the level to which groundwater would rise if not trapped in a confined aquifer. The potentiometric surface is equivalent to the water table in an unconfined aquifer

Portland cement - fine powder produced by pulverizing clinkers consisting of at least 2/3 by mass hydraulic calcium silicates and the remainder consisting of aluminum- and iron-containing clinker phases with calcium sulfate added to control the set time.

Private water system - any water system, other than a public water system, for the provision of water for human consumption, if the system has fewer than 15 service connections and does not regularly serve an average of at least 25 individuals daily at least 60 days each year.

Public water system - any water system that has 15 or more service connections and regularly serves at least 25 individuals daily at least 60 days each year

Ranney collector well – a large diameter vertical reinforced concrete shaft (caisson) with horizontal lateral well screens projected out into a sand and gravel aquifer. These laterals are typically over 200 feet and extend under a river or lake in an effort to induce recharge from the surface water body.

Recharge - the processes by which water is absorbed and is added to the saturation zone, either directly into a formation, or indirectly by way of another formation.

Saturated zone - the portion of consolidated or unconsolidated materials in which all of the pore space is occupied by water.

Shale trap - flexible rubber cone-shaped packer attached to the outside of the well casing that is designed to prevent material such as a grout seal from passing below it.

Static water level - the measured distance from the established ground surface to the water surface in a well that is neither being pumped nor under the influence of pumping nor flowing under artesian pressure.

Stratigraphy - the arrangement of consolidated and unconsolidated strata.

Table drive - the revolving or spinning section of the drill floor that provides power to turn the drill string in a clockwise direction to facilitate the process of drilling a borehole.

Test boring - a boring designed to obtain information on ground water quality and/or geological and hydrogeological conditions.

Unconsolidated - not lithified but loose, soft geologic materials. Alluvium, soil, gravel, clay, and overburden are some of the terms used to describe a formation consisting of unconsolidated materials.

Underground injection well - wells used to place fluids underground for storage or disposal. These wells are divided into six classes based on the well use: Class I wells inject hazardous wastes, industrial non-hazardous liquids, or municipal wastewater for disposal. Class II wells inject brines and other fluids associated with oil and gas production, and hydrocarbons for storage. Class III wells inject fluids associated with solution mining of minerals. Class VI wells inject carbon dioxide for long term storage. Class I, II, III and VI wells sealing plans specific to each well. Class IV wells are banned unless authorized under a federal or state ground water remediation project. Class V All injection wells not included in Classes I-IV. In general, Class V wells inject non-hazardous fluids and are typically shallow, on-site disposal systems.

Viscosity - the property of a fluid or semi-liquid to offer internal resistance to flow.

Well - any excavation, regardless of design or method of construction, created for any of the following purposes: (1) removing ground water from or recharging water into an aquifer; (2) determining the quantity, quality, level, or movement of ground water in or the stratigraphy of an aquifer; and (3) removing or exchanging heat from ground water.

Well log and drilling report - the official Ohio report that is required to be submitted to the ODNR for the purpose of documenting geologic formations that were encountered during the drilling along with the well construction and pumping test information

Well casing - an impervious, durable pipe placed in a well to prevent the walls from caving and to seal off surface drainage or undesirable water, gas, or other fluids, and prevent their entering the well.

Well screen - a machine-slotted or wire-wrapped portion of casing used to stabilize the sides of the borehole, prevent the movement of fine-grained material into the well, and allow the maximum amount of water to enter the well with a minimum of resistance.

Well Sealing Report - the official Ohio report that is required to be submitted to ODNR when a well is sealed for the purpose of documenting the sealing materials and methods used

Yield - the quantity of water which may flow or be pumped from the well per unit of time.

Appendix 1

Contact Agencies

Ohio Department of Agriculture, Division of Plant Health, Pesticide Regulation Section

The Ohio Department of Agriculture (ODA) does not currently provide routine well analysis for pesticides; however, the Pesticide Regulation Section of ODA will sample any well where it is suspected that the use of a pesticide may have contaminated the well. To protect sample integrity, they must be collected by an ODA inspector. Samples are then analyzed at the ODA laboratory in Reynoldsburg. If a water sample is positive for a pesticide, the Pesticide Regulation Section will investigate to determine how the well was contaminated. The ODA will advise the well owner on how to clean up the well, and, if necessary, take appropriate enforcement action under Ohio Pesticide Law. The Ohio Department of Agriculture can be contacted at 614-728-6200.

Ohio Department of Agriculture, Division of Livestock Environmental Permitting (DLEP)

The Division of Livestock Environmental Permitting (DLEP) regulates and enforces state laws and rules for large livestock farms in Ohio. This regulatory program issues Permits to Install (PTI) and Permits to Operate (PTO) to livestock operations classified as Concentrated Animal Feeding Facilities (CAFF). The ODA-DLEP rules are contained in Chapter 901 of the Ohio Administrative Code (OAC) and cover the following areas: siting criteria, geological evaluations and design of new manure storage structures, manure management plans, groundwater sampling and monitoring, insect and rodent control plans, plans for the disposal of dead livestock, emergency response plans, operating record requirements, inspections, closure plans, enforcement (penalties, fines), and public participation. The Ohio Department of Agriculture can be contacted at 614-728-6200.

Ohio Department of Commerce, Division of State Fire Marshal, Bureau of Underground Storage Tank Regulations (BUSTR)

One of BUSTR's responsibilities is to supervise the investigation and cleanup of suspected releases from to protect human health and preserve the environment for the citizens of Ohio. Monitoring wells have been installed at sites around Ohio as part of these investigations and BUSTR should be contacted with any questions prior to their sealing. If a release from a regulated underground storage tanks is suspected of contaminating a water well, they should be contacted at 1-800-686-2878 before sealing the well.

Ohio Department of Commerce, Bureau of Building Standards

Ohio Board of Building Standards administers the rules covering the design, installation, and testing of geothermal heating and cooling piping systems, heating, ventilation, and HVAC equipment for non-residential buildings (Ohio Administrative Code § 4101:2 - Ohio Mechanical Code) and the rules covering the design, installation, and testing of geothermal heating and cooling piping systems serving residential buildings (Ohio Administrative Code § 4101:8 - The Residential Code of Ohio). Permits may be required prior to the removal of piping before sealing an open-loop geothermal heating and cooling system well.

Ohio Department of Health, Division of Prevention

For information on specific regulatory requirements and permits for sealing private wells, or for questions about possible contamination with substances other than pesticides or petroleum products, or to determine the registration status of a private water system contractor (i.e. drilling contractor or pump installers) contact the local health department or the Ohio Department of Health, Private Water System Program (PWSP) at 614-644-7558.

Ohio Department of Natural Resources, Division of Mineral Resources Management

The Division of Mineral Resources Management regulates the abandonment of coal and industrial minerals test borings through the permitting process under the Ohio Revised Code Chapter 1513 and 1514. Most borings are mined through during the removal of the coal or industrial mineral. Those borings that are not removed by mining are required to be properly sealed using procedures approved by the Division. The Division also recommends that the coal operator properly seal any original private water supply wells that are replaced by a new well drilled as a result of a water supply replacement order by the Chief. The Division investigates any ground water contamination or diminution complaints related to coal and industrial minerals mining activities. The contact phone number is 614-265-6633.

Ohio Department of Natural Resources, Division of Oil & Gas Resources

Personnel in the Groundwater Protection Section of the Division investigate ground water contamination cases when oil and gas operations are the suspected cause. If there is reason to believe that an unsealed, unused well on a property is an oil or gas well, the Division also has an Idle and Orphan Well Program that addresses the need to seal abandoned oil and gas wells. For more information on these two programs, contact the Division's Central Office at 614-265-6922.

Ohio Department of Natural Resources, Division of Soil and Water Resources

The Ohio Revised Code, Section 1521.05, requires that a well sealing report be filed with the Division of Soil and Water Resources for all wells sealed in the State of Ohio. Copies of the well sealing report can be obtained from the Division's website or by calling 614-265-6740. The Division also collects well log and drilling reports required to be filed by drilling contractors for wells drilled across the state. This authority also comes from Section 1521.05 of the Ohio Revised Code. Requests for copies of well log and drilling reports on file can be made by calling 614-265-6740.

Ohio Environmental Protection Agency, Division of Drinking and Ground Waters

The Ohio Revised Code 6111.42 gives the Ohio EPA authority to prescribe regulations for the drilling, operation, maintenance, and sealing of abandoned wells as deemed necessary by the director to prevent the contamination of underground waters in the state, except that such regulations do not apply to non-public potable wells. Currently, the Ohio EPA, Division of Drinking and Ground Waters, has regulations for the sealing of public water supply wells (OAC 3745-9-10) and for wells used for the purpose of injecting fluids into the ground (OAC 3745-34-07, 60, and 36). Sealing of monitoring wells is generally handled by the Division that has regulatory authority over the site/facility. For information on specific regulatory requirements for public drinking water wells or for injection wells, the Division of Drinking and Ground Waters should be contacted at 614-644-2752.

The Ohio EPA has no regulations/requirements for a person to report contamination in their private well. Reporting of ground water contamination is only required if an entity is monitoring ground water in accordance with hazardous or solid waste rules. In general, the Ohio EPA will not respond to a request to evaluate a contaminated private well unless the local or state health department requests assistance in investigating the source of the problem. However, this will not affect how the well should be sealed, but may affect when it is sealed if additional investigation is initiated.

An exception to this occurs if the well was used to inject fluid waste. If it was used as an injection well, the owner/operator must contact the Division of Drinking and Ground Waters, Underground Injection Control Unit (U.I.C.) of the Ohio EPA at 614-644-2752. Specific requirements must be followed for the sealing of injection wells.

Appendix 2

Existing State Regulations for Sealing Water Wells

Private water systems – regulated by ODH and Local Health Departments

OAC 3701-28 - <http://codes.ohio.gov/oac/3701-28>

Public and Non-potable wells – regulated by Ohio EPA

OAC 3745-9 - <http://codes.ohio.gov/oac/3745-9-10>

Industrial Mineral exploration borings – regulated by ODNR – Mineral Resources Management

OAC 1501:14 - <http://codes.ohio.gov/oac/1501%3A14>

Coal Exploratory Holes – regulated by ODNR- Mineral Resources Management

OAC 1501:13 - <http://codes.ohio.gov/oac/1501%3A13-13>

Concentrated Animal Feeding Facility test borings or wells – regulated by ODA

OAC 901:10-2 - <http://codes.ohio.gov/oac/901%3A10-2>

Class V UIC wells – regulated by Ohio EPA - Division of Drinking and Ground Waters

OAC 3745-34 - <http://codes.ohio.gov/oac/3745-34>

Filing a well sealing report – regulated by ODNR- Soil and Water Resources

ORC 1521.05 <http://codes.ohio.gov/orc/1521.05>

Appendix 3

Cost Considerations

Although there are many factors not discussed below that can impact the final cost of sealing a well, these considerations can be important details for helping a well owner obtain a helpful and accurate estimate.

Determining the cost for sealing a well begins with preparing information prior to performing a sealing project. The original use of the well may determine the contractor qualifications required for sealing the well. Knowing the diameter, depth, and original construction method of the well is helpful in beginning the process of estimating costs. Knowing whether the pumping equipment has been removed or will require removal can be a minor or significant part of the cost depending upon the size or type of pumping system. Investigating the details of the well to be sealed can often be obtained from well logs or by measuring the depth and diameter of the well. It may not be possible to know the final depth of the well until the pumping equipment or obstructions are removed from the well. Special care should be exercised before any large diameter well is measured to ensure safety of life and property. It may be recommended to have this part of the investigation performed by a registered drilling contractor with experience in large diameter well sealing.

Knowing the regulatory requirements along with collecting the well information can help obtain knowledgeable estimates to determine which contractor to hire for sealing the well. Certain wells such as Private Water System wells have sealing permit costs which vary from county to county.

Logistics of mobilizing equipment in a difficult to reach area or a well located inside a basement or structure can impact the labor or material costs for sealing a well. Wells commonly sealed in Ohio are smaller diameter wells originally drilled with cable tool or rotary drilling equipment. The typical project involves the removal of pumping equipment by hand pulling or using mechanical methods such as a hoist truck. A final measurement would take place to confirm expected construction details and for logging information required on the sealing report. If everything complies with regulatory requirements, course grade bentonite can be poured in by using proper hand methods or by pressure grouting a bentonite slurry using a tremie pipe. An excavation would be performed around the sealed well to allow the termination of the casing to the required depth. Large diameter wells including hand dug wells often involve additional equipment such as dump trucks, excavation equipment, excavators and loaders. The amount of materials required can usually be determined prior to beginning the sealing project for cost estimate and project planning purposes. Access paths to the well may be required if materials such as cement are specified for the sealing project.

Occasionally special sealing conditions are encountered that can affect the cost of sealing a well. A well with high chlorides may require cement or concrete which would be more expensive than if just bentonite were used. A well that has an exposed mineshaft may require additional materials for bridging or shale traps or baskets installed for creating a structure to support the sealing material. State regulations may require certain types of constructed wells to be over-drilled or excavated to certain depths for proper sealing. A registered drilling contractor with experience in your unique well sealing conditions should be consulted.

The final use of the well site such as a driveway or road can cause the requirement of certain sealing materials which can increase costs. Backfilling with materials to match native materials or whatever else is required for future use completes the onsite sealing project.

Using the information obtained through measurements and materials used, a well sealing report can then be filed with the proper regulatory authorities and ODNR.

Appendix 4

List of Acronyms

ANSI/NSF – American National Standards Institute/National Science Foundation

ASTM - American Society for Testing and Materials (now known as ASTM International)

API - American Petroleum Institute

BUSTR - Bureau of Underground Storage Tank Regulations

DP - Direct Push

PVC - polyvinyl chloride

OEPA - Ohio Environmental Protection Agency

OEPA-DDAGW - Ohio Environmental Protection Agency – Division of Drinking and Ground Waters

OEPA-DERR - Ohio Environmental Protection Agency – Division of Environmental Response and Revitalization

OEPA-DMWM - Ohio Environmental Protection Agency – Division of Materials and Waste Management

OEPA-DSW - Ohio Environmental Protection Agency – Division of Surface Water

OAC - Ohio Administrative Code

ODA - Ohio Department of Agriculture

ODH - Ohio Department of Health

ODNR - Ohio Department of Natural Resources

ODNR-DGS - Ohio Department of Natural Resources –Division of Geological Survey

ODNR-DOGR - Ohio Department of Natural Resources –Division of Oil and Gas Resources

ODNR-DMRM - Ohio Department of Natural Resources –Division of Mineral Resources Management

ODNR-DSWR - Ohio Department of Natural Resources –Division of Soil and Water Resources

ORC - Ohio Revised Code

PPM - parts per million

SCCGW - State Coordinating Committee on Ground Water

UIC - Underground Injection Control

USGS-OWSC - United States Geological Survey - Ohio Water Science Center