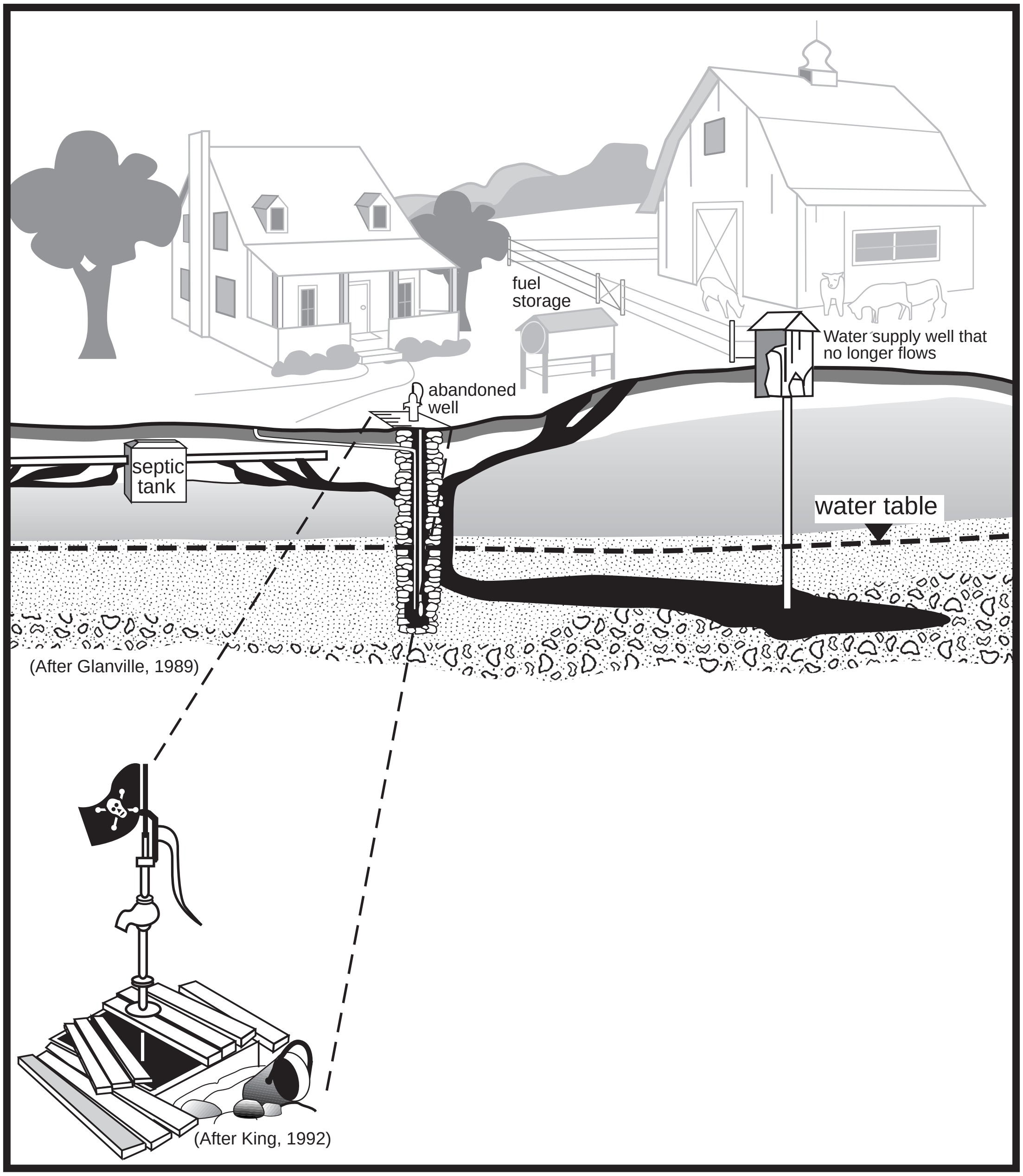
State of Ohio
Technical Guidance
for
Sealing Unused Wells



by the

State Coordinating Committee on Ground Water
1996

TECHNICAL GUIDANCE FOR SEALING UNUSED WELLS

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Preface

In early 1992, Ohio's State Coordinating Committee on Ground Water identified a list of major issues and problems that they determined should be addressed in some form by the Committee. The issue of the lack of consistent standards and regulations regarding the sealing of abandoned wells and test borings was identified as a major issue of concern by the Committee. The Natural Resource Conservation Service (NRCS, formerly the Soil Conservation Service) approached the Committee in the spring of 1994 regarding a new USDA cost sharing program for sealing abandoned wells that could be implemented by the states. The program required that the states develop technical standards that would be adopted by the state technical committee at the NRCS. Once these technical standards were adopted, counties participating in the cost share program could choose to offer cost share funds to farmers for sealing abandoned wells on agricultural properties. Based on this new opportunity from the NRCS, and due to increasing concerns by many of the participating state agencies and the well drilling industry, the Committee decided to form a workgroup in June, 1994 to develop consistent technical standards for sealing abandoned wells and test borings. Both the Ohio Environmental Protection Agency and the Ohio Department of Health have committed to revising their rules regarding well sealing to be consistent with the resulting new technical guidance document. The Well Sealing Workgroup began meeting in July, 1994; what follows is the product of eighteen months of meetings, research, edits, and revisions.

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). 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.

Acknowledgements

The preparation of the Technical Guidance for Sealing Unused Wells involved the contribution and hard work of a number of individuals on the Well Sealing Workgroup of the State Coordinating Committee on Ground Water. The development of the Technical Guidance was supported by the State Coordinating Committee on Ground Water and its member agencies. Special appreciation and acknowledgement is given to Katherine Sprowls for her extensive work in organizing, editing and authoring these guidelines. The workgroup also thanks the many industry professionals who graciously took the time to review and provide comments on the guidelines. In addition, the following are deserving of special thanks for the time and effort they devoted to generating the figures found in the guidelines: Janet Welday of the U. S. Geological Survey, Anne Mischo of the Ohio State University Extension, and Wayne Jones and David Orr of the Ohio Department of Natural Resources. Grateful acknowledgement is given to the following workgroup members for their technical research and text authorship, report editing and preparation:

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State Coordinating Committee on Ground Water Member Agencies

Ohio Environmental Protection Agency

Ohio Department of Natural Resources

Ohio Department of Health

Ohio Department of Agriculture

Ohio Public Utilities Commission

Ohio Department of Development

Ohio Department of Commerce - State Fire Marshal

Ohio Department of Transportation

United States Geological Survey

Natural Resources Conservation Service

—Rebecca Petty

Introduction

An unused or abandoned water **well**[1] is a well that is no longer in service or is 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). In addition, wells are often abandoned when their **yield** has diminished, or the quality of the water they supply has degraded. Each year, many wells are abandoned when homes are connected to community water supplies. No accurate accounting of abandoned wells exists for the State of Ohio. However, it has been estimated that there could be more than 200,000 unused wells in the state (Golden, pers. comm., 1995).

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 improperly sealed abandoned 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).

This guidance outlines the materials and methodologies that should be used to properly seal a well. The intent of this guidance is 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, which start on page 20.

In addition, this guidance covers the procedures for sealing **monitoring wells** and **boreholes**. Readers interested in these procedures are probably already conversant with most of the information presented throughout this document. Therefore, the procedures for sealing monitoring wells and boreholes are addressed separately in Appendix 4.

Any well 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.

Overview of Regulations

Current regulations for private (Ohio Administrative Code (OAC) 3701-28-07) 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. However, the regulations specify only that the well/**test boring** be completely filled with **grout** in order to seal the **aquifer** and protect the ground water.

The authority for enforcement for public water supplies is the Ohio Environmental Protection Agency (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.

Proper sealing of all abandoned wells must be documented per the Ohio Revised Code (ORC) Section 1521.05 (B). A well sealing report (Figure A) must be submitted to the Ohio Department of Natural Resources (ODNR), Division of Water. An appropriate form can be requested from the ODNR (614-265-6739). Also, ODH's Private Water Systems Rules require that the local health department be notified when an abandoned well has been sealed. In most counties, sending the local health department a copy of ODNR's well sealing report is an acceptable form of notification.

[1] All terms in bold print can be found in the glossary.

WATER WELL SEALING REPORT
(For Abandoned or Unused Wells)
OHIO DEPARTMENT OF NATURAL RESOURCES
Division of Water, Water Resources Section
1939 Fountain Square Drive
Columbus, Ohio 43224-1360

LOCATION

County DELAWARE Township GENOA Section 4
Property Owner E. J. FUDD
Address of Property 12345 SMOTHERS RD., WESTERVILLE, OH, 43081
Location: 1/2 miles EAST (n, e, s, w) of SUNBURY RD. (nearest intersection)
on the NORTH (n, e, s, w) side of SMOTHERS ROAD (road name)

ORIGINAL WELL

ODNR Well Log Number N/A Copy attached? Yes or No (circled: No) (circle one)

MEASURED CONSTRUCTION DETAILS Date of measurements 8/31/92

Depth of Well 101.5 Static Water Level 14.5
Size of Casing 8 INCH Length of casing ?
Well Condition ABANDONED

SEALING PROCEDURE

Method of Placement PRESSURE GROUT - 1" TREMIE TUBE

Placement:	From	To	Sealing Material	Volume
	101.5	SURFACE	BENSEAL/E-Z MUD	385 GAL

Was Casing Removed? Yes or No (circled: No) (circle one)
Condition of Casing GOOD
Perforations: From To
From To
Date Sealing Performed 8/31/92
Reason(s) for Sealing WELL ABANDONED - NO LONGER NEEDED AND IN THE WAY OF CONSTRUCTION

CONTRACTOR

Name ACME DRILLING COMPANY ODH Registration # 3456
Address 1234 MAIN ST.
City/State/Zip SOCKERDOWNE, OH, 56789 Signature W. E. Coyote

DNR 7810.93 **SUBMIT COMPLETED FORM TO ODNR-DIVISION OF WATER**

Figure A. Example well sealing report

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**.

Eliminate Physical Hazard

One of the most obvious reasons to properly seal a well is the physical hazard (Figure B). A good example of this danger was seen a few years ago 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. 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 borings are often drilled on farmland that is in the process of being sold for commercial or industrial use. 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 B). 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 direct disposal of contaminants down the well, and by bacterial 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 upon 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).

Contaminated 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, contaminated surface water can seep down along the space (called the **annular space**) between the casing and the borehole wall of an improperly grouted well. This is an important consideration because most older water wells do not meet today's construction standards.

Illegal direct disposal of contaminants down unused wells is a common occurrence. 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 bacteria to the ground water (Smith, 1994).

Prevent 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 B). 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, the well will flow 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

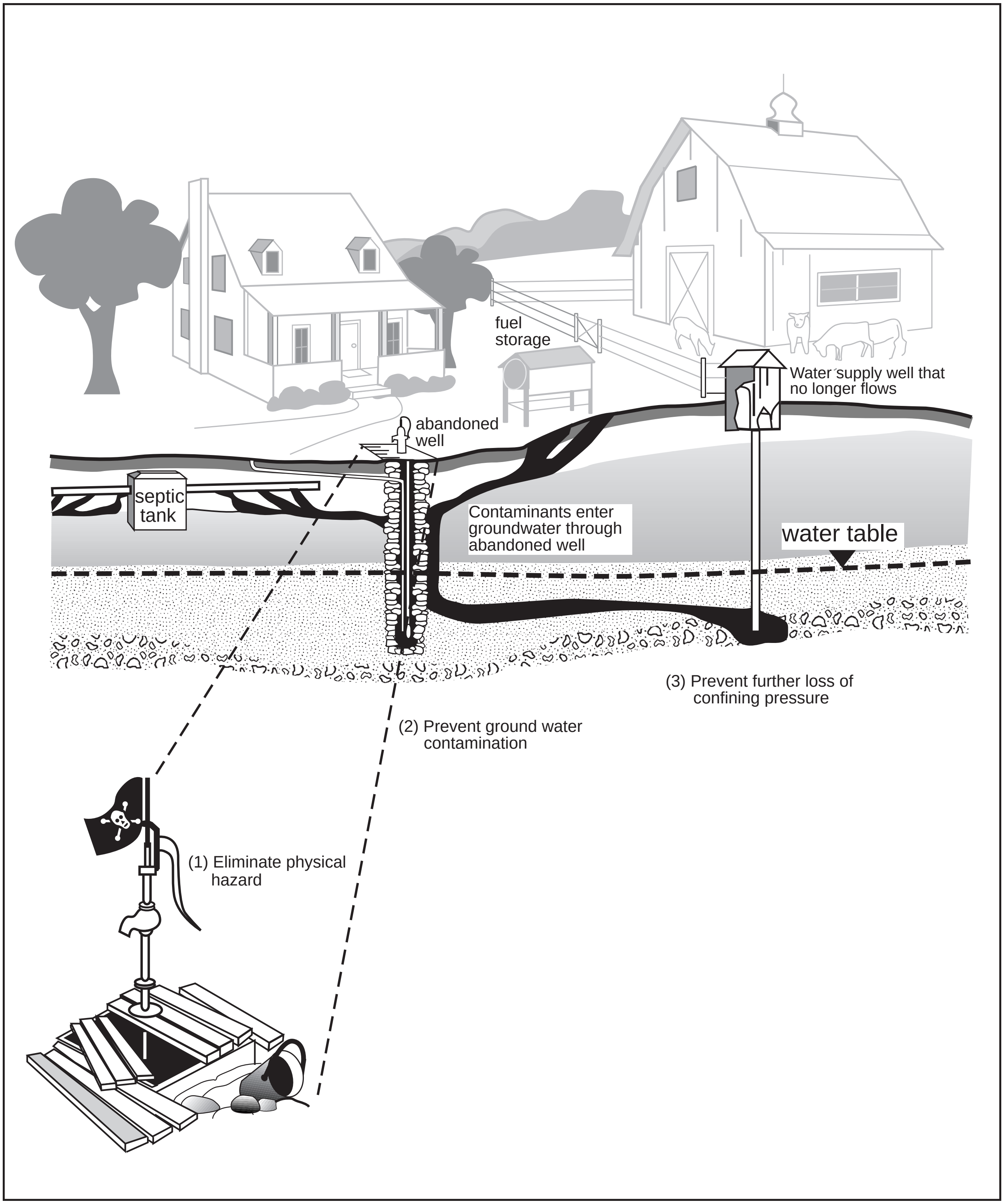


Figure B. Reasons to properly seal an unused well
(After Glanville, 1989, and King, 1992)

water from the aquifer onto the ground surface. Therefore, it is especially important to ensure that abandoned wells penetrating confined aquifers are properly sealed.

Who Should Perform Well Sealing?

It may seem that anyone who can rip open a bag of grout and pour it down the hole could seal a well. However, effective well sealing requires skill and cannot be done carelessly. A sealed-in leaking shaft or hole will most likely result if too little grout is emplaced, or it is mixed improperly, or seals are not set at the right depths, or annulus openings are left outside the casing. The consequence is continued threats to other wells and direct pathways to the ground water (Smith, 1994).

There are no qualifications specified in regulation for persons who can 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. Some work may also need to be supervised by a qualified hydrogeologist or qualified engineer. 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. Personnel should be trained and equipped for sites with potential for exposure to contamination or other hazards (Smith, 1994).

In some instances, shallow large diameter **dug wells** can be successfully sealed by a non-professional with minimal amount of special equipment. Be aware, however, that once a well has been sealed improperly, it is costly to correct because the defective seal has to be drilled out. An experienced registered drilling contractor should be consulted, at a minimum, in all sealing situations. It is recommended that wells with one or more of the following characteristics be sealed by an experienced registered drilling contractor only:

- drilled wells,
- flowing wells,
- wells greater than 100 feet in depth,
- wells where water is seeping from around the casing,
- wells where pumping equipment is difficult to remove,
- wells which produce gas, and
- monitoring wells (Zahniser and Gaber, 1993).

Types of Wells Defined by Method of Construction

Wells can be described in different ways, either by their method of construction, or by the type of aquifer in which they are developed. To describe wells by their method of construction, it is necessary to understand what it takes to “make a well.” There are three commonly used methods of well construction: digging (by hand or backhoe), driving, and drilling.

Dug Wells

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

Driven Wells

Driven wells, for the purposes of this document, will refer to well points exclusively (Figure D). 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 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.

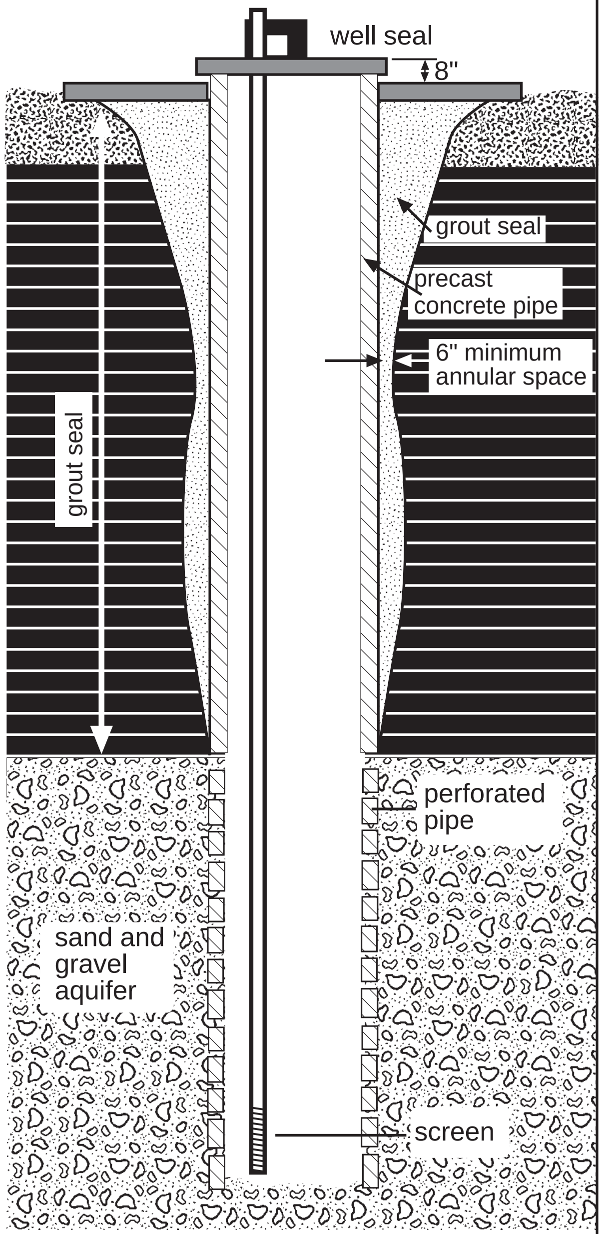


Figure C. Typical dug well design
(After Midwest Plan Service, 1979)

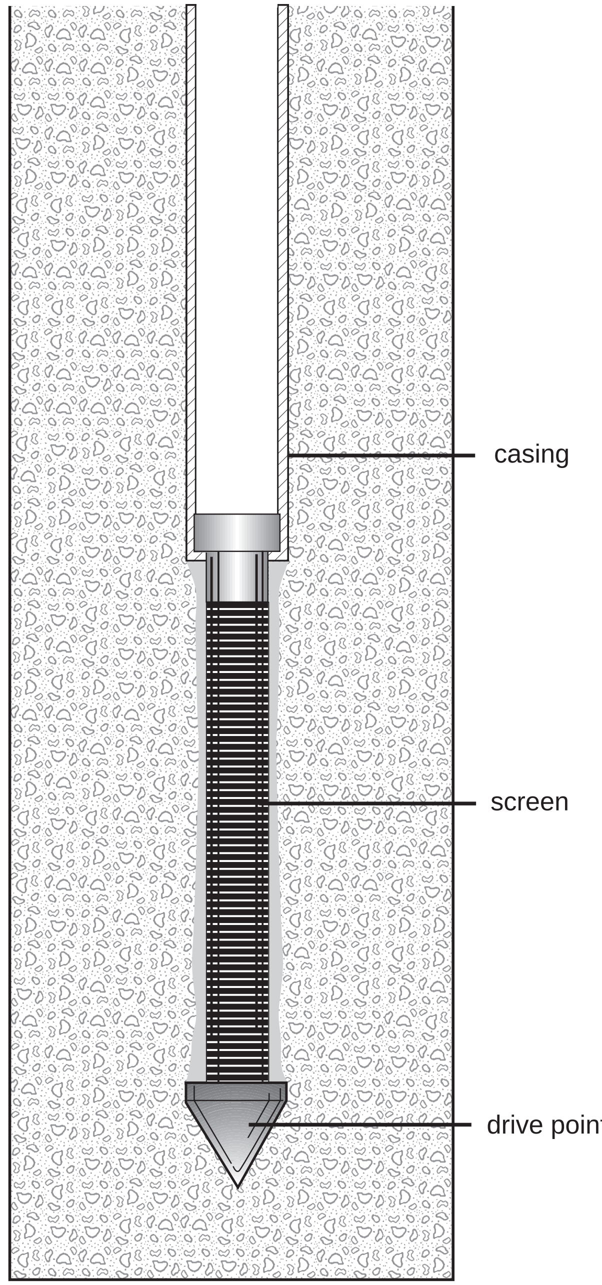


Figure D. Driven well

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: boring, cable tool, rotary, and vibratory drilling.

Bored

Bored wells are also known as augered wells and 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 50 to 150 feet, but in some areas they can reach 250 feet in depth (Driscoll, 1986). In Ohio, a bucket-augered well generally is cased with concrete pipe or vitrified tile, and in many respects will resemble a dug well.

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 (Figure E). 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. 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.

Cable Tool

Cable tool (sometimes called “spudder”) rigs operate by repeatedly lifting and dropping a string of **drill tools** into the hole (Figure F). The **drill bit** at the bottom of the drill tools breaks or crushes the formation and when mixed with water forms a slurry. After drilling a certain number of feet, 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. In some cases, drilling a well deep into unconsolidated sediments requires that two strings of casing be used; that is, the driller will start with a particular diameter casing, then when this size casing can no longer be driven, a smaller diameter casing is set inside the larger casing and the drilling and driving process continues until the well is completed. This technique works because the smaller diameter casing has less friction working against it. However, when drilling a well into the bedrock with a cable tool rig, usually a single casing string is set a few feet into the bedrock, and drilling continues open hole until the desired depth is reached. Cable tool drilling is still the most commonly used method of drilling water wells in Ohio. About 79 percent of the drilling contractors operating in the state of Ohio own cable tool rigs.

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 outside diameter of the well casing will be at least 2" smaller than the diameter of the borehole. Therefore, it is important that the space between the casing and borehole wall (annular space) be 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. 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 G shows typical rotary-drilled well construction.

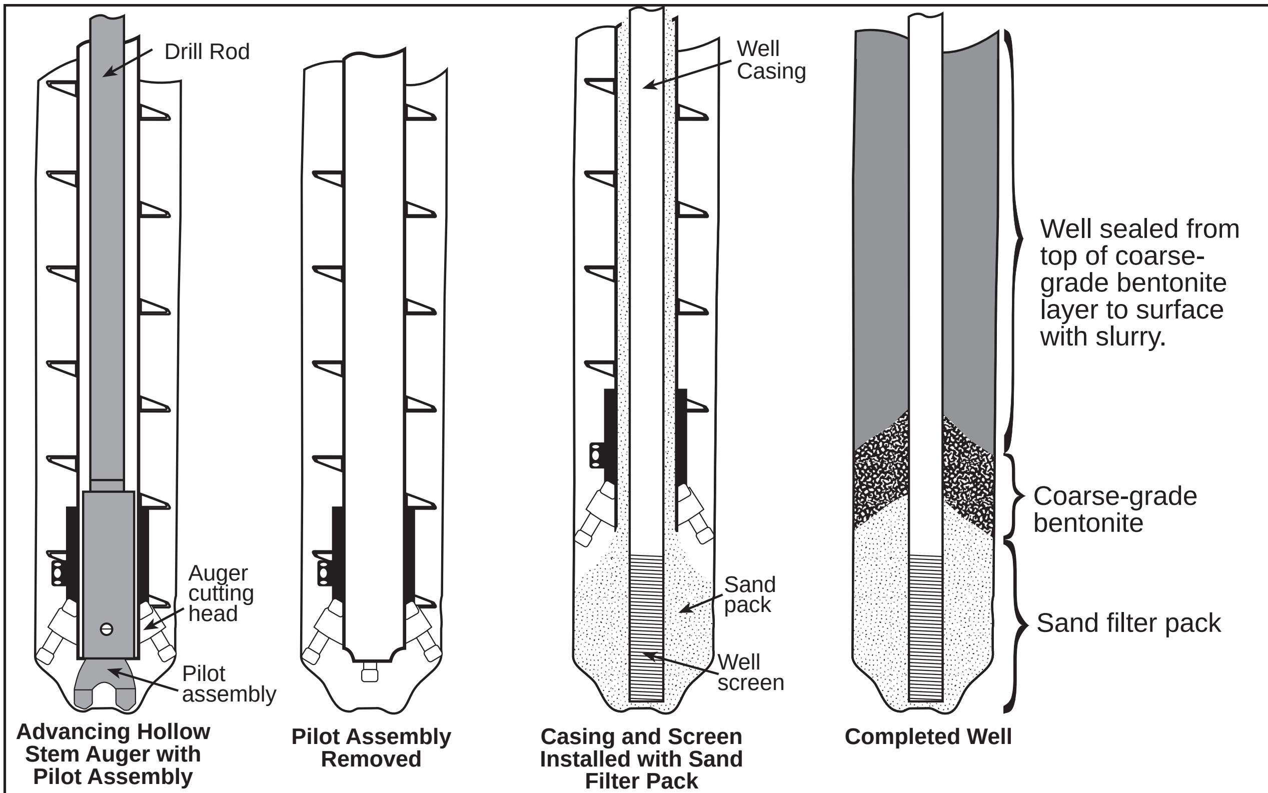


Figure E. Well construction using hollow stem augers
(Modified from Hackett, 1987 and 1988)

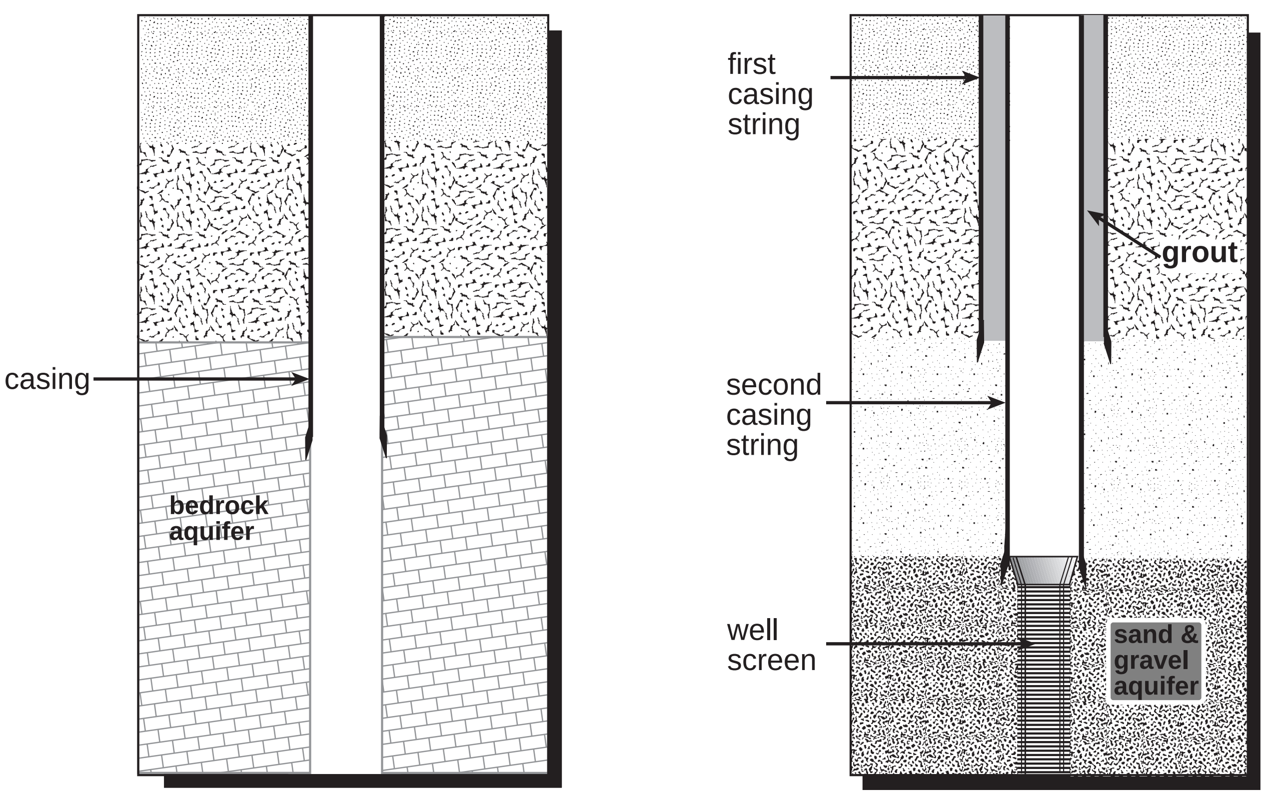


Figure F. Cable tool-drilled wells

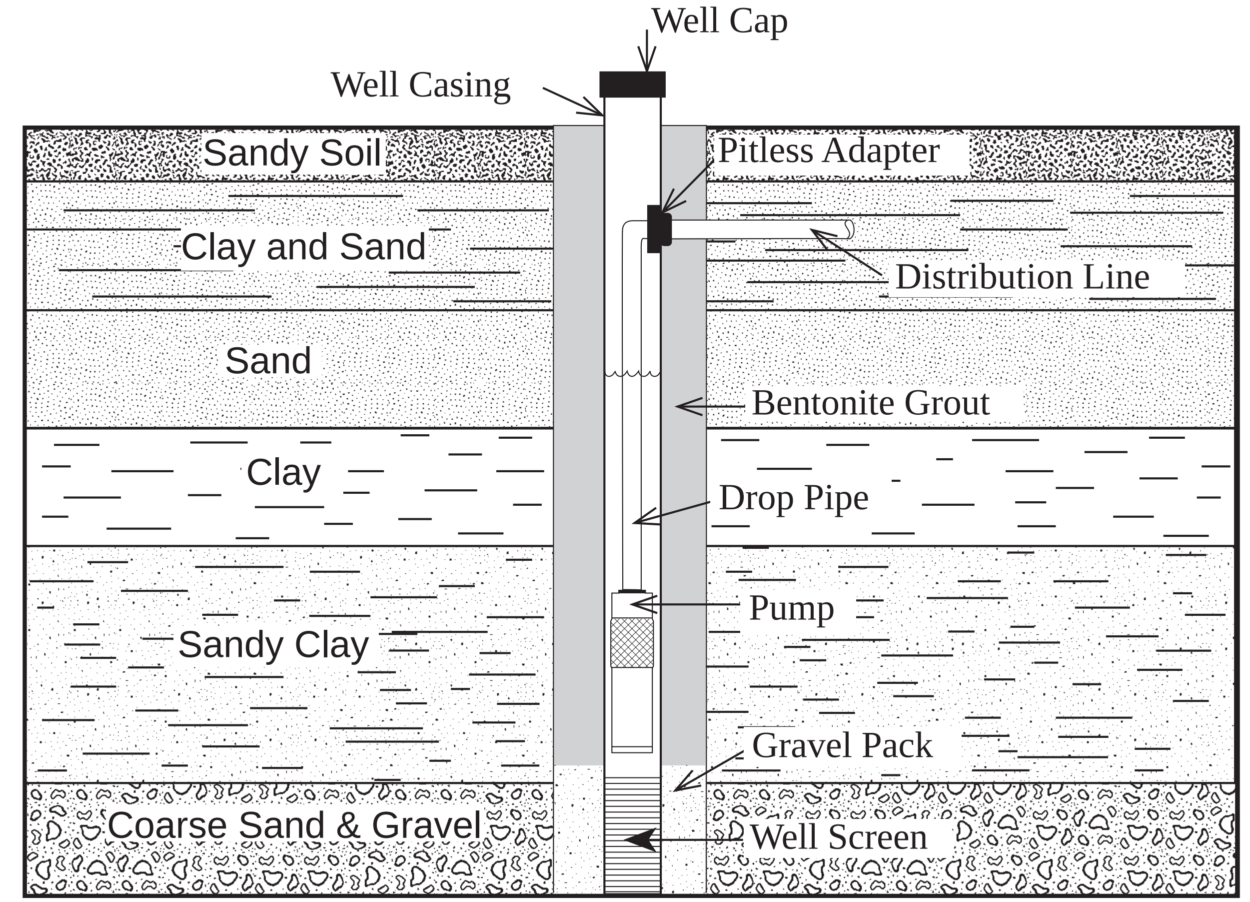


Figure G. Rotary-drilled well with screen, developed in a sand and gravel aquifer

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 rotated by table drive exclusively, as 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 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 (Driscoll, 1986).

Vibratory

Vibratory drilling involves the use of a resonance source through the drill rods to drill a hole to the desired depth. The resonance through the casing (rods in this case) pushes the cuttings into the side wall of the hole and into the center of the pipe. This method produces a minimal amount of cuttings, uses no drilling mud, and produces a continuous core. This drilling method is used mostly for geotechnical and environmental sampling purposes. Monitoring wells can be set through the casing if desired.

Types of Wells 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 H shows the statewide distribution 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, are directly related to the types of geologic formations that comprise the aquifers. For example, the white areas on the map signify aquifers that typically yield less than five gallons per minute to a well. The aquifers in these areas generally consist of shales, or interbedded limestone and shale, or, in some cases, interbedded shale, limestone, and sandstone.

Geologic formations in Ohio will be 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 the benefit of casing. Consolidated aquifers in Ohio generally consist of sandstone, limestone, or shale. The most productive consolidated aquifer is cavernous limestone. Sealing wells that penetrate fractured and cavernous rock may have special problems due to loss of grouting 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 beds** between the zone of saturation and the surface (see Figure I for example). They are often referred to as water table aquifers. The upper surface of

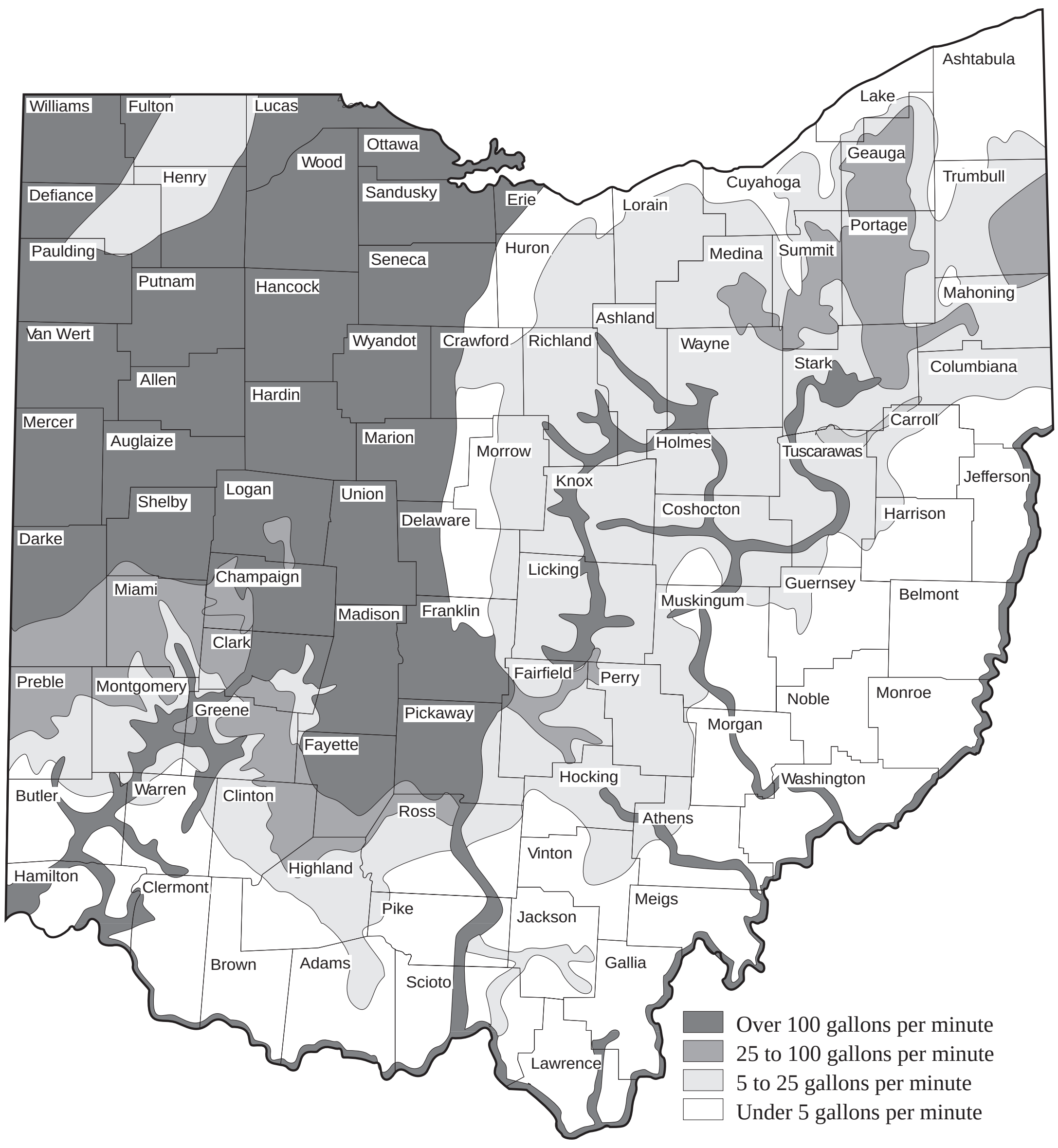


Figure H. Generalized map of ground water resources in Ohio

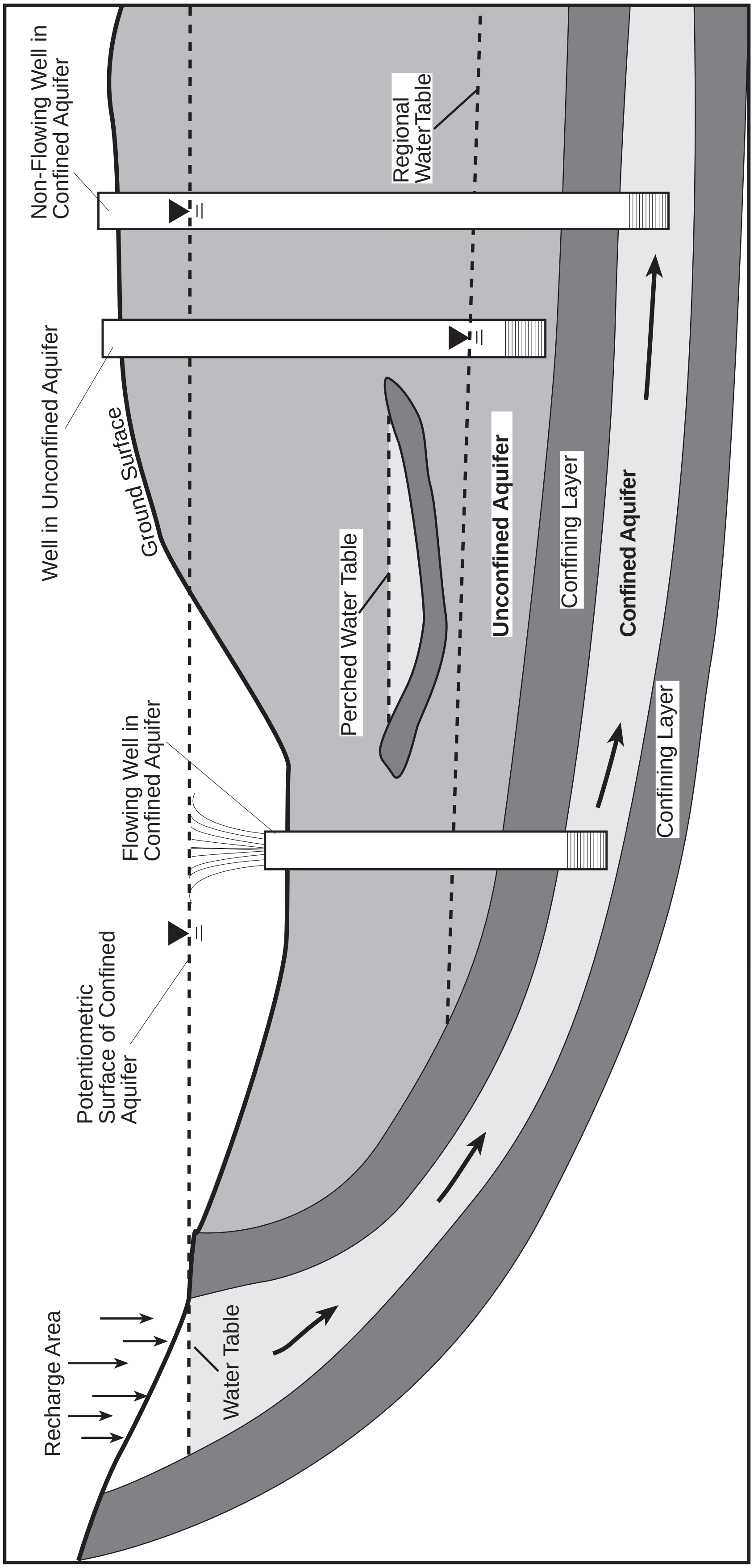


Figure I. Confined and unconfined aquifers
(After U. S. Department of the Interior, 1977)

an unconfined aquifer is in direct contact with the atmosphere through open **pores** of the material above and is everywhere in balance with the hydraulic head in the **recharge** area. 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 aquifers that are overlain by a confining bed (see Figure I 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 confining unit to an elevation that is equivalent to the hydraulic head of the confined aquifer. 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 developed in confined aquifers can present a special problem when it comes time to seal them. Also, wells screened across several aquifers will require more care in sealing. These wells must be sealed in such a manner so that there is no intermixing of water between the aquifers. In addition, careful consideration must be given to choosing an appropriate sealing method for wells screened in a single aquifer but penetrating several aquifers. These scenarios and others will be addressed in the section on **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 are 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.

The best source of information is the “Well Log and Drilling Report” that is completed by the driller at the time of construction. These logs contain well construction information and a record of formations encountered during well installation. Figure J is an example of a well log. An accurate well log will enable a drilling contractor to select the most appropriate sealing method for that well. Copies of these reports are filed with the Ohio Department of Natural Resources, Division of Water, and, within the last 10 to 15 years, each county health department. 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, the names of the nearest cross roads, and the approximate year in which the well was drilled. It may not be possible to discover all of this information, but the Division of Water will 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. Call the Division of Water, Water Resources Section at 614-265-6740 to have the files searched for a specific well log and drilling report.

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 depths and construction. If a well is free of obstructions (including old pumps), then the depth 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.

Other methods for examining the condition of a well include casing-depth indicators, borehole video cameras, 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. These methods are likely to be expensive, but most wells will not need such detailed investigations. Local drilling contractors should be able to locate firms possessing this equipment, if necessary.

Casing Issues

Well casing is usually constructed of plastic (PVC), steel (in drilled wells), or concrete pipe, vitrified tile, brick, or cobbles (in dug wells). The well screen is a section of wire-wrapped or machine-slotted casing through which water enters the well. In many older wells, it was common

DNR 7802.94

TYPE OR USE PEN
SELF TRANSCRIBING
PRESS HARD

WELL LOG AND DRILLING REPORT

Ohio Department of Natural Resources
Divison of Water, 1939 Fountain Square Drive
Columbus, Ohio 43224 Phone (614) 265-6739

Permit Number WI9500009

COUNTY FRANKLIN TOWNSHIP WASHINGTON SECTION/LOT No. 3 (Circle One)

OWNER/BUILDER (Circle One or Both) R. D. RUNNER (First / Last) PROPERTY ADDRESS (Address of well location) 12345 RINGS ROAD (Number / Street) DUBLIN (City) 43002 (Zip Code + 4)

LOCATION OF PROPERTY 1/8 MILE EAST OF COSGRAY, NORTH SIDE OF RINGS ROAD

CONSTRUCTION DETAILS

CASING *(Length below grade) Borehole Diameter 9 in.

1 Diameter 5 in. Length* 157 ft. Wall Thickness SDR21 in.

2 Diameter ___ in. Length* ___ ft. Wall Thickness ___ in.

Type: 1/2 Steel 1/2 Galv. [X] 1/2 PVC 1/2 Other ___

Joints: 1/2 Threaded 1/2 Welded [X] 1/2 Solvent 1/2 Other ___

Liner: Length ___ Type ___ Wall Thickness ___ in.

SCREEN

Type (wire wrapped, louvered, etc.) MACHINE SLOTTED Material PVC

Length 5 ft. Diameter 5 in.

Set between 162 ft. and 157 ft. Slot 0.050

GROUT

Material BENSEAL/E-Z MUD Volume used 280 GALLONS

Method of installation 1" TREMIE TUBE

Depth: placed from 152 ft. to SURFACE ft.

GRAVEL PACK (Filter Pack)

Material #4 PARRY SAND Volume used 500 LBS

Method of installation GRAVITY

Depth: placed from 165 ft. to 152 ft.

Pitless Device [X] Adapter ☐ Preassembled unit

Use of Well RESIDENTIAL

[X] Rotary ☐ Cable ☐ Augered ☐ Driven ☐ Dug ☐ Other ___

Date of Completion 2/17/95

WELL LOG*

INDICATE DEPTH(S) AT WHICH WATER IS ENCOUNTERED.

Show color, texture, hardness, and formation: sandstone, shale, limestone, gravel, clay, sand, etc.	From	To
YELLOW BROWN CLAY	0	11
GRAY CLAY & GRAVEL	11	63.5
SAND & GRAVEL	63.5	65.5
GRAY SILTY CLAY	65.5	89
SAND WITH GRAVEL	89	92
GRAY CLAY & GRAVEL	92	144
SAND	144	150
SAND & GRAVEL	150	165

*(If additional space is needed to complete well log, use next consecutively numbered form.)

WELL TEST

☐ Bailing ☐ Pumping* [X] Other AIR LIFT

Test rate 25 gpm Duration of test 3/4 hrs.

Drawdown 20 ft.

Measured from: ☐ top of casing [X] ground level ☐ Other ___

Static Level (depth to water) 30 ft. Date: 2/17/95

Quality (clear, cloudy, taste, odor) CLEAR

*(Attach a copy of the pumping test record, per section 1521.05, ORC)

PUMP

Type of pump SUBMERSIBLE Capacity 20 gpm

Pump set at 100 ft.

Pump installed by OTHERS

WELL LOCATION

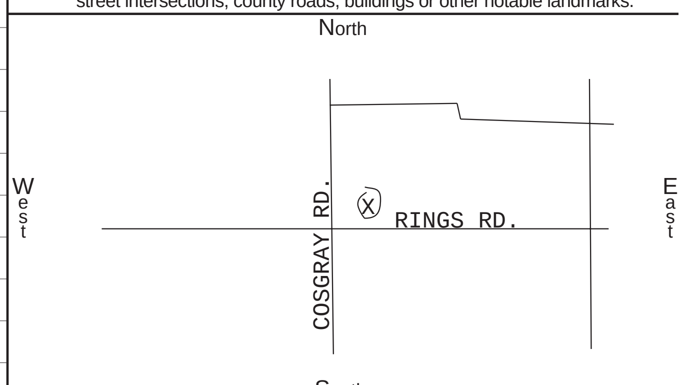
Location of well in State Plane coordinates, if available:

Zone ___ x ___ y ___

Elevation of well ___ ft./m. Datum plain: ☐ NAD27 ☐ NAD83

Source of coordinates: ☐ GPS ☐ Survey ☐ Other ___

Sketch a map showing distance well lies from numbered state highways, street intersections, county roads, buildings or other notable landmarks.



I hereby certify the information given is accurate and correct to the best of my knowledge.

Drilling Firm ACME DRILLING COMPANY Signed W. E. Coyote

Address 1234 MAIN ST. Date 2/27/95

City, State, Zip SOCKERDOWNE, OH 56789 ODH Registration Number 3456

Completion of this form is required by section 1521.05, Ohio Revised Code - file within 30 days after completion of drilling.

ORIGINAL COPY TO - ODNR, DIVISION OF WATER, 1939 FOUNTAIN SQ. DRIVE, COLS., OHIO 43224

Blue - Customer's copy Pink - Driller's copy Green - Local Health Dept. copy

Figure J. Example well log and drilling report 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", however, are highly inefficient and susceptible to corrosion and plugging. The casing and screen prevent the surrounding formations from caving into the well. Some formations are sufficiently consolidated that the well will remain open and no well screen is required.

Water can migrate along the space between the casing and the borehole wall; therefore, the best way to seal a well is to remove the casing and screen (if any), and grout the open hole. If there is no well log or other information about the construction of the well, or if the well casing is in poor condition, then it is probably best not to remove the casing (unless the well is an environmental well that can be easily overdrilled). Consideration should be given to having a registered drilling contractor rip or perforate the casing in such cases.

Sealing Materials

The data in this section relies heavily on information found in the Michigan Water Well Grouting Manual (Gaber and Fisher, 1988).

Materials used for sealing abandoned water wells must have certain properties to make them desirable for use. The ideal grout should 1) be of low permeability in order to resist flow through them, 2) be capable of bonding to both the well casing (if necessary) and borehole wall to provide a tight seal, 3) be chemically inert or nonreactive with formation materials or constituents of the ground water with which the grout may come in contact, 4) be easily mixed, 5) be of a consistency that will allow the grout to be pumped and remain in a pumpable state for an adequate period of time, 6) be capable of placement into the well through a 1-inch diameter pipe, 7) be self-leveling in the well, 8) have minimal penetration into permeable zones, 9) be capable of being easily cleaned from mixing and pumping equipment, 10) be readily available at a reasonable cost, and 11) be safe to handle.

Grouting materials currently used in water wells are comprised of either cement or bentonite. Although there are advantages and disadvantages with each material and none of the grout materials available today exhibit all of the desirable characteristics listed above, field experience has shown each to be suitable under most geological conditions. Table 1 lists advantages and disadvantages of cement and bentonite grouts.

Final permeability of the grout is recommended to be 1×10^{-7} centimeters per second to retard fluid movement. Table 2 shows approximate permeability values for various sealing materials.

Cement–Based Grouts

Cement Properties

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 components. 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 anhydride 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 in the formation material at the cement/borehole interface and 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, use of additives, and surrounding temperatures. Excessive heat of hydration may adversely affect the structural properties of any PVC plastic 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 3 shows total curing times for various cement grouts.

Table 1
Grout Properties

	Advantages	Disadvantages
CEMENT-BASED GROUTS	Suitable Permeability	Shrinkage & Settling
	Easily Mixed & Pumped	Long Curing Time
	Hard-Positive Seal	High Density Results in Loss To Formations
	Supports Casing	Heat of Hydration
	Suitable For Most Formations	Affects Water Quality
	Proven Effective Over Decades Of Field Use	Equipment Clean-Up Essential
	Properties Can Be Altered With Additives	Casing Cannot Be Moved After Grouting
BENTONITE-BASED GROUTS	Suitable Permeability With High Solids Grouts	Premature Swelling And High Viscosity Result in Difficult Pumping
	Non-Shrinking & Self-Healing	Difficult Mixing
	No Heat of Hydration	Subject to Wash Out in Fractured Bedrock
	Low Density	Subject to Failure From Contaminated Water
	No Curing Time Required	Equipment Clean-Up Difficult
	Casing Movable After Grouting	Limited Field Experience
		Usage Instructions Vary For Each Product
		Limited Availability

Table 2
Permeability of Various Sealing Materials

Sealing Material	Permeability (K) in cm/sec
Neat Cement (6 gal water/94 lb sack)	10^{-7}
Bentonite Grout (20% Bentonite)	10^{-8}
Bentonite Pellets	10^{-8}
Granular Bentonite	10^{-7}
Granular Bentonite/Polymer Slurry (15% Bentonite)	10^{-8}
Coarse Grade Bentonite	10^{-8}
(From American Colloid Co, and N.L. Baroid/N.L. Industries, 1989)	

Table 3
Cement Curing Time Required

Grout Type	Curing Time
Neat Cement - Type I	48 Hours
Concrete Grout - Type I	48 Hours
Neat Cement w/2% $CaCl_2$	24 Hours
Hi-Early Cement - Type III	12 Hours
Concrete Grout - Type III	12 Hours

Cement Types

Several types of cement are manufactured to accommodate various chemical and physical conditions which may be encountered. The American Society for Testing and Materials (ASTM) Specifications C150 (ASTM, 1992) is the standard used by cement manufacturers.

Portland cement Types I and IA are readily available throughout Ohio. Type II cement is available at some of the larger building supply outlets. Other cements are available by special order through cement suppliers. The different types of cement and their appropriate usage are described as follows:

Type I — General purpose cement suitable where special properties are not required.

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 ppm.

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). When Type III cement is used, the water to cement ratio must be increased to 6.3 to 7 gallons of water per sack.

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.

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.

Expansive-type cements are also available in Ohio. This type of cement will expand upon curing by use of additives in the mix, such as gypsum or aluminum powder.

Neat Cement Grout

Neat cement slurry is comprised of Portland cement and fresh water, with no aggregate present. It was first used as a grouting material in Texas and Oklahoma oil fields in the early 1900's (Smith 1976). Neat cement has since been used extensively in both the oil & gas and water well industries. Field experience has shown it to be effective for sealing off formations when properly applied. It can be mixed using a wide variety of methods. Generally, lower pressures are developed while pumping neat cement grouts. The main disadvantages of using 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.

In some states, neat cement is considered superior to bentonite-based grouts in situations where bedrock is encountered within 25 feet of ground surface. This is because it will form a hard, rock-like seal consistent with the bedrock and will not wash out or dilute from higher ground water flow rates encountered in some highly fractured formations.

The amount of shrinkage or settling, and compressive strength, of neat cement is dependent upon the proportion of water to cement in the slurry (Coleman and Corrigan, 1941; Halliburton Services, 1981). 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.

The American Petroleum Institute (API) recommends a water to cement ratio of 0.46 by weight or 5.2 gallons of water per 94-lb sack of cement. This is the amount of water needed to hydrate the cement. More than 5.2 gallons/sack ratio will thin the grout and make it easier to pump, but will adversely affect the grout's sealing properties. This guideline recommends that the maximum amount of water mixed per sack of cement be 6 gallons. The neat cement slurry at 6 gallons of water per sack of cement should weigh a minimum of 15 lbs/gal before pumping. 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 the consulting engineer or regulatory agency to specify an increase in the water to cement ratio. Factors such as the cement type, addition of additives, and quality of ground water will affect the grout performance and should be considered when planning the grouting operation.

Concrete Grout

Concrete grout consists of Portland cement, sand, and water. The addition of sand to a neat cement slurry results in less shrinkage and tighter bonding to the casing and borehole. Also, the sand in the slurry will aid in bridging pores in permeable formations. Concrete grout should be used only under specific sealing circumstances, such as 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. Concrete grout must be pumped down a tremie pipe, or, if the borehole is free of water, poured down. Placing concrete grout through a column of water will cause the separation of sand from the slurry and 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 on plastic pipe. Concrete grout can also cause excessive pump wear.

Other Cement Additives

Accelerators may be added to cement to decrease its setting time when attempting to cement off flows in and around casings. This will 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 retarders, weight-reducing agents, weighting agents, lost circulation control agents, and water reducing agents are available for cements but are not routinely used for water well sealing.

Bentonite—Based Grouts

Clay Properties

Clays 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 term clay is frequently applied to a variety of fine-grained materials including clays, shales, and clayey soils. They are all composed of small crystalline particles which are known as the clay minerals.

The common characteristic associated with clays 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. This, coupled with the ability of certain clays to swell many times their original volume when **hydrated**, accounts for many of the properties and uses for clays.

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. Bentonite particles tend to remain in suspension an indefinite period of time when placed in water. The resulting slurry is of 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). That is why mixing cement and bentonite is ineffective for preventing shrinkage of cement as it cures. Calcium ions in the cement replace sodium ions in the bentonite by a process called ion exchange. The resulting calcium bentonite has little or no swelling capability, and is therefore unable to prevent shrinkage of the cement (Smith, 1994).

Properties of Bentonite/Water Slurries

Three important physical properties of a water/bentonite slurry are: 1) density, 2) viscosity, and 3) gel strength. 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. 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 4.

Measurements should be taken after each grout batch is mixed and a grout sample should also be collected after the grout appears at the surface. The grout discharged from the well should have a density equal to that of the grout before it was pumped. The grout must be pumped into the well until dilution is minimal.

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 (Driscoll, 1986). Viscosity can be measured with a Marsh funnel viscometer, which determines the time it takes to dispense one quart of fluid through the funnel. Water has a Marsh funnel viscosity of approximately 26 seconds; bentonite-based grouts should have a 70 second viscosity. Grout should be periodically checked for adequate viscosity. A low viscosity grout will make a less effective seal than a grout with the proper viscosity.

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.

Table 4
Grout Slurry Densities

Product	**Water Ratio**	**Minimum Density Lbs/Gal**	**Volume ft³/sack**
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 & CaC1 (accelerator)	6.0 gal./sack of cement CaC1- 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 maximum water	17.5	2.0
Bentonite			
Benseal/EZ-Mud	Benseal - 1.5 pounds/gallon of water EZ-Mud - 1 quart/100 gallons of water	9.25	4.75
Volclay	2.1 pounds/gallon of water	9.4	3.6
(*From Halliburton Services, 1981)			

The gel strength is affected by how well the clay particles are dispersed in solution and the amount of water the particles have absorbed. Gel strength is not typically measured in the field. However, it is related to the fluid density and is dependent largely on the quality of the bentonite.

High-Solids Bentonite Grout

Within the last decade, bentonite products developed specifically for well grouting have appeared on the market. Some use chemical additives when mixing to control the development of viscosity and gel strength. By design, these products are meant to be easy to pump, place, and clean up. Premature swelling and/or high viscosities may make them difficult to pump when they are not mixed properly. 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.

For example, high concentrations of chlorides in the water will supress the hydration of bentonite unless it has been mixed with an agent that counteracts the effect of the chlorides (Smith, 1994).

The bentonite-based grouts currently available can be broadly grouped into four classifications. The classifications reflect the degree of processing and the particle size of the bentonite constituent. The four classes of materials are: 1) powdered bentonite, 2) granular bentonite, 3) coarse grade bentonite, and 4) pelletized bentonite. Each class of bentonite requires a different handling and placement method. Manufacturers recommend that mixing and placement methods should be assessed with regard to the depth to the water table, the required depth of grouting, and other pertinent geological information.

Powdered Bentonite/Clay Grout

Powdered bentonite/clay products available are similar in texture, appearance, and packaging to the high yield drilling mud grade bentonite. They are a mixture of bentonite clays (sodium and calcium) and other clays and do not possess the expansion characteristics of grouts containing predominantly sodium bentonite. They are marked as high solids clay grout with a resulting slurry of 15 to 20 percent clay solids by weight of water and are designed to have extended workability. When properly applied, they result in a flexible seal of low permeability. Adequate mixing of this product requires the use of a venturi-type mixer and a mud rotary type mud pump and recirculation system or a paddle mixer.

Some products utilize an inorganic chemical additive (magnesium oxide) referred to as an initiator, to aid in the development of gel strength. Exclusion of the initiator can result in decreased set strength, affecting the quality of the seal. 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) can result in a disappearance of the grout material from the well. This is due to a lack of gel strength development, resulting in settling of bentonite material in the well or loss to surrounding formations. For this reason, the use of these products requires placement of the material the entire length of the borehole. A bentonite pellet or neat cement cap a few feet thick is also recommended near the surface.

Granular Bentonite Slurries

Granular bentonites are generally manufactured from high-yield, non-drilling grade bentonite. The bentonite is processed to provide coarse granular particles (predominantly 8 to 20 **mesh**) which possess considerably lower surface area-to-mass ratios than the finely ground, powdered bentonite. This results in slower water absorption and delayed hydration and expansion when compared to a finely ground bentonite.

One advantage of the granular bentonite slurry is that the delay in swelling of the bentonite particles for a short period of time (15 minutes or less) allows preparation of a slurry possessing a lower viscosity. If mixing and pumping are done efficiently, the granular bentonite slurries allow placement of a high density grout in a low viscosity state. Expansion of the bentonite then occurs downhole. Granular bentonite may be prepared with 15 to 20 percent bentonite content by weight. This results in a set grout which exhibits excellent permeability and gel strength characteristics.

These products rely on the addition of a synthetic organic polyacrylamide polymer to suppress the hydration and delay swelling of the bentonite particles. The use of such products requires particular attention to the manufacturer's mixing recommendations. One recommended mixing procedure requires addition of the polymer to water at a rate of 1 quart of polymer per 100 gallons of water prior to adding the granular bentonite at 1-$^1/_2$ to 2 lbs. per gallon (Smith and Mason, 1985). 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. Upon addition of the bentonite, pumping of the grout material 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 are sized from $^3/_8$ to $^3/_4$ inch and are intended to fall without bridging through a column of water in a borehole. When placed properly, the coarse grade bentonite provides a high density, flexible down-hole seal of low permeability.

Due to the size of the coarse grade bentonites, care should be taken in their use. Since the material cannot be pumped, placement of the material requires pouring from the surface. Placement may be accompanied by tamping to insure that bridging has not occurred. The bentonite must be poured slowly, and the pouring rate should not exceed the manufacturer's specifications.

Prior to using this material, it should be sieved through $^{1}/_{4}$-inch mesh screen to remove 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. Water should be poured on top of any coarse grade bentonite above the water table to induce swelling.

Pelletized Bentonite

The pelletized bentonite consists of $^{1}/_{4}$ to $^{1}/_{2}$-inch size, compressed bentonite pellets. As with coarse grade bentonite, pelletized bentonite provides a dense and flexible seal. Pelletized bentonite can be poured directly into the well through standing water. Precautions similar to those for the use of coarse grade bentonite are required to avoid bridging.

Availability Of Bentonite Grout Materials

Bentonite products are not as widely available as Portland cement and must be obtained from water well equipment suppliers. New bentonite grouting products with higher solids and improved workability will most likely be developed by the bentonite industry in the future.

Fill Materials

Complete filling with a bentonite material may not be economically feasible in wells that have exceedingly large volumes. Most wells in this category are of large diameter and, therefore, present a physical hazard. This type of well must be filled with load-bearing materials (Gordon, 1988). For example, large diameter, shallow dug wells can be filled with clean clay, such as that sold in 100 pound bags as fireclay (Peck, 1987). This clay, however, should not be used as a sealing material or fill material in other types of wells because it does not seal as effectively as commercially prepared bentonite products (Carlton, 1975) and can bridge in deeper, smaller diameter wells. There are other well types - such as wells completed in fractured limestones or extremely coarse gravel - that can contribute to the excessive loss of sealing materials. Fill materials can be used in such instances to bridge fractures and large voids in the water-producing zone before sealants are emplaced (Gordon, 1988).

There are a variety of low-cost materials which can be used to fill space where an impermeable seal is not required in a certain section of the borehole, as specified in the next section of these guidelines. Depending upon the application, these materials may be clean, disinfected sand, gravel, crushed stone, or clay. In all cases, the material should be clean — free of sticks, leaves, or other foreign matter. Additionally, the material should be free of any toxic chemical residue. 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).

Procedures for Sealing the Well

General Sealing Procedures

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 adapters**, and suction lines. Pumps that are stuck and cannot be pulled should be pushed to the bottom of the hole, if possible. Other obstructions could 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.

After the obstructions have been removed from the well, the next step is to decide what to do with the casing. As discussed earlier, the casing can be removed (by pulling, overdrilling, drilling out, or jacking out), ripped or perforated, or left intact if the annular seal is judged to be adequate. The treatment of the casing will depend on the condition and type of casing, and the type of well being sealed. Another factor to consider when attempting casing removal is the type of formation in which the well is developed. Wells developed in unconsolidated formations should be sealed by simultaneously removing the casing and adding the sealing and /or fill material(s) to the well. This is necessary because once the casing is removed from a well developed in an unconsolidated formation, the borehole walls may collapse, preventing complete sealing of the borehole. It is highly recommended that this and all other steps in the sealing process be performed by an experienced registered drilling contractor.

Ripping or perforating a casing should be done by experienced registered drilling contractors that have the specialized tools needed for this work. Well casings should be ripped or perforated when the casing cannot be removed and:

- 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, or
- any combination of the above.

Overdrilling is not a commonly used method of casing removal in the water well industry; rather, it is used more often to remove casings from environmental wells. Overdrilling a well requires a drilling contractor to drill a larger diameter borehole over 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. The borehole where the well was located is then grouted. Well casings should be overdrilled when the casing cannot be pulled, the condition of the annular seal is questionable, and:

- 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.

Once the casing issue has been resolved, the next step is to disinfect the well. Chlorine is the most commonly used disinfection product, and is sold in many forms: bleach, tablets, pellets, powder, etc.. At concentrations of 150 to 200 parts per million (or milligrams per liter), the chlorine will kill any bacterial organisms that may exist in the water. As a result, water forced back into the formation by the sealing process will not cause bacterial contamination of any wells that are downgradient of the sealed well and developed in the same aquifer. The well may be disinfected before casing removal if it is suspected that the borehole may collapse after removal of the casing.

Installation of the sealing material follows the disinfection process. The method of installation and the sealing materials used must be matched to the type of well being sealed. In most situations (except for shallow wells), the method that provides the easiest installation and best seal is pressure grouting with a neat cement or bentonite slurry. Pressure grouting involves pumping a mixture of neat cement and water, or bentonite, polymer or initiator, and water down a small diameter plastic or steel pipe (called a tremie pipe) which has been lowered to the bottom of the borehole or well (Figure K). As the slurry is pumped, the pipe is pulled back at a rate that keeps the end of the pipe submerged in the slurry. The slurry will displace any water in the well and force it to the surface. The well has been filled when the slurry reaches the surface. Time should be allowed for any settlement of the slurry to occur before the final steps in the well sealing procedure are followed.

Precautions must be taken to ensure that the sealing material does not bridge when sealing wells with coarse grade bentonite products. Chipped bentonite products can be used in wells 200 feet deep or less. Pelletized bentonite products can be used in wells 100 feet deep or less. 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 poured at a rate no faster than 3 minutes per 50 pound bag (Figure L). 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. A tamping device should be used where possible to break any bridges that form. The total volume of products used to fill the well should be very close to

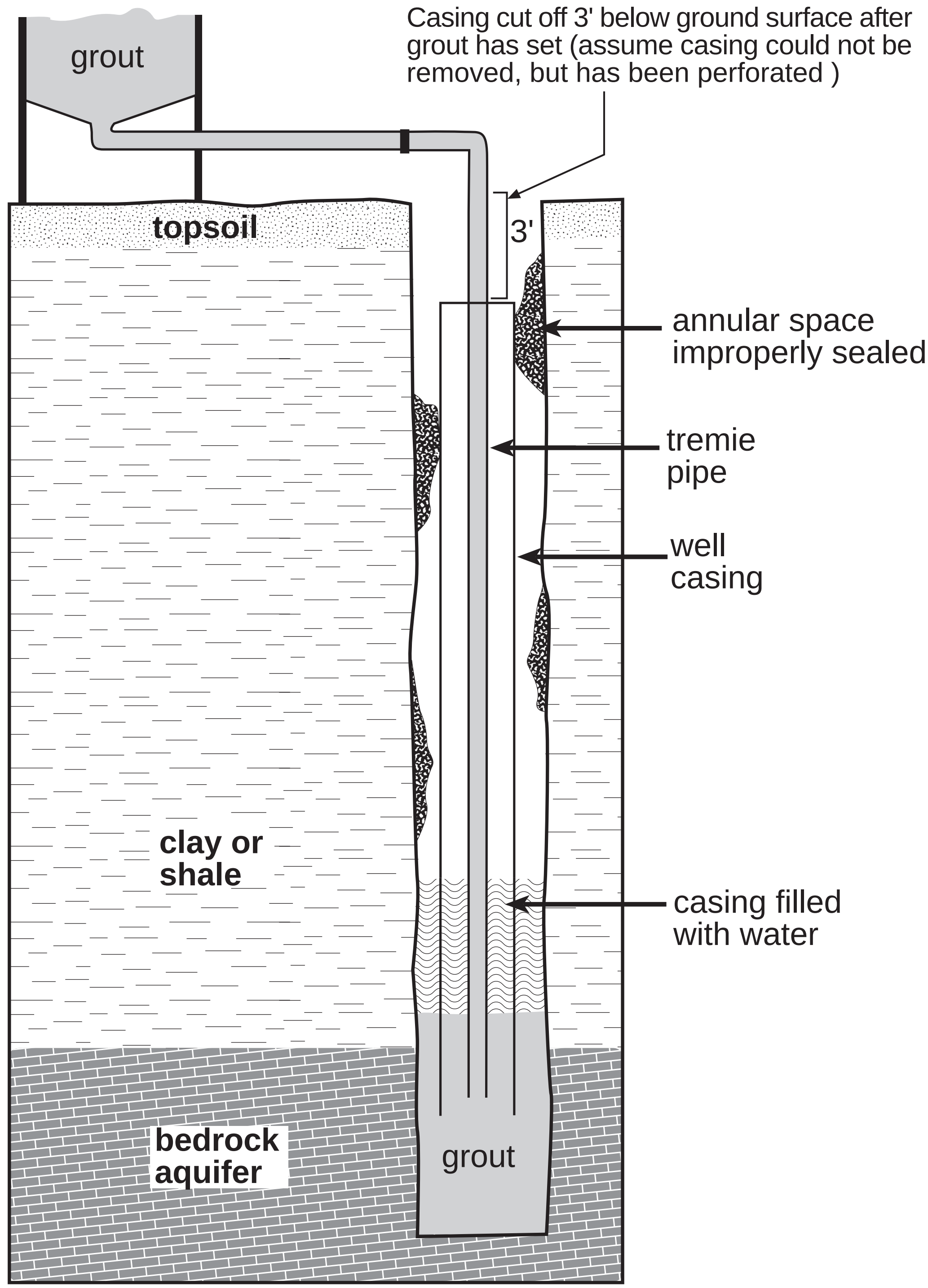


Figure K. Grouting bedrock well using tremie pipe method

the estimate of the amount needed for sealing. After the well has been sealed, it should be left unfinished overnight to see if any settling has occurred.

When the installation of sealing material has been completed, any remaining casing must be cut off to a depth of three to four feet below ground level. Then the remaining hole should be filled with clean soil and mounded at ground surface to ensure that surface water will drain away from the well. This procedure may be subject to change, depending upon the use of the land where the well is located.

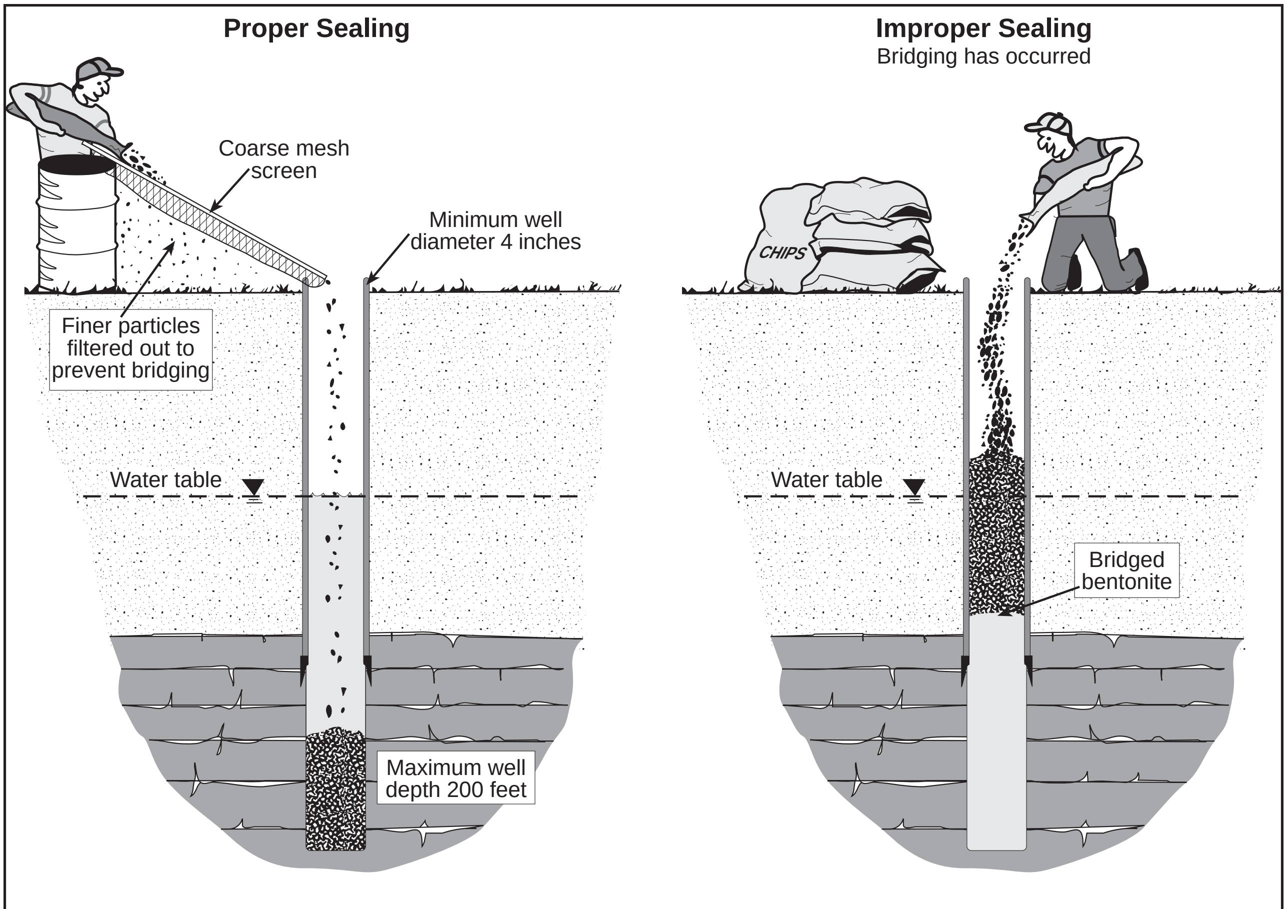


Figure L. Sealing wells with coarse grade bentonite products using pouring method
(Modified from Wisconsin Department of Natural Resources, 1993)

The final step in the well sealing process is the submission of a well sealing report to the Ohio Department of Natural Resources, Division of Water (Figure A). This form is readily available from the Division of Water upon request, and most drilling contractors will have a supply on hand.

Specific Well Sealing Procedures

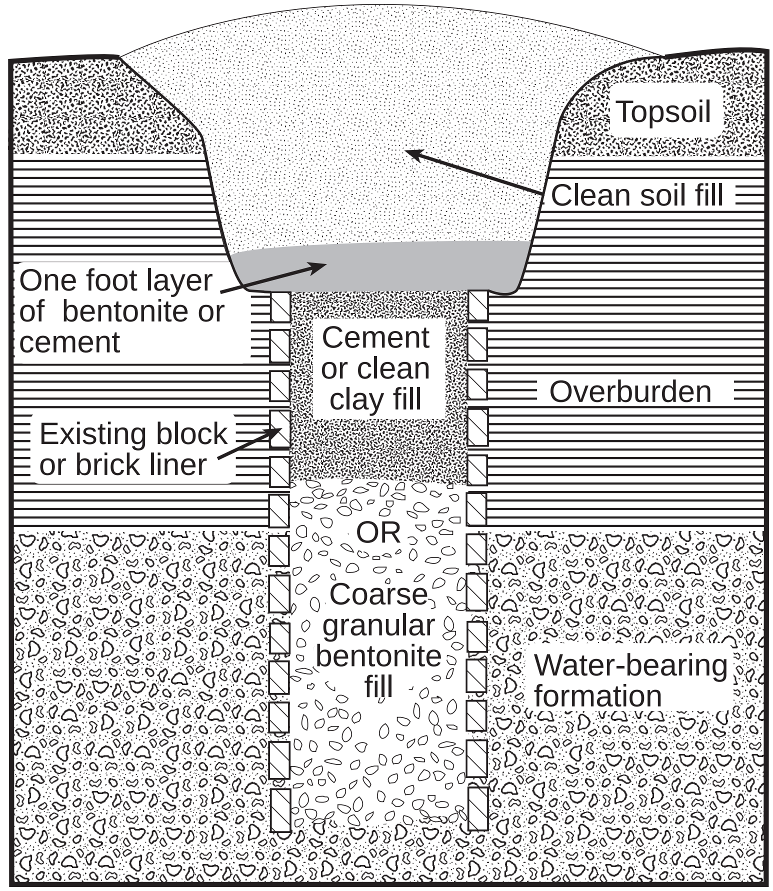
Sealing Dug and Bucket-Drilled Wells

The procedure for sealing dug and bucket-drilled wells differs somewhat from the general procedures described earlier in this guidance (Figure M). Once any obstructions are removed, the liner (casing equivalent) should be left intact except for the upper 3 to 5 feet (this number is dependent upon the measured static level in the well). The static water level in the well should be measured, and the well pumped dry if it contains water. The well should be disinfected, wet or dry.

Backfill with clean clay or cement to the measured water level if the static water level is less than five feet below ground surface, and the well is greater than twenty-four inches in diameter and twenty-five feet or less in depth. Remove the liner to the depth of the measured water level and excavate 6 inches beyond the original outside diameter of the well. Add a one foot thick layer of impermeable sealing material at the depth of the measured water level. This layer could consist of coarse grade bentonite or cement. If the impermeable sealing material used is coarse grade bentonite, it should be hydrated before completion if the well has been pumped dry. Five gallons of potable water should be added per fifty pound bag of bentonite. Fill the remainder of the well with clean soil and mound at ground surface to ensure drainage of surface water away from the well.

Backfill with clean clay or cement to the measured water level if the static water level is greater than five feet below the ground surface, and the well is greater than twenty-four inches in diameter and twenty-five feet or less in depth. Add a one foot thick layer of impermeable sealing material and hydrate. Then add more clean clay or cement to three feet below the ground surface. Remove the top three feet of liner and excavate six inches beyond the original outside diameter of the well. Add another one foot of sealing material and hydrate it if necessary. Fill the remainder of the well with clean soil and mound at ground surface to facilitate drainage of surface water.

Wells less than or equal to twenty-four inches in diameter with water levels greater than five feet below ground surface, or, wells greater than twenty-four inches in diameter and greater than twenty five-feet in depth, should be treated as drilled wells and sealed in a manner appropriate for drilled wells.



(Well is 25 feet deep or less and greater than 24 inches in diameter, and has a static level of less than five feet.)

Figure M. Sealing procedures for dug or shallow, large diameter wells

Sealing Driven Wells

After inspection and removal of any obstructions, the well should be disinfected. Casing removal should then be attempted. The well should then be filled with coarse grade or pelletized bentonite, bentonite slurry, or cement slurry to ground surface. The casing should be cut off three feet below the ground surface if it was not successfully removed. The area excavated around the well to access the casing should be filled with clean soil and mounded at ground surface to ensure drainage of surface water away from the well.

Sealing Wells Drilled Through a Single Unconsolidated Aquifer or an Unconfined, Unconsolidated Aquifer

After any existing obstructions have been removed from the well, the casing should be removed, ripped or perforated, or left intact. The type and condition of the casing will determine which procedure should be attempted. Before installing the sealing materials, the well should be disinfected. Then, clean sand and/or gravel can 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. Next, the well should be pressure grouted with bentonite or cement slurry, or coarse grade bentonite products can be slowly poured, from twenty-five feet to ground surface. Hydrate any coarse grade or pelletized bentonite products used, if necessary. Periodically tamp the coarse grade bentonite products to prevent bridging. These filling and sealing procedures should be done as the casing is being removed from the hole, if removal is to be attempted. If the well is not of great depth or large diameter, an alternative sealing method would be to pressure grout the entire well bore from bottom to ground surface with bentonite or cement slurry as the casing is being removed from the hole.

The casing should be cut off three feet below ground surface if it was not removed while sealing. The remaining excavation should be filled with clean soil and mounded at ground surface.

Sealing Wells Drilled Through Multiple Unconsolidated Aquifers

Remove any obstructions present in the well. After the well has been disinfected, simultaneously install the sealing materials and remove the casing, if it is to be removed. The well should be pressure grouted from the bottom of the well to ground surface with bentonite or cement slurry if the well penetrates multiple aquifers but is open only to one, or penetrates multiple aquifers and is screened across multiple zones. Or, if there is detailed information available on the depth and thickness of each aquifer penetrated, 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 (Figure N). Then the well should be sealed from the top of the uppermost aquifer to the surface with neat cement or bentonite products. Coarse grade bentonite products (chips) can be slowly poured into the well until they appear at ground surface if the well is 200 feet deep or less, and is 4 inches or more in diameter (Figure N). Pelletized bentonite products can be used if the well is 100 feet deep or less, and is 4 inches or more in diameter. These bentonite products, when used, should be periodically hydrated, if necessary, and periodically tamped to prevent bridging.

Any casing not removed should be cut off three feet below ground level, and the remainder of the well can be filled with clean soil and mounded at ground surface.

Sealing Wells Drilled Through Confined, Unconsolidated Aquifers

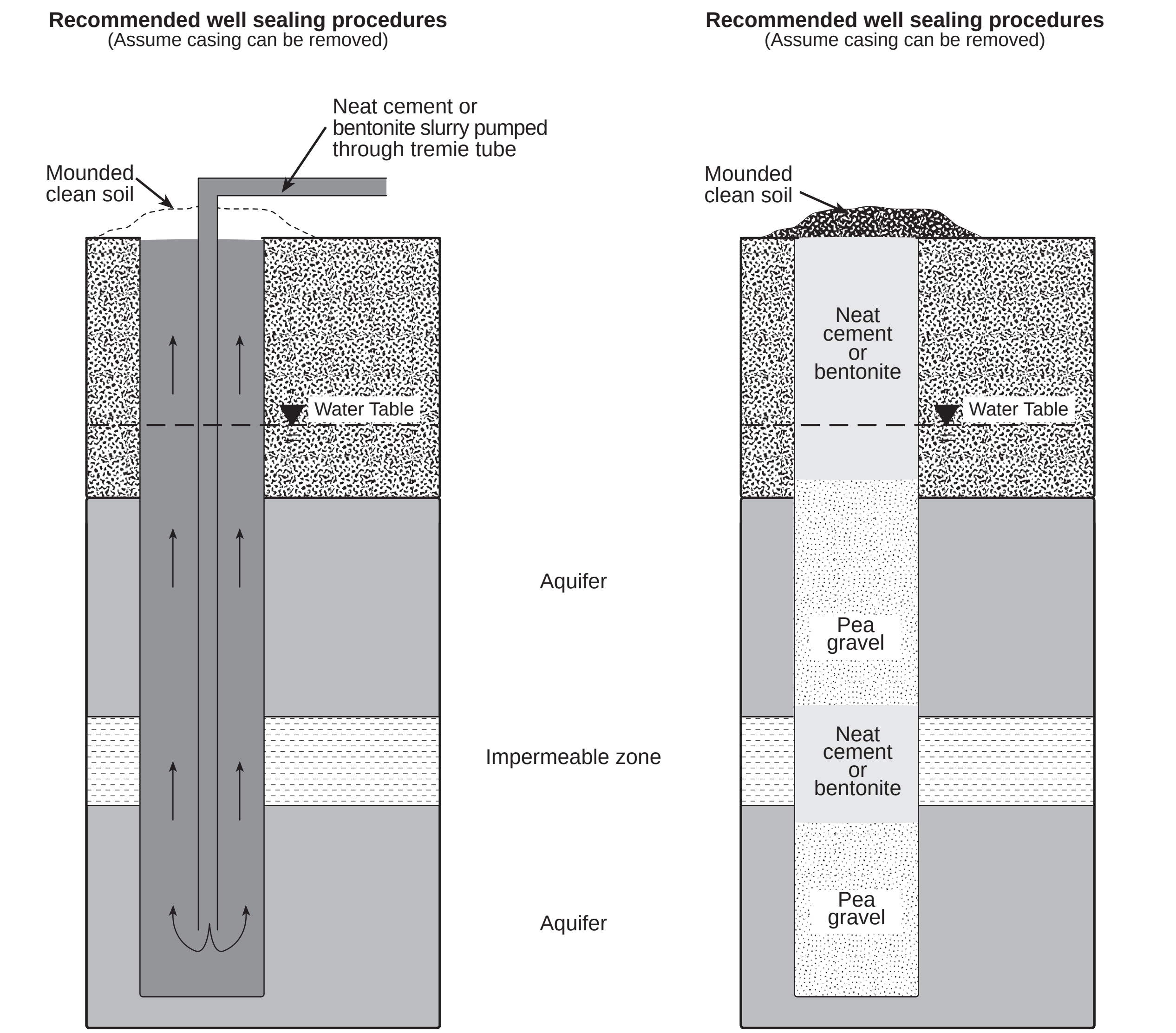


Figure N. Methods for sealing wells penetrating multiple aquifers

Wells drilled through confined aquifers can be difficult to seal because they can flow. 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.

Once any obstructions are cleared, the casing must be removed, ripped or perforated, or left intact, depending upon the condition of the casing and the proposed sealing method. The well should then be disinfected, if possible, before the sealing materials are installed. 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 flowing from within the casing only, an attempt should be made to determine the hydraulic head. Extend the casing high enough to keep the well from flowing if the hydraulic head is low enough to permit casing extension (Figure O(1)). Pressure grout with cement from the bottom of the well to the ground surface. Coarse grade bentonite products (100 feet or less for pelletized bentonite, 200 feet or less for chipped) may be poured from the bottom of the well to ground surface if the

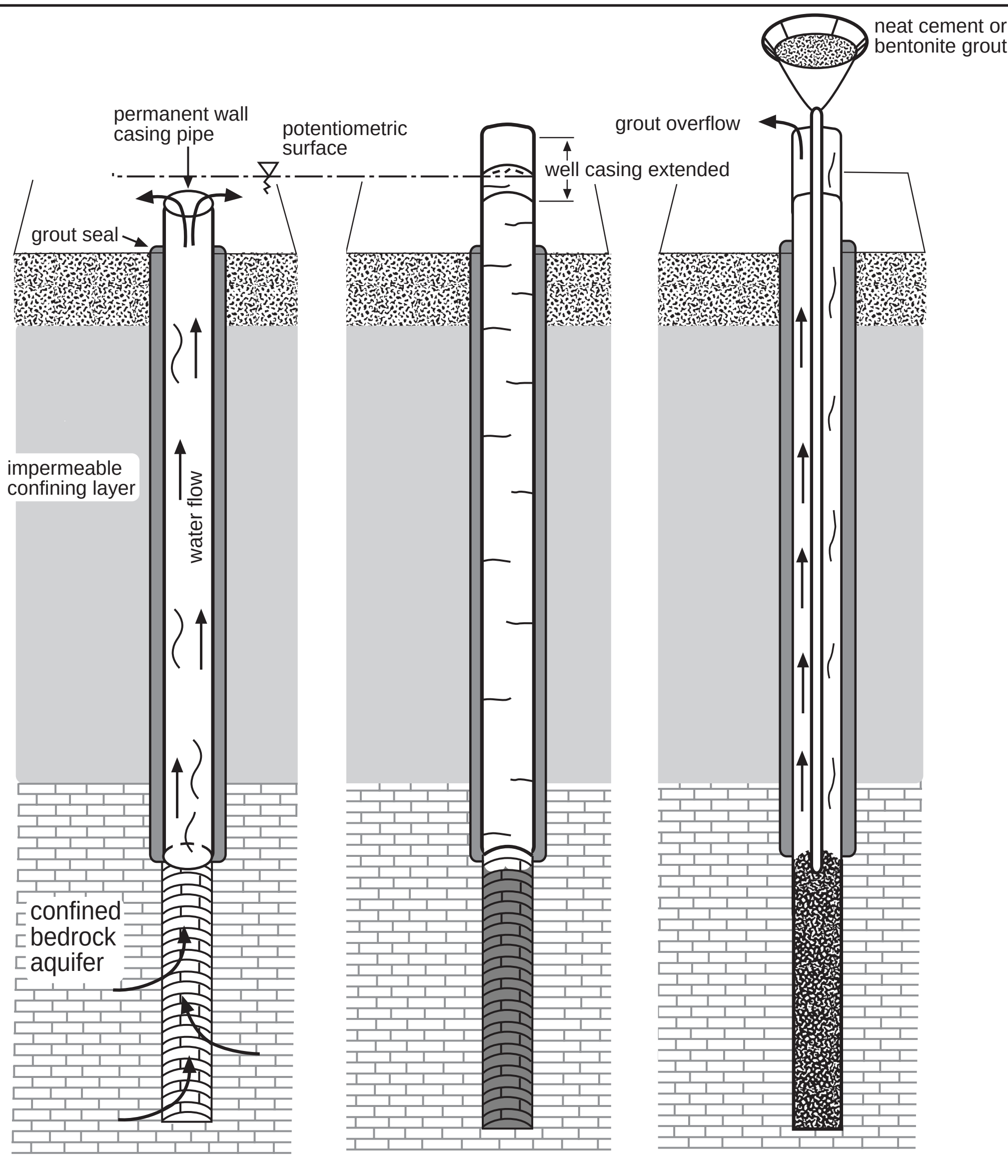


Figure O(1). Reducing or stopping flow of well by casing extension
(After Wisconsin regulations, 1994)

flow has been completely stopped by casing extension. The casing can then be cut off three to four feet below ground surface, and the remaining excavation filled with clean soil and mounded.

The well can be sealed by attempting to stop the flow, or by other methods that will allow sealing while the well is flowing, if the hydraulic head is too high to permit casing extension. An inflatable packer should be placed at the top of the producing formation to attempt to stop or restrict the flow (Figure O(2)). Then the well can be pressure grouted with cement or bentonite slurry through the packer from the bottom of the hole to the bottom of the packer. The packer can then be deflated and grouting continued to ground surface. 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 or bentonite slurry from the bottom of the well to the ground surface.

Another alternative for slowing the flow is to pour disinfected gravel into the well in an attempt to reduce the flow to a point where it becomes possible to use pressure grouting equipment to seal the well (Figure O(3)). Once the grout has set, any remaining casing can be cut off three to four feet below the ground surface. The resulting hole can then be filled with clean soil and mounded at ground surface.

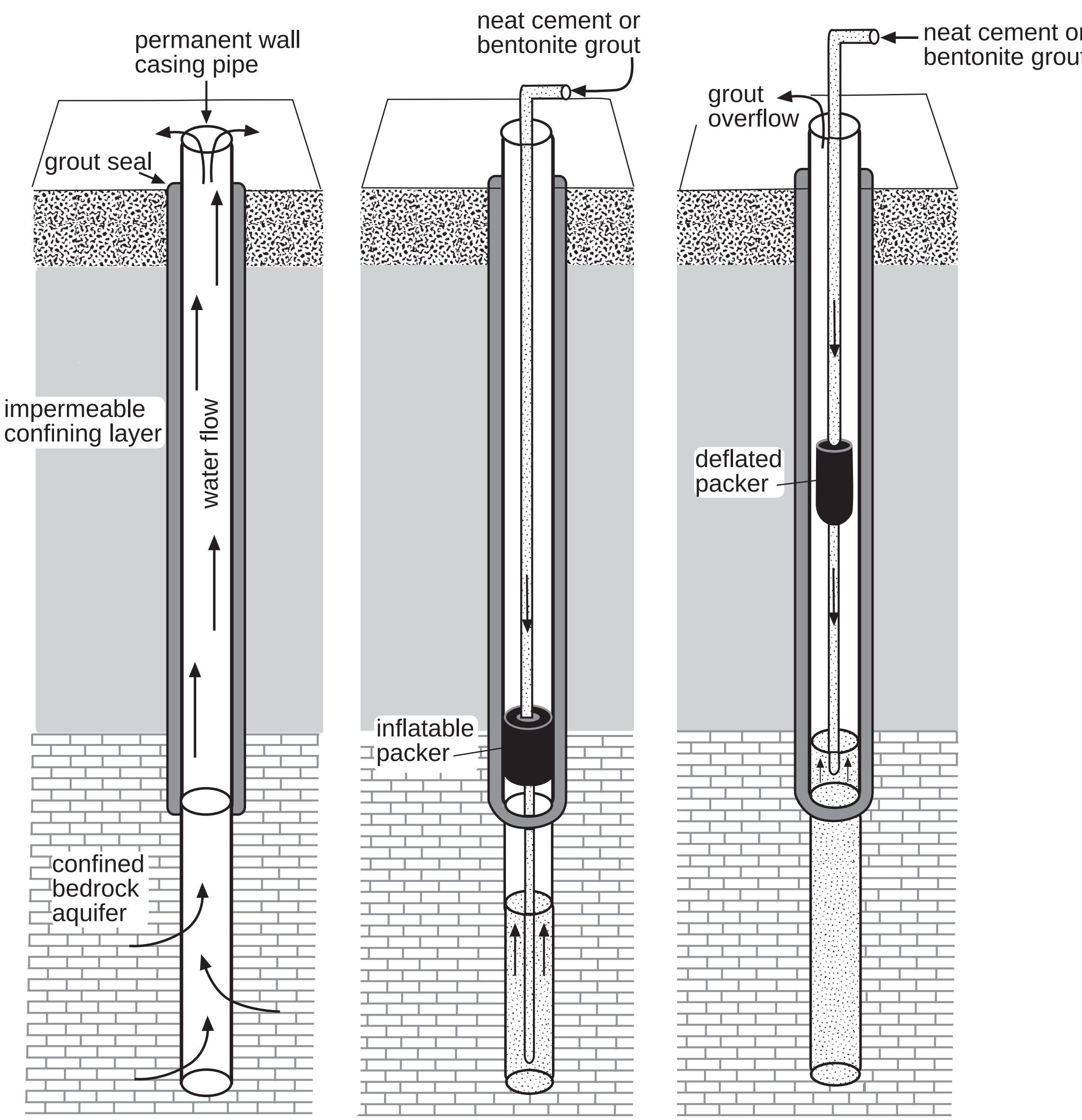


Figure O(2). Using inflatable packer to restrict flow
(After Wisconsin regulations, 1994)

The well should be pressure grouted continuously from bottom to top with a fast setting cement 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. If the casing cannot be removed, tremie lines should be run along the outside of the casing if there is an annular space, 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.

Sealing Wells Drilled Through Single Consolidated Aquifers

These types of wells should be sealed in the same manner as wells drilled through single unconsolidated aquifers, except that the casing removal and sealing need not occur simultaneously. Please refer to that section for sealing procedures.

Sealing Wells Drilled Through Multiple Consolidated Aquifers

Any obstructions should be removed and the casing should be removed, perforated, ripped, or left intact. The well then should be disinfected prior to the installation of the sealing materials. The well should be pressure grouted with cement or bentonite slurry from the bottom of the well to the ground surface. Alternatively, if there is enough information available about the construction of the well and

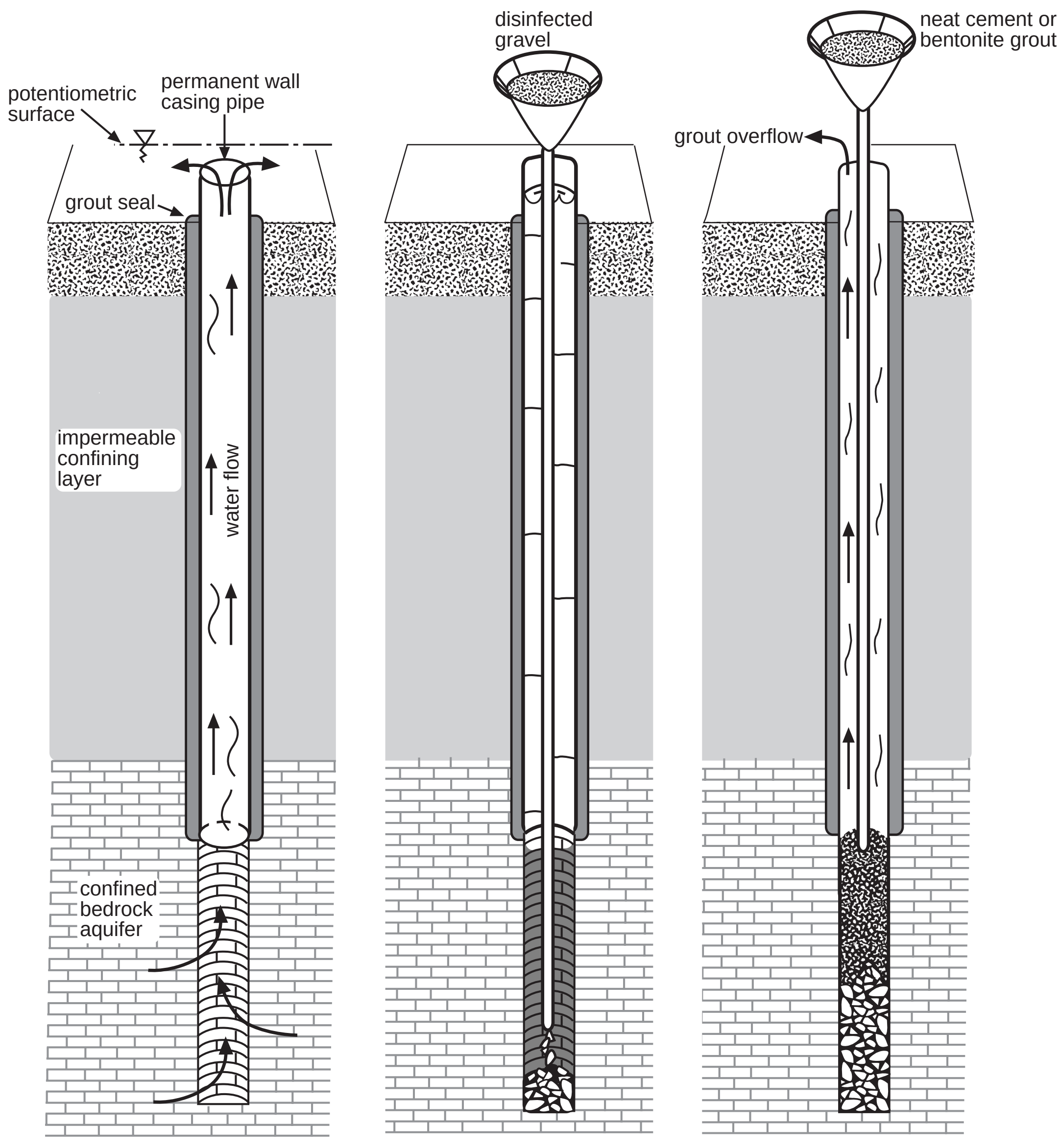


Figure O(3). Pouring disinfected gravel into well to reduce flow
(After Wisconsin regulations, 1994)

formations penetrated, gravel fill can be used in the water-bearing zones, while an impermeable sealing material (bentonite or cement) can be used to seal the confining layers. An impermeable material also can be used as a seal from the top of the uppermost aquifer to the surface. Any remaining casing should then be cut off three to four feet below the ground surface, and the resulting excavation should be filled with clean soil and mounded. Refer to Figure N for details on these sealing methods.

Sealing Wells Drilled Through Fractured or Cavernous Formations

Once initial issues of obstructions, casing, and disinfection have been taken care of, the next step is to try to determine the depth(s) at which the fractured or cavernous zones occur. During sealing, a plug may be placed above the cavernous interval, and then the well may be pressure grouted with cement or bentonite slurry from the top of the plug to the ground surface. A well with a highly fractured zone of known depth could be sealed in the same manner (Figure P). The well could be filled with coarse gravel to the top of the fractured or cavernous zone, and then pressure grouted from the top of that zone to the ground surface (no plug would be needed above the gravel fill) if the fractured or cavernous zone is not extensive. The casing should be cut off three to four feet below the ground surface, and the remaining hole filled with clean soil and mounded, to complete the sealing process.

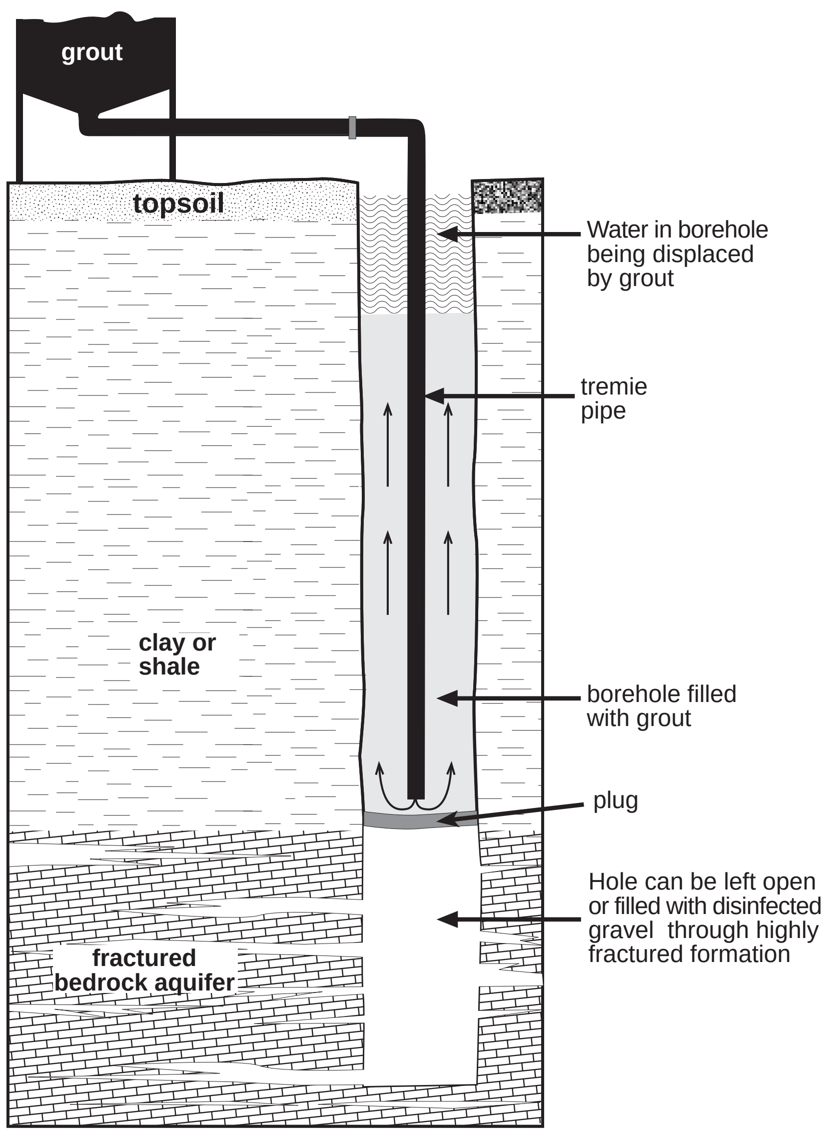


Figure P. Sealing procedures for wells penetrating fractured or cavernous formations

Sealing Flowing Wells Drilled Through Single or Multiple Consolidated Aquifers

Flowing wells drilled through consolidated aquifers can be sealed in the same manner as wells drilled through confined, unconsolidated aquifers. Please refer to the procedures in that section for well sealing information.

Sealing Wells of Unknown Construction

After any obstructions have been removed, the casing should be left in place due to the lack of information on the construction details of the well. Disinfect the well, then attempt to determine the depth of the well. The well should be pressure grouted from bottom to top with bentonite or cement slurry if the depth of the well is 300 feet or less, and the diameter is twenty four inches or less. Wells greater than 300 feet in depth should be pressure grouted as well, but specialized equipment may be required to pump grout to these depths.

The casing should be cut off three to four feet below ground surface. The remainder of the well should be filled with clean soil and mounded at ground surface.

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 Water. A summary of all the well sealing procedures discussed in this section can be found in Table 5.

Conclusions

Unsealed or improperly sealed abandoned wells present a very real threat to the quality of ground water in Ohio. With potentially as many as 200,000 existing abandoned wells scattered across the state, it is apparent that steps must be taken now 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.

Table 5 Summary of Recommended Well Sealing Procedures

WELL TYPE		MATERIALS							METHOD OF INSTALLATION
		Clean fill		Concrete	Neat cement slurry	Coarse grade bentonite		Bentonite slurry w/70 second viscosity	
		Gravel and/or sand	Clay			Chips	Pellets		
UNCONSOLIDATED FORMATION(S)	Dug & bucket-drilled wells >24" in diam. and ≤ 25' in depth	No	Yes-to static level[1]	No	Yes	Yes	Yes	No	Material may be poured into well
	Driven wells	No	No	No	Yes	Yes[5]	Yes[5]	Yes	Slurry must be tremied, coarse grade bentonite must be slow-poured[2]
	Wells drilled through single aquifer ≤ 24" in diam., >25' deep	Yes- to top of aquifer or 25' below ground surface[3]	No	No	Yes	Yes[2]	Yes[2]	Yes	Slurry must be tremied, gravel may be poured, coarse grade bentonite must be slow-poured
	Wells drilled through multiple aquifers ≤ 24" in diam., >25' deep	Yes[4]	No	No	Yes	Yes[2]	Yes[2]	Yes	Slurry must be tremied, coarse grade bentonite must be slow-poured
	Flowing wells drilled through single or multiple aquifers	No[7]	No	Yes	Yes	Yes[6]	Yes[6]	Yes	Slurry must be tremied
CONSOLIDATED FORMATION(S)	Wells drilled through single aquifer ≤ 24" in diam., >25' deep	Yes-to top of aquifer or 25' below ground surface[3]	No	No	Yes	Yes[2]	Yes[2]	Yes	Slurry must be tremied, gravel poured, coarse grade bentonite must be slow-poured
	Wells drilled through multiple aquifers ≤ 24" in diam., >25' deep	Yes[4]	No	No	Yes	Yes[2]	Yes[2]	Yes	Slurry must be tremied, gravel poured, coarse grade bentonite slow-poured
	Wells drilled through fractured or cavernous formations	Yes- through fractured or cavernous zones only	No	Yes	Yes-from top of plug or cavern fill to surface	Yes-from top of plug or cavern fill to surface	Yes-from top of plug or cavern fill to surface	Yes-from top of plug or cavern fill to surface	Slurry must be tremied, gravel only (no sand should be used) poured, coarse grade bentonite slow-poured
	Flowing wells drilled through single or multiple aquifers	No[7]	No	Yes	Yes	Yes[6]	Yes[6]	Yes	Slurry must be tremied
Drilled wells of unknown construction		No	No	No	Yes	No	No	Yes	Slurry must be tremied
Any wells >24" in diam. and >25' deep		Yes[4]	No	No	Yes	Yes[2]	Yes[2]	Yes	Slurry must be tremied, chips and pellets must be slow-poured and tamped periodically

[1] The clay fill must be topped with a 1ft. thick layer of bentonite or cement extending 6" beyond the original outside diameter of the well.
[2] The bentonite chips or pellets 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. Pellets should be used in wells no deeper than 100 feet, chips in wells no deeper than 200 feet. These products should be tamped periodically and hydrated if they are placed above the water table, or if the well is dry. The diameter of the well must be 4" or greater.
[3] The well should then be filled to the surface with cement or bentonite products.
[4] Gravel and/or sand may be used in aquifer zones provided there is an impermeable plug of bentonite or cement placed between these zones, and from the top of the uppermost zone to the surface.
[5] Coarse grade bentonite may be used in wells 25 feet deep or less as long as it is tamped periodically. Wells deeper than 25 feet must be sealed with a tremied slurry.
[6] Coarse grade bentonite may be used if flow has been stopped by casing extension and products are able to fall to the bottom of the well. Well should be 200 feet deep or less, and at least 4 inches in diameter.
[7] Gravel may be used in flowing wells only to slow flow enough to allow grouting to proceed.

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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.
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.
Borehole	a hole in the earth made by a drill; the uncased drill hole from the surface to the bottom of the 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.
Cistern	a large receptacle used for storing water, especially an underground tank in which rainwater is collected.
Confining bed	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 volume, usually expressed in grams per cubic centimeter.
Drill rod	the extension rods used to attach the bit to the drilling rig to enable the penetration into the earth.
Drill 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.
Drill 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.
Formation	a body of consolidated or unconsolidated rock characterized by a degree of lithologic homogeneity which is prevailingly, but not necessarily, tabular and is mappable on the earth’s surface or traceable in the subsurface.
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.
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.
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.
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.
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.
Pitless adapter	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.
Plasticity	the capability of being deformed permanently without rupture.
Pore	a tiny opening, usually microscopic, in consolidated or unconsolidated materials.
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.
Static level	the distance measured from the established ground surface to the water surface in a well being neither pumped nor under the influence of pumping nor flowing under artesian pressure.
Stratigraphic	the arrangement of consolidated and unconsolidated strata.
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.
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 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.
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, 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. Samples must be collected by an ODA inspector to protect sample integrity, and then analyzed at the ODA laboratory in Reynoldsburg. The Pesticide Regulation Section will investigate to determine how the well was contaminated if a water sample is positive for a pesticide. 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 Commerce, Division of State Fire Marshal, Bureau of Underground Storage Tank Regulations (BUSTR)

In the event that any potable or non-potable water well is suspected of being contaminated with petroleum from a leaking petroleum underground storage tank (such as those used at gas stations), contact BUSTR at 1-800-686-2878 before sealing the well.

Ohio Department of Health, Division of Quality Assurance

For information on specific regulatory requirements for sealing private wells, or for questions about possible contamination with substances other than pesticides or petroleum products, contact the local health department or the Ohio Department of Health Private, Water System Program (PWSP) at 614-466-1390.

To determine the registration status of a particular private water system contractor (i.e., drilling contractor or pump installer), contact the local health department or the ODH-PWSP Public Inquiries Assistant at 614-466-0148.

Ohio Department of Natural Resources, Division of Mines & Reclamation

The Division of Mines and Reclamation regulates the abandonment of test borings for coal and industrial minerals exploration through the permitting process under the Ohio Revised Code Chapter 1513 and 1514. Most exploratory borings are mined through 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 complaints related to coal and industrial minerals mining activities.

Ohio Department of Natural Resources, Division of Oil & Gas

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 614-265-6926.

Ohio Department of Natural Resources, Division of Water

The Ohio Revised Code, Section 1521.05, requires that a well sealing report be filed with the Division of Water for all wells sealed in the State of Ohio. Copies of the well sealing report can be obtained from the Division by calling 614-265-6739. 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

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 614-644-2905. Specific requirements must be followed for the sealing of injection wells.

Appendix 2

Cost Considerations

When obtaining estimates for well sealing from local drilling contractors, it is necessary to understand upon what the contractor's price will be based. As seen in the guidelines, there are many steps in sealing a well properly. The preliminary steps, which involve researching the history of the well by obtaining a well log and drilling report or talking to neighbors, can be done by the well owner. However, except perhaps in the case of shallow dug wells, the remaining steps of the sealing process should be handled by a registered drilling contractor with experience in sealing abandoned wells.

The contractor must consider many factors in order to provide the best estimate possible. Besides the cost of the materials used to seal the well, the contractor must also consider the cost of the labor and equipment used to install them. For example (brand names used in this section are for illustrative purposes only and do not imply an endorsement of any particular product), most contractors can currently buy a bag of Benseal (a granular bentonite product installed in slurry form) from their supplier for approximately $7 per bag. The contractor must then add the cost of labor for installing the Benseal, the cost of the pumping equipment, and the cost of the polymer mixed with the Benseal. This will raise the price per bag of Benseal to approximately $75 per bag, installed. Multiply this by the 5 bags it takes to seal a 100 foot deep, 6 inch diameter well (see Table 6, and note that the number of bags required has been rounded up to the nearest whole bag), and the result is an estimate of $375. Or, suppose the well is to be sealed with a neat cement slurry. The installed price of cement slurry per bag is about $30. To seal the same well cited above, it will cost almost $480 because it will take nearly 16 bags of cement to fill the well (Table 6). These prices will probably not reflect the removal of any obstructions from the well, such as pumping equipment, the disinfection of the well, or removing, perforating, or cutting off the casing. These are all factors that will affect the contractor's estimate.

Another commonly used well sealing material is coarse grade bentonite, which consists of chips of bentonite ranging from $^3/_8$" to $^3/_4$" in size. Coarse grade bentonite is poured into the well, not pumped like a slurry. Therefore, the equipment and labor costs are lower. Assume that Holeplug is to be used to seal a 100 foot deep, 6 inch diameter well. Most contractors could probably purchase Holeplug from their suppliers for about $7 per bag. Add labor to install the Holeplug, and the price is raised to approximately $15 per bag. However, it will take almost 29 bags of Holeplug (Table 6) to fill the well. The result is a cost estimate of $435. Then, any of the factors mentioned in the previous discussion could add to this cost.

In some cases, more than one type of material may be used to seal the well. If the well to be sealed penetrates a highly fractured bedrock formation, such as limestone, the contractor may wish to fill the fractured portion of the well with gravel or aggregate, then finish the sealing process with a cement or bentonite slurry or a coarse grade bentonite product. Table 6 shows volumes of a standard size aggregate required to fill wells of varying depths and diameters. One cubic yard (27 cubic feet) of #8 aggregate (roughly $^3/_8$" in size) averages about $16. With labor included the cost averages $40. Keep in mind that the well should not be filled entirely with this aggregate. There must be impermeable material between the top of the aggregate layer and the ground surface. This type of sealing procedure should be used only under certain geologic conditions.

The most costly factor in sealing a water well is removing or perforating the casing. Depending upon the equipment used to remove or perforate the casing and the hours of labor involved in the process, the cost of the well sealing operation could be increased anywhere from $200 to $500. Some of the other factors, such as removing existing pumping equipment and cutting off the casing below ground surface, also may be labor intensive if any difficulties are encountered. This too will add to the total sealing price.

Obviously, there are many factors to be considered when a contractor provides an estimate for sealing a well. By being aware of these factors, the well owner can ask the contractor intelligent questions and be involved in the estimation process. This also will give the well owner a basis for evaluating different estimates to determine which contractor to hire to do the job.

Hole Diameter Inches	Gallons Per Foot	Gallons to be Plugged in 100'well	Bags Required to Plug a 100 ft Well*			Hole Volume Cu Ft/Ft depth	Feet Filled by One Bag of Holeplug	Bags of Holeplug to Fill 100' Well*	Cu Ft of #8 Aggregate to Fill a 100' Well
			Benseal	Enviroplug	Neat Cement				
2	0.17	17	1	1	2	0.022	31.30	4	2.2
3	0.38	38	2	2	4	0.049	14.30	7	4.9
4	0.67	67	3	3	7	0.087	7.90	13	8.7
5	1.00	100	4	5	11	0.136	5.10	20	13.6
6	1.51	151	5	7	16	0.196	3.50	29	19.6
7	2.05	205	7	10	22	0.267	2.60	39	26.7
8	2.70	270	9	13	28	0.349	2.00	51	34.9
9	3.40	340	11	16	35	0.442	1.60	64	44.2
10	4.20	420	13	19	44	0.545	1.30	79	54.5
11	5.00	500	16	23	52	0.660	1.10	95	66.0
12	6.00	600	19	27	62	0.785	0.89	113	78.5
15	9.50	950	30	43	98	1.227	0.57	177	122.7
18	13.60	1360	42	61	140	1.767	0.39	255	176.7
20	16.80	1680	52	75	173	2.181	0.32	315	218.1
25	26.00	2600	80	117	267	3.409	0.20	491	340.9
30	38.00	3800	117	170	390	4.909	0.14	707	490.9
60	152.00	15200	468	679	1559	20.322	0.04	2500	2032.2

* Number of bags has been rounded up to the next whole bag.

Yield Calculations:

Neat Cement: One 94 lb bag plus 6 gallons of water equals 9.75 gallons of grout
Benseal: One 50 lb bag plus 10 oz. of E-Z Mud plus 30 gallons water equals 32.5 gallons of grout
Enviroplug: One 50 lb bag plus 2.5 lb of activator plus 20 gallons of water equals 22.4 gallons of grout

Holeplug is a granular bentonite product, $^3/_8$"– $^3/_4$" in size that is poured, not pumped, into a well.

Table based on product information published by NL Baroid, Wyo-Ben. Inc., and Chemgrout Inc.

Table 6 Table Comparing Volumes of Different Well Sealing Materials Required to Seal a 100 Foot Well

Appendix 3

List of Acronyms

ASTM	-	American Society for Testing and Materials
API	-	American Petroleum Institute
BUSTR	-	Bureau of Underground Storage Tank Regulations
DDAGW	-	Division of Drinking and Ground Waters
EPA	-	Evironmental Protection Agency
OAC	-	Ohio Administrative Code
ODA	-	Ohio Department of Agriculture
ODH	-	Ohio Department of Health
ODNR	-	Ohio Department of Natural Resources
ORC	-	Ohio Revised Code
PWSP	-	Private Water System Program
UIC	-	Underground Injection Control

Appendix 4

Sealing Monitoring Wells and Boreholes[1]

Boreholes that are not completed as monitoring wells and monitoring wells that are no longer being sampled or used for ground water level measurements must be sealed properly to: 1) prevent poor quality water from one saturated zone entering another, 2) prevent contamination of the ground water by surface contaminants, 3) restore an aquifer to as close to its original condition as possible, 4) eliminate physical hazards, and 5) reduce potential for future liability. A suitable program should be designed and implemented to meet these objectives.

The sealing material and the method of sealing depend on: 1) the design and construction of the well/borehole, 2) hydrogeologic conditions, 3) chemical environment, 4) safety hazards and 5) disposal of contaminated materials removed. In general, well sealing should consist either of a method for well removal and simultaneous grouting of the borehole with bentonite, neat cement, or a method for grouting in-place that ensures complete sealing.

Sealing Materials

The chosen sealing material should:

- Not react with contaminants, ground water, or geologic materials.
- Have a hydraulic conductivity comparable to or lower than that of the in-situ material.
- Form a tight bond with the borehole wall and the casing.
- Be resistant to cracking and/or shrinking.
- Be of sufficient structural strength to withstand subsurface pressures.
- Be capable of being placed at the appropriate depth.

No single material will exhibit all of the characteristics mentioned above. Therefore, every situation must be evaluated carefully to determine the appropriate choice. Generally, materials used are comprised of concrete, neat cement, or sodium bentonite.

Most wells completed in unconsolidated formations or non-creviced rock may be satisfactorily sealed with neat cement or bentonite. Wells that penetrate limestone or other creviced or channeled rock formations should be filled with concrete grout or neat cement to ensure seal permanence. The use of fine-grained materials to seal creviced rock may not be desirable because the materials might be displaced by flow of water through crevices (American Water Works Association, 1984). Neat cement or sodium bentonite should be used for sealing an abandoned well/borehole below the water table (Gordon, 1988). Pure sodium bentonite placed above the water table should be hydrated if it is not installed in slurry form due to the lack of water for hydration of pellets or chips. At no time should a borehole or well be backfilled with cuttings or with any materials of unknown integrity. However, in some geologic environments, such as coarse gravel, where excessive loss of sealing materials may occur, or when grout may affect the water quality of nearby monitoring wells, clean sand or gravel in conjunction with regular materials can be used (Gordon, 1988; Kraemer et al., 1991).

Procedures

Planning

Careful review should be conducted prior to sealing monitoring wells. This may include:

- Review of records pertaining to well construction and repair or modifications.
- Review of all analytical chemical data for soil and ground water.
- Review of the hydrogeologic/geologic characteristics in the vicinity of the well.
- Current conditions of the well such as total depth, amount of siltation, etc.

[1] The information in this section is from Chapter 9 of the Ohio Environmental Protection Agency's "Technical Guidance Manual for Hydrogeologic Investigations and Ground Water Monitoring", 1995.

If a well is to be left in place, borehole geophysical techniques may be helpful in determining its integrity. This may include caliper logs to measure inside diameter; television logs to identify casing breaks, screen size, etc.; gamma logs to verify geologic information; cement bond logs to determine if the casing is firmly attached to the grout; flow logs to determine if vertical flow occurs within the casing; and hydraulic integrity tests to determine if the casing is intact (ASTM, 1993).

Prior to the sealing of monitoring wells, it is recommended that a work plan detailing the procedures/methods be submitted to the appropriate regulatory authority[2]. The information should include:

- Reasons for sealing.
- Identification and location coordinates.
- Casing diameter and material.
- Screen material, length, and depth.
- Total depth.
- Geologic materials opposite well screen.
- Drilling log and construction diagrams.
- Type and concentrations of contaminants present[3], if any.
- Procedure for disposal of any contaminated soil, well construction material, and water.
- Method for sealing.
- Type of sealing material.
- An estimation of the volume of sealing material needed.
- Measures to protect the health and safety of individuals.

Field Procedure

Monitoring wells have often been sealed by pulling the surface casing where possible, followed by pouring cement or bentonite into the hole. This procedure is inappropriate, especially if the construction of the well is unknown or the well intake spans more than one saturated zone. Incomplete seals may form due to bridging. Additionally, the procedure has little effect on the filter pack, which may allow communication between saturated zones.

The following basic procedure is recommended for sealing monitoring wells and boreholes. Steps 1 and 2 are not necessary for sealing exploratory boreholes. It should be understood that no single method and material are suitable for all situations. Site-specific characteristics may merit modifications or procedures not discussed below. Additional information can be found in the references listed.

1. 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.

2. Since the primary purpose of sealing is to eliminate vertical fluid movement, it is strongly recommended that the casing and screen be removed and the boring be overdrilled to remove the annular seal and filter pack, unless it can be determined that the original grout seal is intact. When the well is removed, there is less concern about channeling in the annular space or an inadequate casing/grout seal (Aller et al., 1991). 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. The method used should depend on the type, length, and diameter of the casing, conditions of the annular seal, and site geology. Aller et al. (1991) and ASTM 5299-92 provided a discussion on various removal techniques. The borehole should be overdrilled using a bit with a diameter at least $1\frac{1}{2}$ times greater than the original diameter of the borehole. Drilling should

[2] If a regulated entity is conducting a hydrogeologic investigation or a ground water monitoring program, a well sealing work plan should be submitted prior to initiating the program. In this situation, a separate workplan is not necessary.

[3] If contamination was detected or suspected in the original well or boring, appropriate health and safety requirements should be followed.

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 problems occur, or when dealing with large diameter wells, casing removal can be difficult. If the well construction is known, the screen and filter pack do not span more than one saturated zone, and circumstances prevent complete removal of casing and screen, then the following procedure can be used (based on Renz, 1989):

a. The well can be filled with clean silica sand to one foot above the screen in the event that the screened area is adjacent to a highly permeable formation.

b. One foot of bentonite pellets can be placed above the screen in a manner that prevents bridging (i.e., through a tremie pipe or by tamping after installation).

c. The pellets should be hydrated.

d. 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 retractable blade (steel casing).

3. 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 in constant contact with 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. When the observed material is similar to that being pumped in, this stage of the sealing is considered complete. Wells sealed in-situ should be sealed from the bottom up to approximately five feet from the surface.

4. The grout plug should be inspected 24 hours after installation to check for settling and grout should be added if needed. If the well is sealed in place, the casing should be cut off approximately five feet below ground level and a PVC or stainless steel cap should be emplaced. The boring should be grouted to within two to three feet from the surface with appropriate material. 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).

5. The remaining area above the plug should be completed in a manner that is compatible with the site. For example, its top can be covered with one to two feet of soil if vegetative growth is desired. If the area is to be surfaced, then the final seal can be completed with cement or concrete.

6. Proper sealing of monitoring wells should be documented and reported to the implementing regulatory agency managing the site. The information should include, at a minimum:

- Identification (e.g. registration number, location, owner, other features).
- Well construction details.
- Date, time, person responsible, and contractor/consultant performing the work.
- Authority under which the sealing was performed.
- Procedures and materials used.
- Method/procedures for disposal of any contaminated materials.

Additionally, Ohio Revised Code 1521.05(B) requires that a well sealing report be filed with the Ohio Department of Natural Resources (ODNR) on forms supplied by the Department. Figure A is an example of this form. It can be obtained from ODNR, Division of Water (614-265-6739).