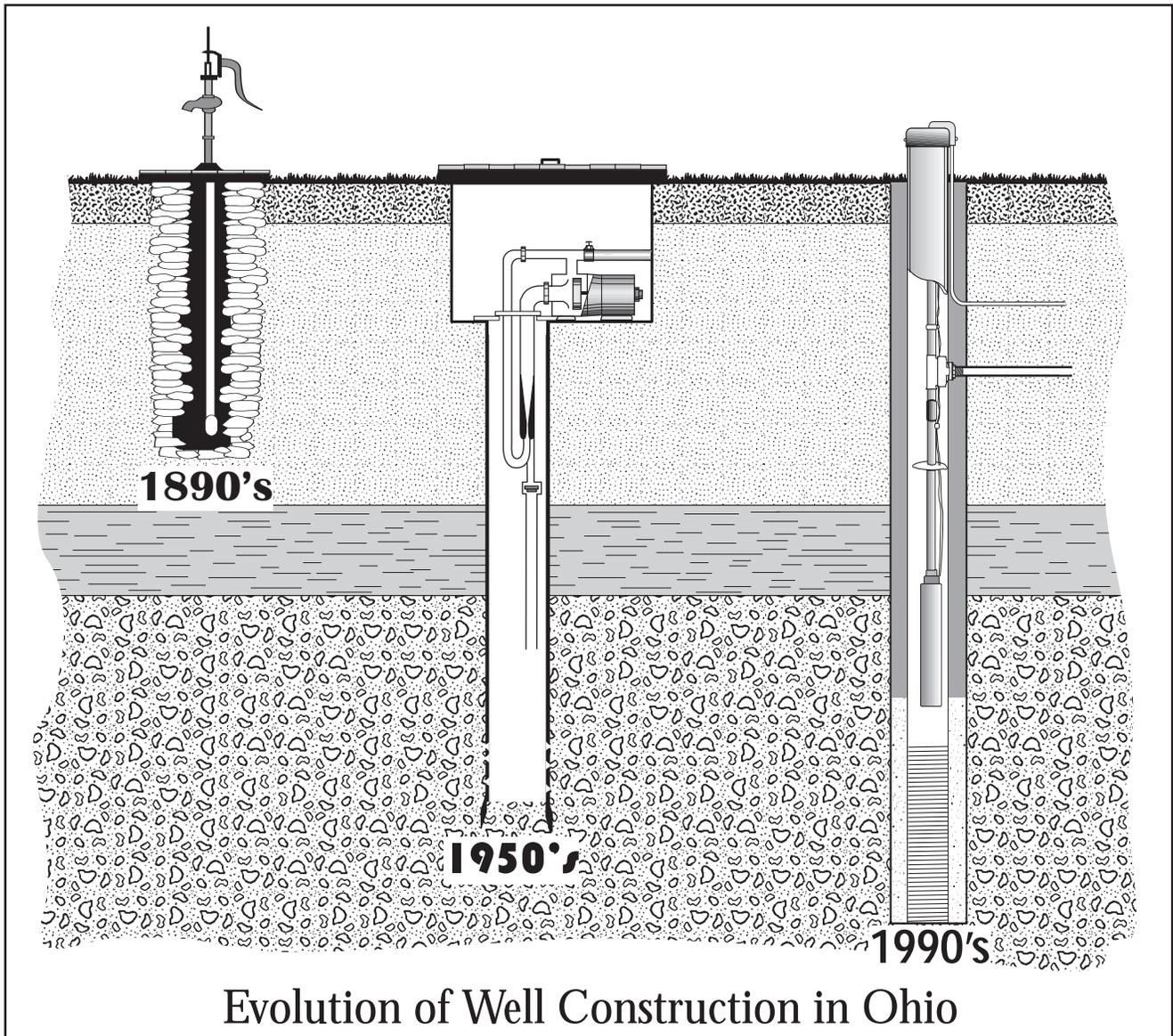


State of Ohio

# Technical Guidance for Well Construction and Ground Water Protection



by the  
**State Coordinating Committee on Ground Water**  
2000

**STATE OF OHIO**  
**TECHNICAL GUIDANCE FOR WELL CONSTRUCTION AND**  
**GROUND WATER PROTECTION**

**BY THE**  
**STATE COORDINATING COMMITTEE ON GROUND WATER**  
**2000**

# Table of Contents

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<b>Table of Contents</b> .....	<b>ii</b>
<b>List of Figures</b> .....	<b>v</b>
<b>List of Tables</b> .....	<b>vi</b>
<b>Preface</b> .....	<b>vii</b>
<b>Acknowledgements</b> .....	<b>viii</b>
<b>Introduction</b> .....	<b>1</b>
Purpose of the Guidance .....	1
Definitions .....	2
Existing Regulations .....	2
Siting Considerations .....	3
Sanitary Isolation .....	6
Areas of Known Contamination .....	7
Proximity to Surface Water .....	7
Sole Source Aquifers and Wellhead Protection .....	8
Well Construction Materials and Equipment .....	8
Materials Used In The Drilling Process .....	8
Materials Used To Construct A Well .....	9
Well Construction Procedures .....	12
General Procedures .....	12
Geological Considerations .....	16
Unconsolidated Formations .....	16
Wells Developed in Consolidated Formations .....	18
Wells Developed in Unconfined Aquifers .....	18
Wells Developed in Confined Aquifers .....	19
Wells Penetrating Multiple Aquifers .....	20
Special Geologic Conditions .....	20
Flowing Wells .....	20
Cavernous or Highly Fractured Formations .....	22
Mine Shaft/Abandoned Mine Wells .....	22
Brine-Producing Formations .....	26
Gas-Producing Formations .....	26
Well Development Procedures .....	26
Mechanical Techniques .....	27
Chemical Techniques .....	29
Well Testing .....	29
Testing For Quantity .....	29
Guidelines For Quantity Testing Requirements .....	30
Testing For Quality .....	32
Chemical sampling .....	33
Well Completion .....	33
Well Disinfection .....	35
Well Maintenance .....	36
Well Alterations .....	37
Reporting Requirements .....	38
Temporary Wells and Other Types of Subsurface Installations .....	38
Dewatering Wells .....	39
Test Borings .....	39
Geothermal Wells .....	39
Cathodic Protection and Ground Wells .....	39
Elevator Shafts .....	39
Conclusions .....	39
<b>References</b> .....	<b>41</b>

# Table of Contents *continued*

Listing of American Society for Testing and Materials (ASTM) Standards Referenced .....	44
Listing of American Petroleum Institute (API) Standards Referenced .....	44
Listing of National Sanitation Foundation (NSF) Standards Referenced .....	44
Listing of Water Systems Council Standards Referenced .....	44
<b>Glossary .....</b>	<b>45</b>
<b>Appendix I Well Drilling Methods Used in Ohio .....</b>	<b>48</b>
<b>Appendix II Grouting Materials .....</b>	<b>50</b>
Cement-Based Grouts .....	50
Cement Properties .....	50
Cement Types .....	50
Neat Cement Grout .....	52
Concrete Grout .....	52
Other Cement Additives .....	53
Bentonite-Based Grouts .....	53
Clay Properties .....	53
Properties of Bentonite/Water Slurries .....	53
High-Solids Bentonite Grout .....	54
Powdered Bentonite/Clay Grout .....	54
Granular Bentonite .....	55
Coarse Grade Bentonite .....	55
Pelletized Bentonite .....	55
<b>Appendix III Well Quantity Testing .....</b>	<b>58</b>
Quantity Testing Methodology .....	58
Electrical tape method .....	58
Wetted tape method .....	58
Airline method .....	58
Flow Rate Measurement .....	59
Circular orifice weir .....	59
Commercial water meters .....	59
Container/timed method .....	60
Weirs and flumes .....	60
Simple Tests To Estimate Well Yield .....	60
Bailing test method .....	60
Air blow test method .....	61
Air lift test method .....	61
Variable pumping rate method .....	61
Pumping Test To Evaluate Well Performance .....	61
Step-drawdown tests .....	61
Constant rate tests .....	62
Preparation .....	62
Test Rate .....	62
Test Duration .....	62
Recovery Data .....	62
Pumping Tests To Evaluate Aquifer Characteristics .....	62
Data Collection And Record Keeping .....	63
<b>Appendix IV Water Sample Collection .....</b>	<b>65</b>
Coliform bacteria sampling .....	65
<b>Appendix V Well Disinfection .....</b>	<b>67</b>
Disinfection of a Drilled Well .....	67
Calculation and Examples .....	67
Disinfection of a Dug or Bored Well .....	68
<b>Appendix VI Monitoring Well Design and Installation .....</b>	<b>70</b>
Design of Multiple-Interval Systems .....	70
Well Clusters .....	70

## Table of Contents *continued*

Multi-Level Wells .....	70
Nested Wells .....	71
Single Riser/Flow-Through Wells .....	71
Casing .....	71
Casing Types .....	71
Fluoropolymers .....	71
Metallics .....	72
Thermoplastics .....	72
Type Selection .....	73
Hybrid Wells .....	73
Coupling Mechanisms .....	74
Diameter .....	74
Installation .....	75
Intakes .....	75
Filter Pack .....	75
Types of Filter Packs .....	75
Nature of Artificial Filter Pack Material .....	75
Dimension of Artificial Filter Pack .....	76
Artificial Filter Pack Installation .....	77
Screen .....	78
Screen Types .....	78
Slot Size .....	78
Length .....	78
Open Borehole Intakes .....	79
Annular Seals .....	79
Materials .....	80
Neat Cement Grout .....	80
Bentonite .....	81
Seal Design .....	81
Seal Installation .....	81
Surface Seal/Protective Casing Completions .....	82
Surface Seal .....	82
Above-Ground Completions .....	82
Flush-to-Ground Completions .....	82
Documentation .....	83
Maintenance .....	84
<b>Appendix VII Contact Agencies .....</b>	<b>85</b>

# List of Figures

---

Figure 1. Example of a completed well log and drilling report. ....	4
Figure 2. Example of a completed well sealing report. ....	5
Figure 3. Examples of recommended well construction using cable tool drilling methods. ....	14
Figure 4a. Example of recommended rotary-drilled well construction for wells developed in unconsolidated formations—total annular space 2 inches or more. ....	15
Figure 4b. Example of recommended rotary-drilled well construction for wells developed in consolidated formations—total annular space 4 inches or more. ....	15
Figure 5. Example of well construction using hollow stem augers. (Modified from Hackett, 1987 and 1988) ....	16
Figure 6. Example of recommended driven well construction. ....	16
Figure 7. Grouting the annular space of wells with coarse grade bentonite products using the pouring method. (Modified from Wisconsin Department of Natural Resources, 1993) ....	18
Figure 8. Confined and unconfined aquifers. (After U.S. Department of Interior, 1997) ....	19
Figure 9a. Recommended well construction for wells penetrating multiple unconsolidated aquifers. ....	21
Figure 10a. Rotary method for flowing well construction—confined bedrock aquifer with an unconsolidated confining bed. ....	22
Figure 10b. Cable tool method for flowing well construction—confined bedrock aquifer with an unconsolidated confining bed. ....	22
Figure 11a. Rotary method for flowing well construction where both confining bed and aquifer are unconsolidated—double casing construction. ....	25
Figure 11a. Cable tool method for flowing well construction—confined unconsolidated aquifer with an unconsolidated confining bed. ....	25
Figure 12. Recommended grouting procedures for wells penetrating fractured or cavernous formations. ....	25
Figure 13. Recommended grouting procedures for wells penetrating fractured or cavernous formations where an upper fractured or cavernous zone has been sealed off. ....	25
Figure 14. Example of pitless adapter installation. ....	33
<b>Appendix III Well Quantity Testing</b> .....	<b>58</b>
Figure 1. Example of airline setup and operation. ....	59
Figure 2. Detail of orifice weir construction. ....	61
<b>Appendix VI Monitoring Well Design and Installation</b> .....	<b>70</b>
Figure 1. Cross-section of a typical single-riser/limited interval monitoring well. ....	70
Figure 2. Artificial filter pack design criteria (Source: Design and Installation of Ground Water Monitoring Wells by D.M. Nielsen and R. Schalla, Practical Handbook of Ground Water Monitoring, edited by David M. Nielsen, Copyright 1991 by Lewis Publishers, an imprint of CRC Press, Boca Raton, Florida. With permission.) ....	77
Figure 3. Selection of screen slot size based on the filter pack grain size. (Source: Design and Installation of Ground Water Monitoring Wells by D.M. Nielsen and R. Schalla, Practical Handbook of Ground Water Monitoring, edited by David M. Nielsen, Copyright 1991 by Lewis Publishers, an imprint of CRC Press, Boca Raton, Florida. With permission.) ....	79
Figure 4. Tremie pipe emplacement of annular seal material. (Source: Design and Installation of Ground Water Monitoring Wells by D.M. Nielsen and R. Schalla, Practical Handbook of Ground Water Monitoring, edited by David M. Nielsen, Copyright 1991 by Lewis Publishers Division, an imprint of CRC pressPress, Boca Raton, Florida. With permission.) ....	82
Figure 5. Typical flush-to-ground monitoring well completion. (Source: Design and Installation of Ground Water MonitoringWells by D.M. Nielsen and R. Schalla, Practical Handbook of Ground Water Monitoring, edited by David M. Nielsen, Copyright 1991 by Lewis Publishers Division, an imprint of CRC Press, Boca Raton, Florida. With permission.) ....	83

# List of Tables

---

Table 1. Common Uses for Water Wells .....	3
Table 2. Well Use Classification .....	31
Table 3. Volume of Water in Well .....	37
Table 4. Amount of Chlorine Added to 100 Gallons of Water for Disinfection .....	37
<b>Appendix II Grouting Materials .....</b>	<b>53</b>
Table 1. Grout Properties .....	51
Table 2. Permeability of Various Sealing Materials .....	51
Table 3. Cement Curing Time Required .....	51
Table 4. Grout Slurry Densities .....	55
<b>Appendix III Well Quantity Testing .....</b>	<b>64</b>
Table 1. Estimating Water Usage .....	64
<b>Appendix V Well Disinfection .....</b>	<b>7</b>
Table 1. Volume of Water in Well .....	67
Table 2. Amount of Chlorine Added to 100 Gallons of Water for Disinfection .....	67
Table 3. Quantity of Bleach for a Bored or Dug Well (1000 ppm) .....	68
<b>Appendix VI Monitoring Well Design and Installation .....</b>	<b>73</b>
Table 1. Common filter pack characteristics for typical screen slot sizes. (From Nielsen and Schalla, 1991) .....	77
Table 2. ASTM Cement Designation (modified from Gaber and Fisher, 1988) .....	80

# Preface

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In early 1992, the 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 lack of consistent standards and regulations regarding the construction of wells and test borings was identified as a major issue of concern by the Committee. This issue was also raised during discussions between the drilling industry, represented by the Ohio Water Well Association and the Private Water Systems Workgroup, which formed to address issues related to private water systems. The Ohio Water Well Association also identified the need for consistent well construction standards across state agency programs and the need for regulation of nonpotable wells. Due to increasing concerns by many of the participating state agencies and the well drilling industry, the widespread acceptance of the Technical Guidance Document for Sealing Unused Wells published in May, 1996, and efforts by the Ohio Department of Health to implement improvements in the private water systems program, the Committee decided to form a subgroup in June, 1996 to develop consistent technical standards for the construction of wells and test borings. Both the Ohio Environmental Protection Agency and the Ohio Department of Health have committed to revising their rules regarding well construction to be consistent with the resulting new technical guidance document. The Well Construction Workgroup began meeting in July, 1996; what follows is the product of 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

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The preparation of the State of Ohio Technical Guidance for Well Construction and Ground Water Protection involved the contribution and hard work of a number of individuals on the Well Construction Standards Workgroup of the State Coordinating Committee on Ground Water. The development of this technical guidance was supported by the state agencies participating on the Committee. Grateful thanks and acknowledgement is given to the committee members who dedicated many hours in workgroup meetings, and their time, expertise, and assistance in authoring and reviewing this document. The workgroup would also like to thank the many industry professionals who took the time to participate in the meetings, or to review and provide comments on this document. Special appreciation and acknowledgement is given to Katherine Sprowls for her work on organizing and editing this guidance, and to David Orr for his work and assistance on preparing the figures, desktop publishing, and printing of this document.

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Ohio Department of Health  
Ohio Department of Agriculture  
Public Utilities Commission of Ohio  
Ohio Department of Commerce - State Fire Marshal  
Ohio Department of Development  
Ohio Department of Transportation  
United States Geological Survey  
Natural Resource Conservation Service

–*Rebecca Petty*

# Introduction

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The state of Ohio currently estimates that over 1 million potable and non-potable water wells and test borings have been drilled statewide. Records regarding the construction and location of these wells are filed with the Ohio Department of Natural Resources (ODNR), Division of Water. Based on the well log filing data, approximately 80% of these wells are used for drinking water and are regulated under the Private Water Systems Program at the Bureau of Local Services, Ohio Department of Health (ODH), or the Public Water Supply Program regulated by the Division of Drinking and Ground Waters, Ohio Environmental Protection Agency (OEPA). The remaining 20% of the well logs filed each year represent wells drilled for non-potable water supply. Currently, there are no regulations for well construction or sealing of unused non-potable wells.

State agencies in conjunction with private industry associations have developed several strategies and water plans that identify the need to establish statewide consistent construction standards for water wells. The Ohio Ground Water Protection and Management Strategy (1985) and Ohio's Water, Ohio's Future (1994) both identify the need to establish consistent well construction and well sealing standards and to implement those standards through subsequent changes in the Ohio Revised or Administrative Code at the respective state agencies. In 1993, the State Coordinating Committee on Ground Water (SCCGW), identified the need for consistent water well and test boring construction and sealing regulations as one of the top priority issues to be addressed by the committee. The SCCGW developed specific recommendations regarding this issue which was forwarded to the state agency directors. As a result of these recommendations, a workgroup of the SCCGW formed to develop the State of Ohio Technical Guidance for Sealing Unused Wells (1996). The Private Water Systems Workgroup was formed in early 1995 to develop a plan to address increasing concerns regarding private water systems and non-potable wells. As a result of this workgroup's efforts, both the drilling industry and public health officials identified the need for consistent well construction standards to be developed concurrent with changes in the regulatory programs. The Well Construction Standards Workgroup was formed to identify and develop the following standards and technical information contained in this document.

## Purpose of the Guidance

The primary purpose of this guidance is to provide consistent state standards on proper well siting, construction, testing, and development/rehabilitation to ensure the protection of public health and the state's ground water resources. A poorly constructed well can provide a direct path for contaminants at the surface to migrate into the ground water. The application of consistent statewide standards by the drilling industry and the state regulatory programs, together with the proper education and support of the individual well owner, is critical to ensure the protection of the ground water resources for drinking water and other beneficial uses. Standards also help ensure that the well provides a reliable, adequate water supply for a reasonable cost, and that long-term maintenance costs are minimized. These factors become particularly important when evaluations are made regarding the economic feasibility of rural water lines and customer satisfaction with existing ground water supplies from individual wells.

The guidance is designed to be used by drilling contractors, hydrogeologists, engineers, and state and local regulatory officials for siting, constructing and developing water wells. Information on aquifer characteristics and ground water availability should be obtained prior to the design, drilling and development of the well. This information should include the aquifer lithology and thickness, depth and estimated yield, and thickness and characteristics of the vadose zone or shallow aquifers that will be penetrated. The design of the water system should also consider the maximum and peak yields required by the user or household on a daily and long-term basis. The drilling contractor, homeowner, and local or state regulatory official need to work closely together to design a water supply system that is safe, provides the maximum yield required for the intended use, and minimizes maintenance requirements while ensuring the long-term reliability of the well.

This guidance describes minimum construction standards for both permanent and temporary well installations. The guidance should be applied to all types of wells used to withdraw ground water regardless of purpose. The guidance includes a discussion of the materials used for well drilling and construction, general construction standards, and specific construction requirements under unique hydrogeologic conditions found in Ohio. The intent of this guidance is to provide a set of uniform standards combined with basic information regarding the application of the standard for well construction materials and construction methods. However, other regulatory authorities may have additional requirements not dis-

cussed in this document that are specific to their respective programs. It is the drilling contractor/well designer's responsibility to ensure that all regulatory statutes and requirements are met before the well is constructed. This document is not designed to be a comprehensive guide on well drilling and construction methods. Information regarding well drilling methods has been included in this document for reference. Additional references describing drilling methods and materials can be found in Appendices I and II. This guidance also includes standards and procedures for constructing monitoring wells which are addressed in Appendix VI.

Recommendations in this document are indented, italicized, and enclosed by lines. Each recommendation or set of recommendations is followed by additional explanatory text.

Although proper well construction is necessary to ensure the protection of ground water resources, it is equally important that any abandoned well, properly constructed or not, be properly sealed to prevent future contamination. A companion document to this guidance has been developed that provides guidance for sealing unused wells. The State of Ohio Technical Guidance for Sealing Unused Wells (1996) describes the recommended procedures, practices and materials for sealing wells that have been abandoned or are no longer used.

## Definitions

A consistent set of definitions for common terms was developed for use throughout this document to facilitate the discussion and application of the construction standards. These definitions may also be used by the regulatory agencies to help ensure uniformity in the interpretation and application of these standards across the state. Several commonly used terms are defined in the following paragraphs to help the reader clearly understand the purpose and scope of this document. Additional definitions of terms highlighted in bold throughout the document can be found in the glossary.

**Ground water** is defined as any water below the surface of the earth in a zone of saturation.

**Aquifer** means a consolidated or unconsolidated geologic formation or series of formations that is capable of receiving, storing, or transmitting water to wells or springs.

**Well** is defined as 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, excluding subsurface drainage systems installed to enhance agricultural crop production or urban or suburban landscape management or to control seepage in dams, dikes or levees; 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, excluding horizontal trenches that are installed for water source heat pump systems.

**Temporary well installation** is a boring or well that is to be installed and used for less than one year. Any well installed for a period of greater than one year should be considered a permanent installation and should follow the guidelines described in this document

Water wells are installed for a wide variety of uses. Table 1 lists common uses and types of wells. This guidance should be applied to all of the wells listed in Table 1. There are a number of special types of wells or excavations that are regulated under federal and/or state laws. These types of wells include Class IV and V injection wells and monitoring or remediation wells regulated by the Ohio Environmental Protection Agency. Wells used for storm water or surface water drainage are considered Class V injection wells and have separate permitting and design requirements not covered under this document.

Other types of wells that may be widely installed across the state include elevator shafts, foundation or test bores, direct push bores, cathodic protection wells, seismic monitoring wells, and radial collector wells. Although this guidance does not specifically cover construction standards for these types of wells or excavations, many of the standards included herein can be directly applied to the installation of these structures. Any type of boring or vertical installation into the subsurface that penetrates one or more aquifers should use the recommended materials and procedures for drilling and completing the well, installation, or borehole to ensure the protection of ground water quality and prevent the diminution of ground water quantity.

## Existing Regulations

A variety of state agencies regulate the construction of water wells and borings in Ohio depending on the use of water and/or the purpose of the well. Water wells used for public water supplies are regulated by

Table 1. Common Uses for Water Wells

Public Water Supply
Private Water Supply
Agricultural (Livestock Watering, Dairy)
Irrigation/Chemigation
Open-loop Geothermal/ Closed Loop Vertical Geothermal
Industrial/Process Water
Power Supply
Cooling
Fire Protection
Dust Control
Dewatering
Pressure Relief
Remediation (Recovery, Extraction, Interception, Air Sparging, Vacuum Extraction)

the Ohio Environmental Protection Agency (EPA) under the Ohio Revised Code Section 6109. Public water supplies can be further categorized into community water systems, transient non-community water systems, and non-transient non-community water systems. Definitions and construction regulations for these systems are described in the Ohio Administrative Code Chapter 3745. Public water systems are defined as a system for the provision to the public of piped water for human consumption, if such system has at least fifteen service connections or regularly serves an average of at least twenty-five individuals daily at least sixty days out of the year. Well site acceptance must be granted by the Ohio EPA prior to drilling a potable water well for use by a public water system. Detailed construction plans for the well, treatment, and distribution systems must be approved by the director of the Ohio EPA prior to placing the well and/or water system in service.

**Private water systems** are regulated by the Ohio Department of Health under the Ohio Revised Code Section 3701. This program is administered through the local health departments and applies to any well, spring, cistern, pond or hauled water and any equipment for the collection, transportation, filtration, disinfection, treatment or storage of such water extending from and including the source of the water to the point of discharge from a pressure tank or other storage vessel. A private water system is any water system for the provision of water for human consumption, if such system has fewer than fifteen service connections and does not regularly serve an average of at least twenty-five individuals daily at least sixty days out of the year. Rules regarding the materials, construction, treatment, rehabilitation, and sealing of private water systems are described in the Ohio Administrative Code Chapter 3701-28. Permits for private water systems are obtained from the local health department who conducts the siting and approval for the well.

Well log and sealing reports are required to be filed with the Division of Water, Ohio Department of Natural Resources for any well as defined under the Ohio Revised Code Section 1521.05. Any person that participates in the construction or sealing of a well is required to keep an accurate record and provide that information on well log or sealing forms provided by the Division of Water. An example of a well log form and sealing report is shown in Figures 1 and 2, respectively. Definitions, requirements for filing and penalties are also described under ORC Section 1521.05.

Other types of wells that are currently regulated also include any monitoring or remediation wells required as part of any regulated facilities or activities under the CERCLA or RCRA program under the authority of the Ohio EPA or the United States Environmental Protection Agency, or under the Voluntary Action Program regulated by the Ohio EPA. Construction standards for monitoring wells have been developed by the Ohio EPA and are included as Appendix VI. A listing of state agencies and contacts with regulatory authority related to well construction and ground water is included in Appendix VII.

## Siting Considerations

This section is intended to provide guidance on the siting of a new well to ensure that the well will meet all applicable regulatory requirements for the setback of new wells from potential sources of contamination. These isolation standards vary, depending upon the intended use of the well. All potable wells need to get site acceptance from the appropriate agency prior to drilling a well. However, for all types of wells it is important to select a location which minimizes the potential for contamination. A new well

TYPE OR USE PEN  
SELF TRANSCRIBING  
PRESS HARD

# WELL LOG AND DRILLING REPORT

Ohio Department of Natural Resources  
Division of Water, 1939 Fountain Square Drive  
Columbus, Ohio 43224-9971 Voice (614) 447-9503

WELL LOCATION	CONSTRUCTION DETAILS																											
County <u>Delaware</u> Township <u>Trenton</u>	<input checked="" type="checkbox"/> Rotary <input type="checkbox"/> Cable <input type="checkbox"/> Augered <input type="checkbox"/> Driven <input type="checkbox"/> Other _____ <b>BOREHOLE/CASING</b> (measured from ground surface)																											
Owner/Builder <u>E. J. Fudd</u> (Circle One or Both) First Last	1 <input checked="" type="checkbox"/> Borehole Diameter <u>7 7/8</u> inches Depth <u>127</u> ft. Casing Diameter <u>5</u> in. Length <u>20</u> ft. Thickness <u>.327</u> in.																											
Address of Well Location <u>181 Green Cook Rd.</u> Number Street Name	2 <input type="checkbox"/> Borehole Diameter _____ inches Depth _____ ft. Casing Diameter <u>5</u> in. Length <u>102</u> ft. Thickness <u>.265</u> in. Casing Height Above Ground <u>1</u> ft.																											
City <u>Sunbury</u> Zip Code +4 <u>43074-9761</u>	Type 1 <input type="checkbox"/> Steel 1 <input type="checkbox"/> Galv. 1 <input checked="" type="checkbox"/> PVC 1 <input type="checkbox"/> 2 <input type="checkbox"/> _____ 2 <input type="checkbox"/> _____ 2 <input checked="" type="checkbox"/> _____ 2 <input type="checkbox"/> Other _____																											
Permit No. <u>960.95</u> Section/Lot No. <u>20</u> (Circle One or Both)	Joints 1 <input type="checkbox"/> Threaded 1 <input type="checkbox"/> Welded 1 <input type="checkbox"/> Solvent 1 <input type="checkbox"/> 2 <input type="checkbox"/> _____ 2 <input type="checkbox"/> _____ 2 <input checked="" type="checkbox"/> _____ 2 <input type="checkbox"/> Other _____																											
Location of Well in State Plane coordinates, if available: Use of Well <u>Residential</u>	<b>SCREEN</b> Diameter <u>5 in</u> Slot Size <u>.050 in</u> Screen Length <u>5</u> ft. Type <u>Machine-slotted</u> Material <u>PVC</u> Set Between <u>122</u> ft. and <u>127</u> ft.																											
N <input checked="" type="checkbox"/> X <u>195339</u> . <u>425</u> +/- <u>20</u> (ft) or m S <input type="checkbox"/> Y <u>1922944</u> . <u>533</u> +/- <u>20</u> (ft) or m	<b>GRAVEL PACK</b> (Filter Pack) Material/Size <u>#4 Parry sand</u> Volume/Weight Used <u>400 lbs</u> Method of Installation <u>Gravity pour</u> Depth: Placed FROM <u>118</u> ft. TO <u>127</u> ft.																											
Elevation of Well <u>1084</u> +/- <u>5</u> (ft) or m	<b>GROUT</b> Material <u>Benseal/EZ Mud</u> Volume/Weight Used <u>175 gal</u> Method of Installation <u>Pumped through 1" tremie tube</u> Depth: Placed FROM <u>118</u> ft. TO <u>surface</u> ft.																											
Datum Plain: <input checked="" type="checkbox"/> NAD27 <input type="checkbox"/> NAD83 Elevation Source <u>Topo map</u>	<b>DRILLING LOG*</b>																											
Source of Coordinates: <input checked="" type="checkbox"/> GPS <input type="checkbox"/> Survey <input type="checkbox"/> Other _____	INDICATE DEPTH(S) AT WHICH WATER IS ENCOUNTERED. Show color, texture, hardness, and formation: sandstone, shale, limestone, gravel, clay, sand, etc.																											
Sketch a map showing distance well lies from numbered state highways, street intersections, county roads, buildings or other notable landmarks. If latitude and longitude are available please include here: Lat: <u>40 12' 09" N</u> Long: <u>82 46' 35" W</u>	<table border="1" style="width:100%; border-collapse: collapse;"> <thead> <tr> <th style="width:70%;"></th> <th style="width:15%;">From</th> <th style="width:15%;">To</th> </tr> </thead> <tbody> <tr> <td>Brown clay</td> <td>0</td> <td>15</td> </tr> <tr> <td>Gray sandy clay</td> <td>15</td> <td>20</td> </tr> <tr> <td>Sand &amp; gravel (dry)</td> <td>20</td> <td>22</td> </tr> <tr> <td>Gray clay w/gravel</td> <td>22</td> <td>33</td> </tr> <tr> <td>Sand &amp; gravel (dry)</td> <td>33</td> <td>39</td> </tr> <tr> <td>Gray clay</td> <td>39</td> <td>119</td> </tr> <tr> <td>Coarse sand &amp; gravel</td> <td>119</td> <td>127</td> </tr> <tr> <td colspan="3" style="text-align:center;">Water encountered at 122'</td> </tr> </tbody> </table>		From	To	Brown clay	0	15	Gray sandy clay	15	20	Sand & gravel (dry)	20	22	Gray clay w/gravel	22	33	Sand & gravel (dry)	33	39	Gray clay	39	119	Coarse sand & gravel	119	127	Water encountered at 122'		
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<b>WELL TEST*</b>																												
Pre-Pumping Static Level <u>20</u> ft. Date <u>12/10/95</u>																												
Measured from: <input checked="" type="checkbox"/> Top of Casing <input type="checkbox"/> Ground Level <input type="checkbox"/> Other _____																												
<input checked="" type="checkbox"/> Air <input type="checkbox"/> Bailing <input type="checkbox"/> Pumping* <input type="checkbox"/> Other _____																												
Test Rate <u>35</u> gpm Duration of Test <u>1</u> hrs.																												
Feet of Drawdown <u>20</u> ft. Sustainable Yield <u>25</u> gpm																												
*(Attach a copy of the pumping test record, per section 1521.05, ORC)																												
Is Copy Attached? <input type="checkbox"/> Yes <input checked="" type="checkbox"/> No Flowing Well? <input type="checkbox"/> Yes <input checked="" type="checkbox"/> No																												
Quality <u>Clear, 1ppm Fe, 30 gpg hardness, pH 7</u>																												
<b>PUMP/PITLESS</b>																												
Type of pump <u>Submersible</u> Capacity <u>10</u> gpm																												
Pump set at <u>65</u> ft. Pitless Type <u>Adapter</u>																												
Pump installed by <u>Acme Drilling Co.</u>																												
I hereby certify the information given is accurate and correct to the best of my knowledge.																												
Drilling Firm <u>Acme Drilling Co.</u>																												
Address <u>1234 Main St.</u>																												
City, State, Zip <u>Anytown, Ohio 56789</u>																												
Signed <u>W.E. Coyote</u> Date <u>1/23/96</u>																												
ODH Registration Number <u>1111</u>																												
	*(If more space is needed to complete drilling log, use next consecutively numbered form.)																											
	Date of Well Completion <u>12/10/95</u> Total Depth of Well <u>127</u> ft.																											

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 43224-9971  
Blue - Customer's copy Pink - Driller's copy Green - Local Health Dept. copy

Figure 1. Example of a completed well log and drilling report.

WATER WELL SEALING REPORT
OHIO DEPARTMENT OF NATURAL RESOURCES
Division of Water
1939 Fountain Square Drive
Columbus, Ohio 43224-9971
Voice: (614) 265-6739 Fax: (614) 447-9503

LOCATION

County Delaware Township Trenton Section Lot Number 20
Owner/Builder E. J. Fudd

Address of Well Location 181 Green Cook Rd.
City Sunbury Zip Code +4 43074-9761

Property Location Description on the East side of Green Cook Rd.
Location of Well in State Plane coordinates, if available N 195339.43 +/- 20 Y 1922944.53 +/- 20

Elevation of Well 1084 +/- 5 Datum Plain: NAD27
Source of Coordinates: GPS

ORIGINAL WELL ODNR Well Log Number N/A Copy attached? Yes or No

MEASURED CONSTRUCTION DETAILS

Date of measurements 12/22/95
Depth of Well 127 ft. Static Water Level 20 ft.
Size of Casing 5 in. Length of casing 127 ft.
Well Condition Good

SEALING PROCEDURE

Method of Placement PRESSURE GROUT - Pumped through 1" tremie tube.
Placement: From 127 To surface Benseal/EZ Mud Slurry 130 gallons
Was Casing Removed? Yes or No
Condition of Casing GOOD
Perforations: From To
Date Sealing Performed 12/22/95
Reason(s) for Sealing WELL NO LONGER NEEDED.

CONTRACTOR

Name ACME DRILLING COMPANY ODH Registration # 1111
Address 1234 MAIN ST.
City/State/Zip Anytown, OH, 56789

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

Completion of this form is required by section 1521.05 (B) (9), Ohio Revised Code - file within 30 days after completion of sealing.
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 2. Example of a completed well sealing report.

should be located only where the new well and its surroundings can be maintained in a sanitary condition, and only where surface and subsurface conditions will not allow contaminants to be conducted into the well. In some cases it may not be possible to obtain a safe ground water supply due to extensive contamination in the area. In these areas an alternate water supply should be developed.

When evaluating a site for drilling a new well it is very important to consider past and future land use in the area. It is recommended that a limited hydrogeologic investigation be conducted in the area of the potential well site prior to purchasing the property to determine if adequate water supplies are available and if any water quality problems exist. It may also be beneficial to determine if any zoning is available to assist in protecting the future water supplies from potential sources of contamination. For new property development, it is strongly recommended that the location of the water well be given priority over the location of the septic system. The owner and driller should work closely with the local health department or Ohio EPA district office to see if there are any specific contamination problems present in the area of interest before the well is drilled. In cases where a new well is drilled as a replacement for a well that has failed or become contaminated, it is important that the old well be properly sealed to prevent ground water contamination from the surface or any contaminated zones. In cases where the new well is an addition to an existing ground water supply, the wells should be spaced to minimize any interference effects.

### Sanitary Isolation

A water well should be located only where the well and its surroundings can be maintained in a sanitary condition, and only where surface and subsurface conditions will not permit contamination of the well or aquifer.

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*Recommended minimum distances (except for public supply wells) between a water source and common potential sources of contamination are:*

<i>Sewers and drains constructed with watertight pipe.....</i>	<i>10 feet</i>
<i>Underground fuel oil tanks, gasoline storage tanks, LP tanks, chemical tanks.....</i>	<i>50 feet</i>
<i>Sewage tanks and adsorption fields .....</i>	<i>50 feet</i>
<i>Leaching pit and leaching privies .....</i>	<i>100 feet</i>
<i>Vault privies .....</i>	<i>50 feet</i>
<i>Stables, manure piles, etc. ....</i>	<i>50 feet</i>
<i>Streams, lakes, ponds, ditches, roads, etc. ....</i>	<i>25 feet</i>
<i>Properly sealed well .....</i>	<i>10 feet</i>
<i>Existing properly constructed water well* .....</i>	<i>10 feet</i>
<i>Structures .....</i>	<i>10 feet</i>
<i>Above-ground chemical storage tanks w/secondary containment .....</i>	<i>10 feet</i>
<i>Above-ground chemical storage tanks w/o secondary containment .....</i>	<i>25 feet</i>
<i>Vertical or horizontal geothermal loop systems w/low toxicity heat transfer fluid .....</i>	<i>25 feet</i>
<i>Vertical or horizontal geothermal loop systems w/high toxicity heat transfer fluid .....</i>	<i>50 feet</i>

*\*If existing well construction is unknown or of poor quality, then the well should be properly sealed.*

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For all public water supply wells, the new well shall be located at such distances from known or possible sources of contamination as the Director determines are necessary to safeguard the health of persons using water from the well, and to prevent contaminants from entering ground water (OAC 3745-9-04(C)(1)).

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*The isolation standards for public water supply wells are based upon the estimated water usage of the system and are listed below as a minimum distance from potential sources of contamination:*

<b>Estimated Water Usage (Q)</b>	<b>Minimum Isolation Radius</b>
0-2,500 gallons per day (g.p.d.) _____	50 feet
2,501-10,000 g.p.d. _____	Square root of Q
10,001-50,000 g.p.d. _____	50 + Q/200
Over 50,000 g.p.d. _____	300 feet

All of the isolation recommendations discussed previously are minimums only. They are subject to change based on actual site conditions. It may be necessary to increase isolation distances to minimize the potential for contamination where fractured bedrock or sand and gravel aquifers are near the surface and lack natural protection from contamination. In areas where a high volume production well is to be installed, the well should be located farther than recommended from potential sources of contamination due to its potentially large radius of influence. Ideally, in any situation, the owner of the well should (and, if it is a public supply, is required to) own all of the land within the isolation distance.

### **Areas of Known Contamination**

In areas of known ground water contamination, the water well driller should contact the local health department or the Ohio EPA district office prior to drilling the well to determine if any special precautions/requirements are necessary to avoid drawing in the contaminants. Also, in some cases, it may be necessary to drill a test well first to determine if a safe water supply can be obtained. If contaminated water is encountered above an aquifer containing potable water, the casing shall be extended to the bottom of the aquifer containing contaminated water or as deep as necessary to prevent the entry of contaminated water. Many times this situation occurs in shallow aquifers, which typically are most vulnerable to bacteriological contamination from surface water or chemical contamination from fertilizers, landfills, and surface spills, etc. In nitrate-impacted areas, the levels of nitrates in the water supply may be reduced by increasing casing depths.

If contaminated water is encountered below an aquifer containing potable water, the lower portion of the well shall be filled with grout to a height sufficient to prevent the entrance of contaminated water into the aquifer containing potable water. This situation may occur in wells where salt water from a deeper aquifer migrates upward and impacts the water quality of the shallower formation.

### **Proximity to Surface Water**

*The Ohio EPA recommends a 50-foot set back from all sources of surface water to improve the chances of obtaining a ground water designation for new wells. Private or non-potable wells should be located at least 25 feet from surface water sources.*

Due to concerns with bacteriological contamination of water supplies, the USEPA requires each state to determine the source of the water for all public water supplies. Sources designated as surface water supplies are required to provide additional treatment to meet USEPA's requirements. The Ohio EPA uses a Water Source Designation Worksheet to determine if the water supply meets the criteria to be classified as ground water. The location of new wells should be selected to provide sufficient horizontal and vertical separation from surface water bodies to ensure that they meet the separation requirements to be designated as a ground water source. The final determination may be contingent on obtaining quarterly bacterial analyses which are negative for coliform bacteria. The Ohio EPA Division of Drinking and Ground Waters (DDAGW) may be contacted for a copy of their complete guidance on source water designation.

#### **Floodplain Considerations**

*It is recommended that all wells in a floodplain be equipped with watertight surface seals and be vented using a metallic pipe which extends to at least 3 feet above the one hundred year flood level (see section on Well Completion for details on well vents in floodplains). All casing for community public water supply wells must be extended to at least 3 feet above the 100-year flood elevation, and either be mounded or equipped with work platforms and be protected from floating debris. Extending only the casing may be accepted for non-community water supply wells.*

No potable water supply wells should be located in a floodway unless the well is protected from floating debris, on a pedestal, and/or equipped with a watertight wellhead seal.

## Sole Source Aquifers and Wellhead Protection

The aquifer protection requirements of the Safe Drinking Water Act amendments of 1986 established procedures for designating areas where an aquifer is the sole or principal source of drinking water. These areas are commonly called Sole Source Aquifers and are defined as an aquifer which supplies 50% or more of the drinking water for an area and may be designated by USEPA or by petition. The purpose of the designation is to prevent grants of Federal financial assistance to projects which may contaminate a sole source aquifer and create a significant hazard to public health (40CFR, 1977). The USEPA can review any project which may have a significant impact on the environment and require that all available alternatives to the project be explored to minimize or eliminate the potential for contamination. There have been four areas designated as sole source aquifers in Ohio. These are the Great Miami/Little Miami River Basin Buried Valley Aquifer System, the Catawba Island Aquifer, the Pleasant City Aquifer, and the Allen County Area Combined Aquifer System. In addition, the Safe Drinking Water Act Amendments of 1996 require that all public water supplies establish a source water assessment and protection program which delineates the recharge areas within a five year time-of-travel to any public water supply well(s). This delineated area is known as a source water assessment and protection area. An inventory of potential sources of contamination within this area is required, along with protection strategies designed to minimize the potential for contamination from these sources.

## Well Construction Materials and Equipment

### Materials Used In The Drilling Process

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#### **Drilling Fluid**

*Any drilling fluid (commonly referred to as drilling mud) used should meet American Petroleum Institute Marsh funnel viscometer discharge requirements of one quart per 32 to 38 seconds. Density of the mud, as measured by a mud balance, should be less than 9.0 pounds per gallon. All drilling muds must meet ANSI/NSF Standard 61.*

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Drilling muds are a mixture of water, clay and often chemical additives used to lubricate and cool the drill bits or other cutting tools, and to carry the cuttings to the surface of the borehole. They are also used to stabilize the borehole and control fluid loss (Driscoll, 1986). For the drilling mud to function properly, its density and viscosity must be properly monitored, as well as the composition of the water used to make up the mud. Contaminants such as calcium, chlorides (salts), and chlorine in the make-up water will affect the performance of the drilling fluid. Drilling mud should be mixed according to the manufacturer's recommendations, and include any treatments for the previously mentioned contaminants. Soda ash can be added to counteract calcium concentrations of 150 parts per million (ppm) or greater, while chlorine concentrations above 150 ppm can be removed by aeration. Water with chloride concentrations above 500 ppm should not be used at all. Finally, drilling fluid should be removed from the borehole prior to and during development of the well.

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#### **Additives**

*Any additive used in the drilling, development, or grouting of a water supply must be designed for that purpose and meet ANSI/NSF Standard 61. Additives not recommended for use include guar gum and biodegradable organic materials.*

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Drilling mud additives can include a variety of compounds, including chemicals as well as organic and inorganic materials. Phosphates, polymers, and clays are just some of the types of additives available today. Phosphates are generally used as a cleaning material for the borehole and casing, and for corrosion and scale control. Use of phosphates should be kept to a minimum, and only in accordance with ANSI or NSF Standard 61. Polymers are generally used for lubrication and control of coagulation and flocculation. As with phosphates, the employment of polymers should be kept to a minimum and be used as approved by ANSI/NSF Standard 61. Clays are generally naturally-occurring substances composed of fine-grained material that includes clays, shales, and other formations with a high clay content. Bentonite is a type of clay that is commonly used in the drilling, grouting, and sealing processes of a water supply. The additives not recommended for use, i.e. guar gum and biodegradable organics, can promote the growth of bacteria if not removed from the well during construction and development. The well must be thoroughly cleaned during well development and disinfected prior to testing if these additives are used.

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**Lubricants**

*All lubricants must meet ANSI/NSF Standard 61 and be easy to use. Lubricants must be able to be flushed from the borehole using standard practices and equipment.*

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Lubricants can consist of petroleum or vegetable-based oils, as well as drilling muds and pressurized air. They are used to control friction and heat on the drill bits, and to help ease assembly of drill stems and other mechanical tools used in the borehole.

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**Drive shoe**

*Drive shoes should be used when driving casing.*

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A drive shoe may be commercially made or can consist of a section of steel casing threaded or welded onto the bottom of the driven casing. The drive shoe is generally hardened steel and has a beveled edge for cutting through rock or other hard, consolidated formations.

## **Materials Used To Construct A Well**

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**Casing**

*Steel casing should be prime, minimum Grade A pipe or tubing. The minimum wall thickness of steel casing should be no less than .188 inch, regardless of whether it is driven or set in the borehole. However, larger diameter casing will require a greater minimum wall thickness. Steel casing should meet ASTM Standard A53, A106, or A589, and API Specification 5L. All casing for public water supply wells shall comply with the minimum wall thickness and other requirements of ANSI/AWWA Standard A100. Steel casing wall thickness may require an additional allowance for corrosion. Tubing that meets the ASTM A500 standard must be hydrostatically tested.*

*PVC (polyvinyl chloride) casing must meet ANSI/NSF Standard 14 for potable water or ANSI/NSF Standard 61 and ASTM F480; with a minimum wall thickness equivalent to SDR (standard dimension ratio) 21. Larger diameter (8" or greater) PVC casing may require greater thickness to meet collapse strength requirements. The manufacturer's recommendations for use should be followed, as collapse strength is a function of wall thickness.*

*Concrete casing must meet ASTM Standard C478 and C913.*

---

Casing is generally a steel or PVC pipe used to line a borehole to prevent it from caving in and to exclude undesirable water, gases, or other liquids. A casing is required to extend a minimum of 25' below grade (unless geologic conditions warrant a variance) and a minimum 12 inches above grade. All steel casing and related materials must meet appropriate ASTM, API, or ANSI/NSF standards, and be certified for use with potable water. The use of casing materials other than steel for public water supply wells must be accepted by the Ohio EPA-DDAGW prior to installation. A determination will be made during well site acceptance. Reject or used pipe should not be used in the casing or development of a potable water supply.

Selection and use of any casing should be based on acceptable and applicable standards and the environment to which the casing will be exposed. Additional criteria for casing selection may depend on the presence of any contaminants. Suitable provisions should be made for the proper and clean storage of all casing pipe. Plastic casing material should be stored where it is free from exposure to direct sunlight. Steel casing should be prime pipe meeting the requirements of ASTM A53, A589, and API 5L with a minimum rating of standard tensile, hydrostatic, and collapse strength. Tubing meeting the requirements of ASTM Standard A500 may be used if the tubing is hydrostatically tested. Polyvinyl chloride (PVC) casing must be new pipe meeting the requirements of ASTM F480 and NSF Standard 14, or equivalent standards and having a SDR of 21 or below. All PVC casing must be NSF approved for potable water and well casing and should be so marked. Other types of casing would include casing made of materials such as concrete or similar composites. Use of other casings should be discouraged. However, if concrete casing is used in a well, the material must meet ASTM Standard C478 and C913, or related testing requirements and be of such quality as to provide a safe container for potable water.

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**Casing Joints**

*All casing joints must be structurally sound, uniform, and watertight. Joints for concrete casing should meet ASTM Standard C990.*

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All joints should be threaded and coupled or welded. Joints can include use of butt-welds, band rings, flared joints, and welding collars. Butt welds should require use of welding collars and/or guides. Joints in concrete casing should be constructed of rubber or mortar and installed according to the manufacturer's recommendations.

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*Threaded pipe must be reamed and drifted and tightly sealed.*

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Use of threaded couplings is acceptable. All threaded pipe and couplings must meet ASTM standard A53 or ASTM A589, API Standard RP 5B1, NSF Standard 14, or equivalent requirements.

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*For solvent welded joints, the manufacturer's recommendations on cleaning and preparation of pipe and application of various solvents and cements must be followed. Spline-lock joints, such as Certa-Lock, should comply with watertightness and mechanical strength requirements.*

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Integrity of all solvent welded joints is dependant on temperature and time requirements and proper application of the solvent. All solvents must meet or comply with ANSI/NSF Standard 14, ASTM F480, or similar requirements. Other types of joints used include Certa-Lock or other snap-fit couplings that provide watertight connections and have the mechanical strength and integrity to withstand installation and borehole pressures. Joints between concrete casing sections will require use of rubber gaskets or other approved devices, or other sealants (e.g. mortar) meeting ASTM Standard C990.

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### **Liners**

*Liners must be watertight and meet NSF Standard 61 or similar requirements. Minimum wall thickness should be equivalent to SDR 26.*

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Liners are generally used in addition to or in conjunction with approved casing. Use of liners in wells will require extension of the liner up to the bottom of the pitless adapter so that it will be visible from the ground surface.

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### **Grout**

*Grout should consist of a high solids (15-30%) high-yield sodium bentonite product or neat cement and meet ANSI/NSF Standard 61. Neat cement should meet ASTM Standard C150. Each should be mixed and installed according to the manufacturer's recommendations. In some circumstances, concrete can be used as a grouting material. Concrete should also be mixed and installed according to the manufacturer's recommendations.*

---

Grout is a material consisting of neat cement or bentonite that has a very low **permeability** and is acceptable for use with potable water. Grout is placed in the annulus, the space between a borehole and the well casing, to seal out unwanted water or other fluids. Grout is placed from the bottom of the casing up to the top of the borehole when an oversized borehole is drilled. When the casing is driven, the grout will be carried down with the casing as it advances. Grout must be as approved by ANSI/NSF Standard 61 or similar requirements and must be mixed and used in accordance with manufacturers' recommendations.

High solids bentonite slurries include bentonite, water, and sometimes additives such as polymers, that have been mixed to specific weights and standards. High solids bentonite grout typically has a solids content of 15% to 30%, unlike drilling mud, which typically has a solids content of only 3% to 6% (Oliver, 1997). High solids bentonite grout is generally pumped to the bottom of the casing or top of the gravel pack and forced up to the top of the well to provide a watertight seal between the borehole and casing. All bentonite grout materials should be mixed and used according to the manufacturer's specifications. Dry granular bentonite should be used to seal driven casing, except where the joints are butt welded together. Butt welded joints will not carry the dry granular bentonite down the hole as readily as flared or coupled joints. Therefore, it is recommended that if butt welded joints are to be used, then an oversized hole should be drilled so that the casing can be set in the borehole then grouted. Dry granular bentonite can also be used to seal a total annular space of four inches or more if the casing is 100 feet deep or less (see the section on **Geological Considerations**).

Neat cement slurry is Portland cement with no aggregate, and water. It usually takes 48 hours to cure and generates considerable heat (heat of hydration) during the curing process. Attention must be paid to the depths that neat cement will be used and the type of casing installed. Enough heat can be generated during the curing process to melt PVC casing pipe. Neat cement also has a tendency to shrink and crack. Bentonite can be added at a content of 3% to reduce the cracking problem, but it will not prevent shrinkage (Smith, 1994). Care must also be taken when using additives such as calcium. Calcium will reduce

setup time, but will also increase the heat of hydration. Neat cement should be pumped into place, not gravity fed, due to its tendency to separate in water.

Use of concrete as an annular sealant is not recommended unless it is installed through a tremie tube. Concrete grout is very abrasive on plastic; if this type of grout is used on a routine basis, the tremie pipe used for installation should be metallic. Like neat cement, concrete should be pumped into place to avoid separation problems in water.

Materials not suitable for use as grouting material include fireclay and cuttings. Fireclay and cuttings particles can range in size from nearly powder to chunks almost an inch across. The inconsistent size, moisture content, and plasticity of these materials make them generally unsuitable for use as a grouting material. Unpredictable and uncontrollable bridging of materials also can occur.

---

### **Screens**

*A screen should have enough uniform openings to create at least 8% (preferably more) open area per foot of screen, and to maintain an entrance velocity of 0.1 foot per second. The screen materials and construction method need to provide sufficient column and collapse strength to withstand installation and borehole pressures. Plastic screen materials should meet ANSI/NSF Standard 61. The use of handmade or hand-cut screens is not recommended. Mild steel screens tend to have short working lives in most environments due to rapid corrosion; therefore, their use in water wells is not recommended.*

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A screen is an intake structure with uniform openings designed to retain the formation, prevent collapse of the borehole adjacent to the screen, accommodate a yield adequate for the intended use of the well, and maximize the life of the well. Screens should have a minimum of 8 percent open area, constructed of non-clogging slots. Open areas of 30-40 percent are common for continuous slot screens without any loss in screen strength. Screen openings should be continuous around the screen with screen openings V-shaped and widening inward to facilitate development and enhance screen life. The screen materials and construction need to provide sufficient column and collapse strength to withstand installation and emplacement pressures. Screen materials should be selected to resist corrosion. Mild steel screens typically undergo rapid corrosion, and are not generally recommended for use in water wells. Where metal screens will be used, screen materials that are the same as the casing materials should be used to minimize corrosion due to dissimilar metals being in contact with each other. Metal screens may also be joined to PVC casing. PVC screens may be attached to metal casing with the use of appropriate couplers (NGWA, 1998).

Screens must facilitate well development, have a low head loss through the screen, control the entrance of fine-grained materials, and be resistant to incrusting and biofouling (Driscoll, 1986). The majority of screens used today are made from stainless and carbon steel, and PVC. Screens are generally made following four basic designs. These are: continuous-slot, wire-wrapped, machine-slotted, and louvered.

The proper selection of the screen size openings and screen length must be determined by the well contractor based on the aquifer type, aquifer grain size and uniformity coefficient, the desired volume or flow of water, size of pump, depth of the well and other considerations. The experience and expertise of the contractor also plays a role in proper screen selection. To maximize well efficiency and screen design life, the percent open area of the screen should be roughly equivalent to the **porosity** of the aquifer. Screens with large open areas typically have low **entrance velocities**, and subsequently less encrustation and greater resistance to corrosion. Five general steps should be followed in selecting the screen size openings and length: 1) perform a grain size analysis either visually or using sieves; 2) decide to naturally develop or gravel pack the well; 3) select a slot size using the 50/50 rule; 4) determine the screen diameter and length; and 5) check the entrance velocity using the manufacturer's curves. In order to obtain the best well design, a sieve analysis should be performed on the aquifer materials to determine the **effective grain size** and **uniformity coefficient** of the aquifer materials to help select the correct screen size opening and/or determine the need for a filter pack. Driscoll (1986) provides a discussion of determination of effective grain size and uniformity coefficient, and both Driscoll (1986) and U.S. EPA (1975) provide recommendations on screen size selection based on aquifer conditions.

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### **Gravel Pack/Filter Pack/Formation Stabilizer**

*Gravel pack/filter pack/formation stabilizer materials should consist of well-rounded particles, 95% siliceous, that are smooth, uniform, free of foreign matter, properly sized, washed, and disinfected. Pack material should extend 40% of the screen length above the screen, or a minimum of 2 feet for wells 6 inches in diameter or less, and a minimum of 4 feet for wells greater than 6 inches in diameter, to allow for settling after development. The gravel pack*

*should be no less than 3 inches thick, and no greater than 8 inches thick, due to difficulties related to proper well development.*

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A gravel pack generally consists of small, well-rounded sand or gravel that has been washed and cleaned of fines and any foreign materials. Where the aquifer materials are non-homogeneous, the uniformity coefficient of the aquifer is less than 3.0 and the effective grain size is less than 0.01 inches, a filter or gravel pack should be used (U.S. EPA, 1975).

All gravel pack materials should be disinfected prior to placement in the well to prevent contamination. Gravel for gravel packs can be purchased pre-chlorinated, but the well will still require chlorination. The gravel pack is placed between the well screen and the borehole wall to prevent fine materials from passing through the screen and entering the well. The gravel pack also helps prevent clogging of the screen by this fine-grained material.

Unless clean gravel pack materials are purchased for each well, the contractor must provide a clean storage area free from contamination. Approved gravel pack sand and gravel is available from various supply companies.

The gravel pack should be installed from the bottom to the top of the well screen by slowly pouring down the annular space, or tremied with water, to prevent separation and bridging. Installation of a gravel pack above the well screen may make a well more difficult to disinfect. Contamination from bentonite grouting materials can be avoided by extending the gravel pack above the screen by a minimum of 15% or according to the guidelines specified above, and by the placement of 6-12 inches of bentonite pellets on top of the gravel pack prior to regular grouting.

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### **Packers**

*Packers should be made from inert materials such as rubber, neoprene or other materials that meet ANSI/NSF Standard 61. Packers should be used with telescoping well screens.*

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A packer is generally used to form a seal between a telescoping well screen and the well casing, or the casing and the borehole wall. Most packers are now made from neoprene or similar inert materials. The use of lead must be prohibited. Packers should be approved for use with potable water and should meet the requirements of NSF or similar industry standards.

## **Well Construction Procedures**

### **General Procedures**

There are many procedures which are common to all types of well construction. These procedures deal with subjects involving minimum siting requirements, plumbness and alignment of the borehole, minimum casing depths and diameters, gravel pack, and grouting the annular space. Minimum siting requirements were discussed earlier in this document (see pp. 3-7). However, it should be noted that, during drilling, it is very important that the selected well site be maintained in a secure and sanitary manner to prevent contamination of the well. All materials used during well construction should be kept clean and not placed directly on the ground to minimize the potential for contamination. All wells intended to be vertical wells should have boreholes that are sufficiently plumb and straight to receive the casing without binding (U.S. EPA, 1975). The plumbness can also affect the performance of some types of pumps, such as turbine pumps, which need a fairly straight borehole to operate properly (Driscoll, 1986).

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### **Casing**

*Minimum casing depth for all wells should be 25 feet below ground surface.*

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Some geologic conditions may dictate that there be less than 25 feet of casing set (see Geological Considerations for a more detailed discussion of exceptions), but in no instance should there be less than 15 feet of casing set in the borehole. Wells developed in shallow aquifers should require variances from appropriate regulatory agency to allow less than 25 feet of casing to be set in the well.

The minimum casing diameter for a well is largely determined by its use and the aquifer in which it is to be developed. For most domestic wells, a diameter of 5" is sufficient to provide an adequate household supply, and allow easy installation and maintenance of the pumping equipment. Well diameters of less than 5" are not recommended for any use. Drilling (as opposed to driving, jetting, or excavating) is the recommended method of well installation.

While some driven wells are only 2" in diameter, their use should be limited to specific geologic conditions (see section on Geological Considerations). Industrial or public supply wells, on the other hand,

may have diameters of 12" or larger to allow more water to be pumped from the wells to satisfy greater water demands. However, some wells may have larger diameters to allow for storage in the borehole if the aquifer in which they are developed yield little water. Consequently, the intended use of the well, and the nature of the aquifer, are critical factors in determining the diameter of casing to be used in a well. For more information on how to estimate water needs for a house, industry, small public supply, etc., please see Table 1 in Appendix III.

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#### ***Filter Pack/Formation Stabilizer***

*The annular thickness of the filter pack should range between 3 and 5 inches. The filter pack should extend above the screen a distance equivalent to 40% of the total screen length, or a minimum of 2 feet in wells 6 inches in diameter or less, and a minimum of 4 feet in wells greater than 6 inches in diameter, to account for settling and loss during development, and to avoid contamination from the grouting material used.*

---

Filter pack, also known as gravel pack, is used when well screens are installed. It consists of clean sand or gravel of selected size and gradation which is installed in the annular space between the screen and the wall of the well bore. As discussed previously, the particles should be well-rounded, of 95% siliceous materials, and be smooth, uniform, free of foreign materials, properly sized to the slot openings of the screen used (90% of the filter pack material should be retained), washed, and disinfected. The filter pack should not be extended above the minimum casing length, except in temporary dewatering wells. True filter packs are typically used in large diameter, high capacity production wells, such as a municipal supply well.

In Ohio, what is commonly called gravel pack in domestic wells is really a formation stabilizer. The annular thickness of the formation stabilizer is usually no more than 2 to 3 inches, with nearly 100% of the stabilizer material retained by the screen. The stabilizer materials are similar to what is used for the filter packs, and they can be installed by the same methods. Due to their coarse nature, the formation stabilizer should extend at least two feet above the top of the screen in wells 6 inches or less in diameter. Formation stabilizers can also be used with perforated liners in wells developed in incompetent bedrock formations.

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#### ***Grouting***

*The annular space in all wells should be grouted, regardless of the method of construction. When the drilling method involves drilling an oversized borehole, it is recommended that wells up to 14 inches in diameter have a minimum of 2 inches of total annular space. For wells greater than 14 inches in diameter, the minimum total annular space should be 4 inches. Grout should be pumped into place through a tremie tube from the bottom of the casing, or top of the gravel pack, to the ground surface. When the drilling method involves driving the casing, the dry driven method of grouting should be used.*

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Grouting procedures will vary by drilling method (more information on drilling methods used in Ohio can be found in Appendix I). However, there are general procedures that apply to most drilling methods (see **Geologic Considerations** for exceptions).

#### ***Cable Tool/Driven Casing Hammer***

Single-cased wells drilled by the cable tool or driven casing hammer method should be grouted using the dry driven grout method. If the well is double-cased, then the annular space between the inner and outer casing should be grouted, and the outer casing removed (see Figure 3). If the outer casing is to remain in place, it should be dry driven grouted as it is installed. For public water supply wells, the Ohio EPA will accept the use of the dry driven method of grouting. The construction of the well must follow the recommendations in this document (including the use of welded flare joints or collar joints, and a drive shoe). However, under certain circumstances (i.e. where bacteriological or chemical contamination of an upper aquifer exists, areas of shallow bedrock, or for wells greater than 10 inches in diameter) it is recommended that the well be drilled with a larger temporary outer casing and the annular space grouted with a tremie pipe while the outer casing is being removed. Another acceptable method is to use temporary grout tubes which are driven along the well casing to allow grout to be injected into the annular space while the tubes are being withdrawn. This will ensure that the annular space is sufficiently grouted to the native soils/rock materials.

#### ***Rotary (Mud and/or Air)/Percussion Hammer***

Wells constructed using rotary or percussion hammer methods should be pressure grouted because these drilling methods create a significant annular space. As stated earlier, the minimum total annular

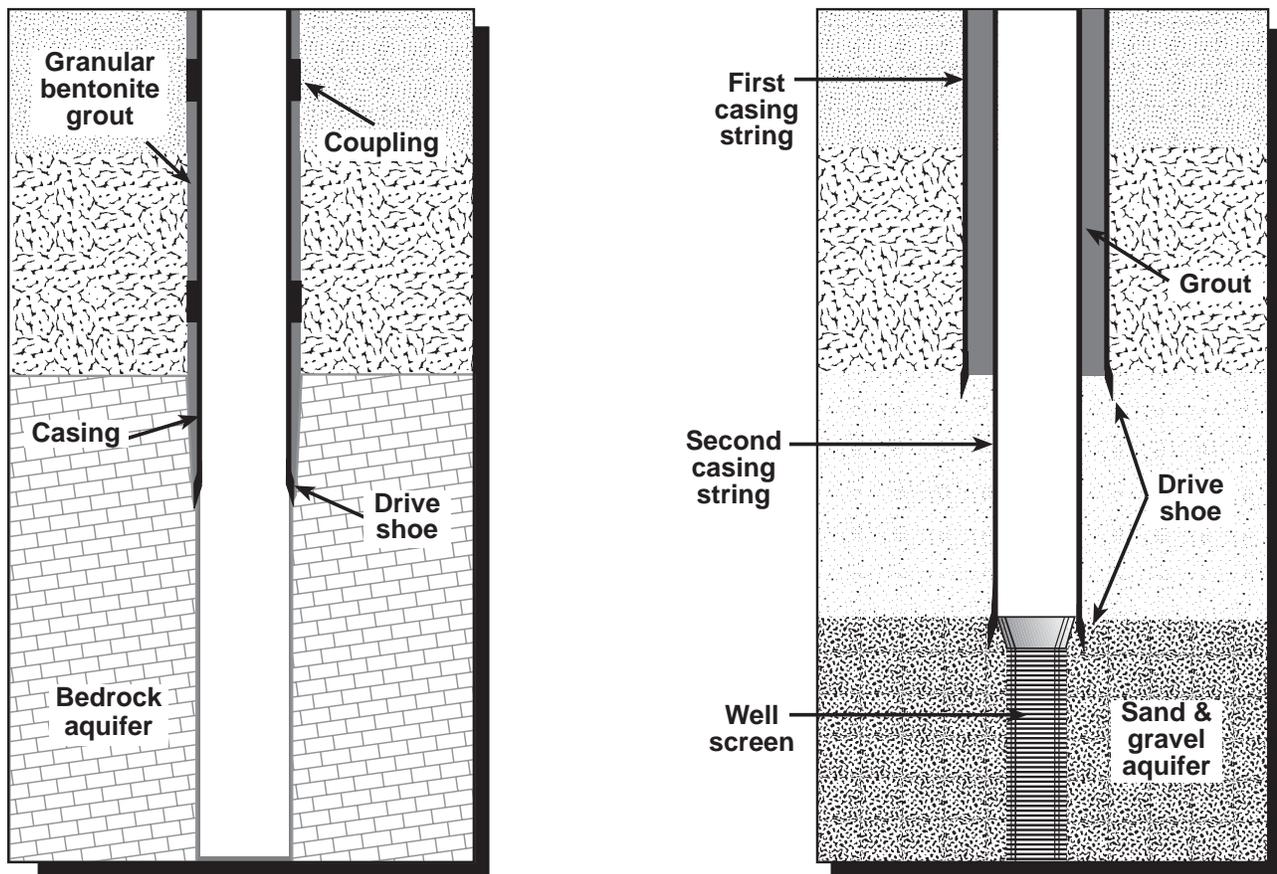


Figure 3. Examples of recommended well construction using cable tool drilling methods.

space for wells up to 14 inches in diameter should be 2 inches (Figure 4a). Wells greater than 14 inches in diameter should have a minimum total annular space of 4 inches (Figure 4b). If the total annular space is greater than 4 inches and the well depth is less than 100 feet, then, regardless of the diameter of the well, the annular space can be sealed with bentonite chips if there is a minimal amount of water in the borehole. Water should then be added to hydrate the chips. If there is a problem getting a tremie tube to the bottom due to narrowing or blockage of the annular space, the well should be grouted using the displacement method. The displacement method involves filling the inside of the casing with the grouting material, then forcing it down through the bottom of the casing and into the annular space.

*Auger (Hollow Stem, Solid Stem, Bucket)/Reverse Circulation Rotary*

Wells constructed with a hollow stem auger should be grouted using the methods as mud/air rotary-drilled wells (see Figure 5). For solid stem auger, bucket auger, and reverse-circulation rotary-drilled wells completed in **unconsolidated formations**, the grout must be placed from the top of the filter/gravel pack to the surface. A minimum of 25 feet of casing and grout, or casing and grout to the top of the aquifer is recommended. Bentonite chips can be used when the total annular space is greater than 4 inches, there is minimal water in the borehole, and the total depth is less than 100 feet. Again, water should be added to hydrate the chips.

*Driven*

Driven wells, such as well points (Figure 6), should be grouted using the dry driven grout method (see Appendix II for fact sheet on dry driven grout method). Geologic or working zone (non-potable wells) conditions may dictate the length of casing used.

*Jetting*

This method is not recommended for permanent well installation. An oversize borehole should be drilled, then surface casing should be set and grouted. Temporary installations will need 5 feet of surface seal.

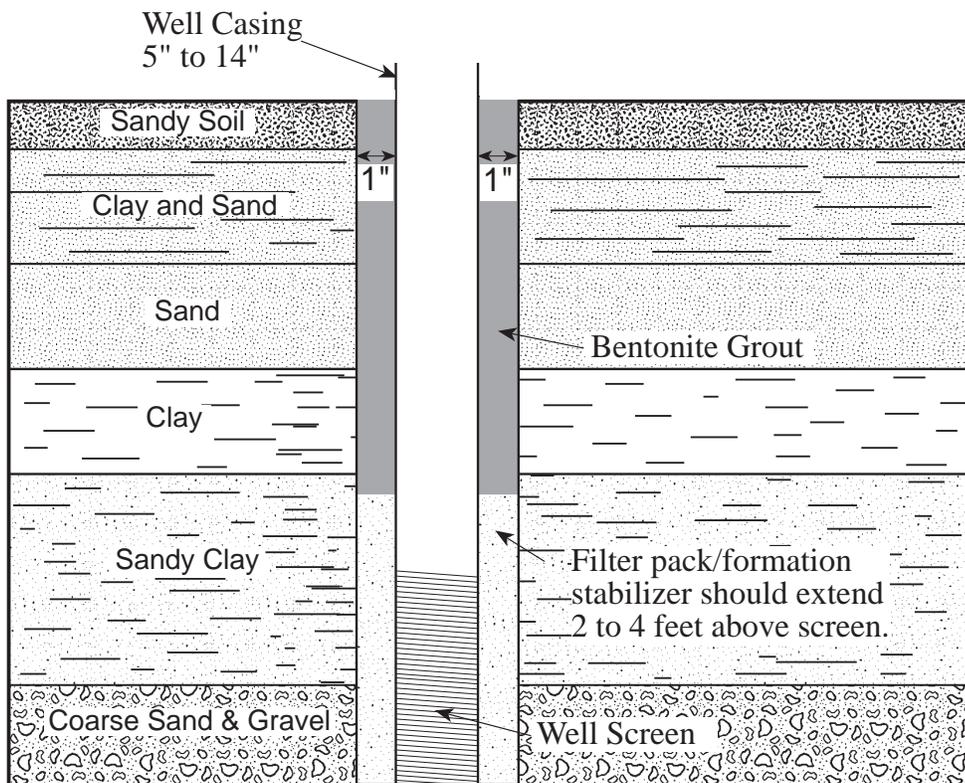


Figure 4a. Example of recommended rotary-drilled well construction for wells developed in unconsolidated formations—total annular space 2 inches or more.

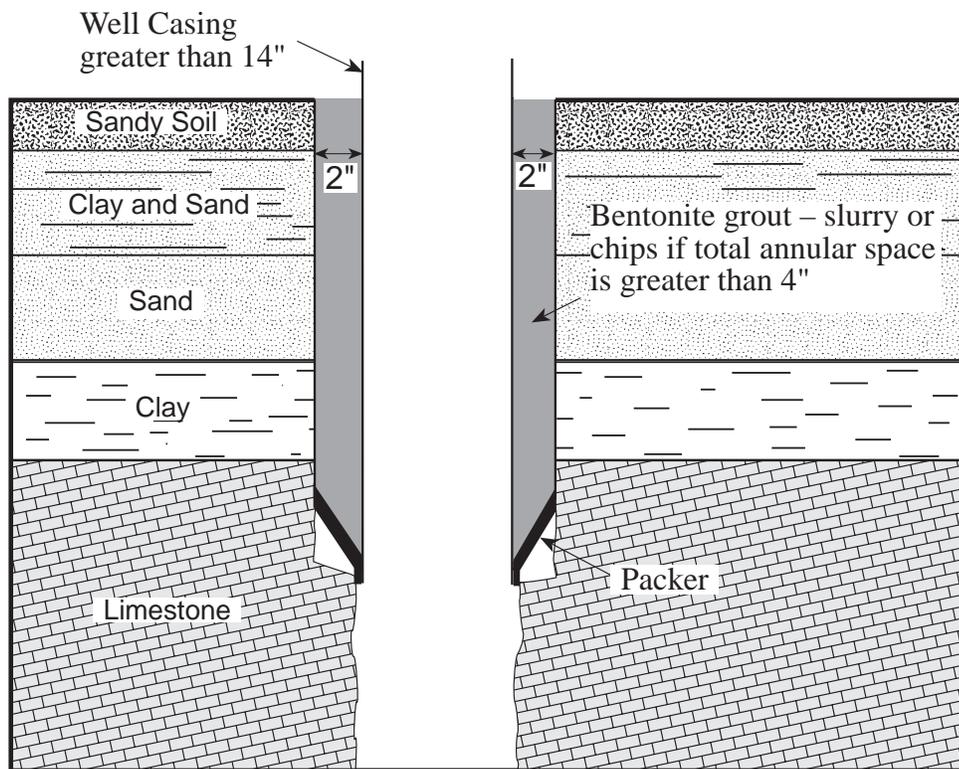


Figure 4b. Example of recommended rotary-drilled well construction for wells developed in consolidated formations—total annular space 4 inches or more.

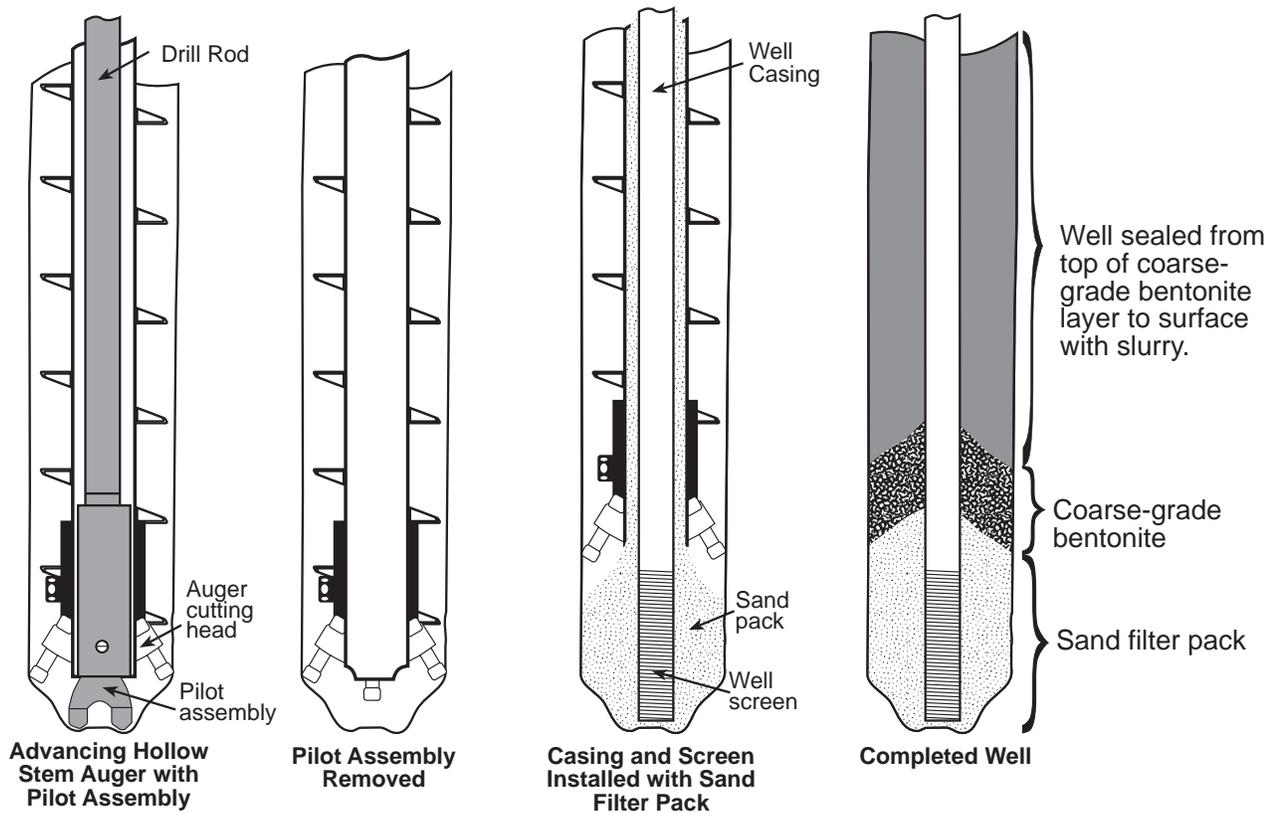


Figure 5. Example of well construction using hollow stem augers. (Modified from Hackett, 1987 and 1988)

### Large Diameter Excavated Wells

Large diameter wells that are installed by a variety of excavating methods must have a minimum of 1 foot of bentonite installed in the annular space. The bentonite should be chips or pellets and should be installed on top of a layer of pea gravel. The pea gravel would be installed on top of the gravel pack above the formation supplying water. The bentonite will need to be hydrated if located above saturated conditions in the soil. The annular space should be backfilled to the surface with clean, impermeable clays and recompact as much as possible. The top of the well should be finished with an impermeable surface seal sloping away from the well and extending beyond the edges of the excavation.

The general well construction procedures discussed here may change, depending on the geologic conditions encountered while drilling the well. The next section will discuss what geologic conditions could influence the construction procedures, and what changes in the procedures would be necessary.

## Geological Considerations

### Unconsolidated Formations

The use of unconsolidated geologic formations for water supplies is very common throughout Ohio. Unconsolidated formations consist of rock and mineral fragments that have been deposited in layers but are not cemented or are only partially cemented together. Ground water flows through the pore spaces between the grains of an unconsolidated formation. Unconsolidated formations in Ohio often form very productive aquifers with yields ranging from 100 to over 1000 gallons per minute. These aquifers are

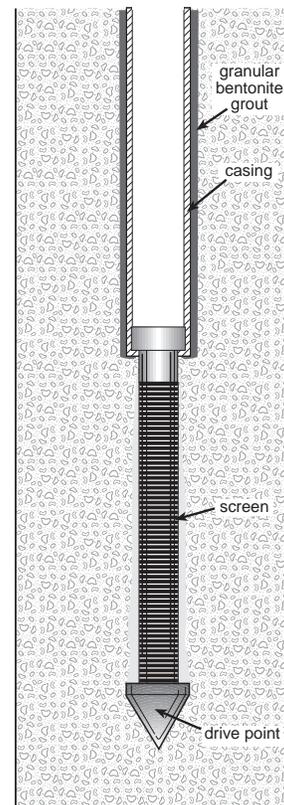


Figure 6. Example of recommended driven well construction.

primarily composed of layers of sand and gravel deposited from meltwaters from glaciers that once crossed Ohio. Unconsolidated aquifers are found in several **hydrogeologic settings** including buried valleys, moraines and kames, and current river valleys. Buried valley aquifers are remnants of channels cut into bedrock by rivers that flowed prior to or between periods of glaciation. These valleys subsequently filled with coarse sand and gravel deposits forming thick, productive aquifers. Modern rivers often flow on top of these buried valleys providing a source of recharge to the aquifers. Sand and gravel lenses may also be found in other glacially deposited features such as end moraines, beach ridges, kames and eskers. Alluvial deposits of sand and gravel may also be found in modern day river valleys.

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### **Casing**

*A minimum of 25 feet of casing is recommended. Where shallow aquifers overlie nonproductive bedrock, less than 25 feet of casing may be used. Less than 15 feet of casing is not recommended under any conditions.*

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In some areas of Ohio, shallow sand and gravel deposits overlie nonproduction bedrock formations. This is common in areas of northeastern Ohio in Lake and Ashtabula counties where beach ridge deposits overlie non-water-bearing shales. These shallow aquifer conditions may necessitate the use of less than 25 feet of casing to obtain water from a well. No less than 15 feet of casing is recommended for wells used for drinking water supply. Well points are often used in these types of formations, but are not recommended for use as drinking water supply.

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### **Screens**

*Wells completed in unconsolidated formations should use screens that meet the performance standards described on page 11. Minimum recommended length of a screen is 2 feet unless the formation is thinner. For maximum yield in an unconfined aquifer, the screen should penetrate 30-50% of the formation. The bottom of the screen should be sealed. Where a telescoping screen is used, the screen must be attached either directly to the bottom of the casing or to a packer. For naturally developed wells in non-homogeneous aquifers, the slot size selected should retain at least 40-50 percent of the aquifer material. For artificially gravel packed screens, the slot size selected should retain between 85 and 100 percent of the filter material.*

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The presence of large boulders or cobbles in some geologic formations may prevent the successful use of screens. In these situations, the use of a screen as recommended in the above standard may be impractical. Conversely, in very fine sandy or silty formations, properly sized screens may be unable to prevent the entrance of the formation into the well. In these cases it may be necessary to use settling tanks or low flow devices to prevent the entrance of sediment into the water system.

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### **Filter Pack or Formation Stabilizer**

*The use of a filter pack or formation stabilizer is recommended where the natural materials are non-homogeneous and not conducive to proper well development, or may slough or collapse in the borehole prior to development. The pack/stabilizer should not extend above 15 feet below the ground surface.*

### **Grouting**

*The annular space should be grouted from the top of the screen or filter pack to the ground surface. Where the annular space is greater than 2 inches per side, is dry or has a minimal amount of water in the borehole, and the borehole depth is less than 100 feet, dry granular bentonite may be installed by pouring into the annular space (see Figure 7). The granular bentonite should be screened and poured slowly to minimize bridging, with periodic tamping. The volume of the annular space should be calculated and compared to the volume of bentonite used as a check to make sure bridging in the annular space has not occurred. Water should be added to hydrate the bentonite.*

### **Packers**

*The use of a synthetic packer is recommended with the use of telescoping well screens.*

### **Geological Issues**

*In very fine sandy or silty formations, properly sized screens may be unable to prevent the entrance of the formation into the well. In these cases it may be necessary to use settling tanks or low flow devices to prevent the entrance of sediment into the water system. In areas of extremely low yield or very thin, shallow aquifers, traditional drilled wells may not*

provide adequate yield and large diameter excavated well installations may be necessary. These wells should follow the recommendations for casing, grout and well completion described in the appropriate sections of this document.

### Wells Developed in Consolidated Formations

**Consolidated formations** in Ohio consist of limestones and dolomites, shales, and sandstones. Ground water in these formations occurs and moves primarily in fractures and bedding planes that are often interconnected. Yields from these aquifers vary significantly with relatively poor yields from shales and shaley limestones (less than 5 gallons per minute), moderate yields from sandstones and some limestones/dolomites (5-100 gallons per minute), and moderately high yields from highly fractured limestones and dolomites (greater than 100 gallons per minute).

#### Casing

A minimum of 25 feet of casing is recommended.

#### Liners

Perforated liner casing may be used to maintain the integrity of the borehole where formations are prone to collapse, but perforations must not occur within 25 feet of the ground surface. Liners must be securely attached to the permanent casing.

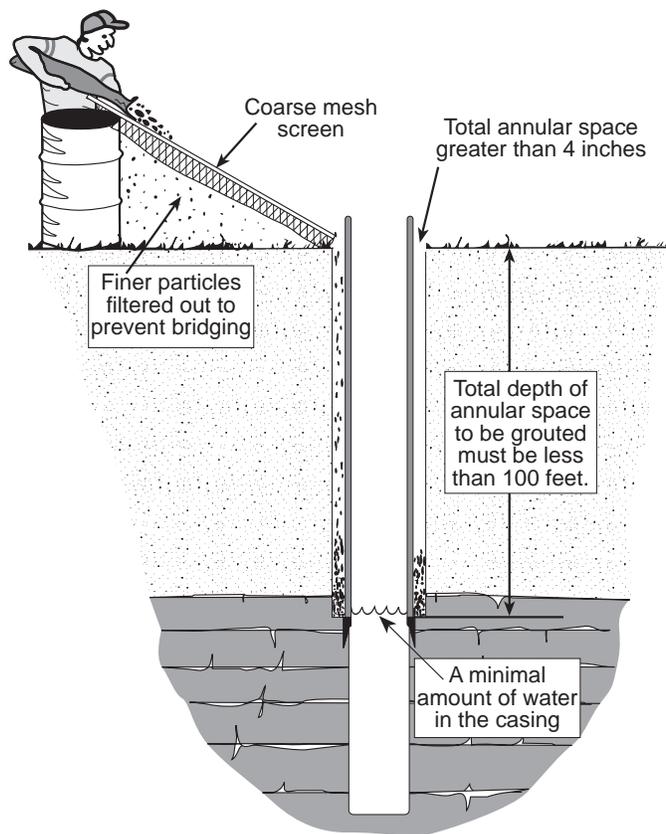


Figure 7. Grouting the annular space of wells with coarse grade bentonite products using the pouring method. (Modified from Wisconsin Department of Natural Resources, 1993)

In areas of southeastern Ohio, thin, alternating beds of limestones, shales, sandstones and coals provide low yields to wells. Wells are often drilled to penetrate multiple aquifers to maximize yields. Some of these formations are prone to collapse, necessitating the use of perforated liners.

#### Grout

Wells should be grouted from the bottom of the casing to the surface using the grouting method recommended for the method of drilling.

#### Geologic Issues

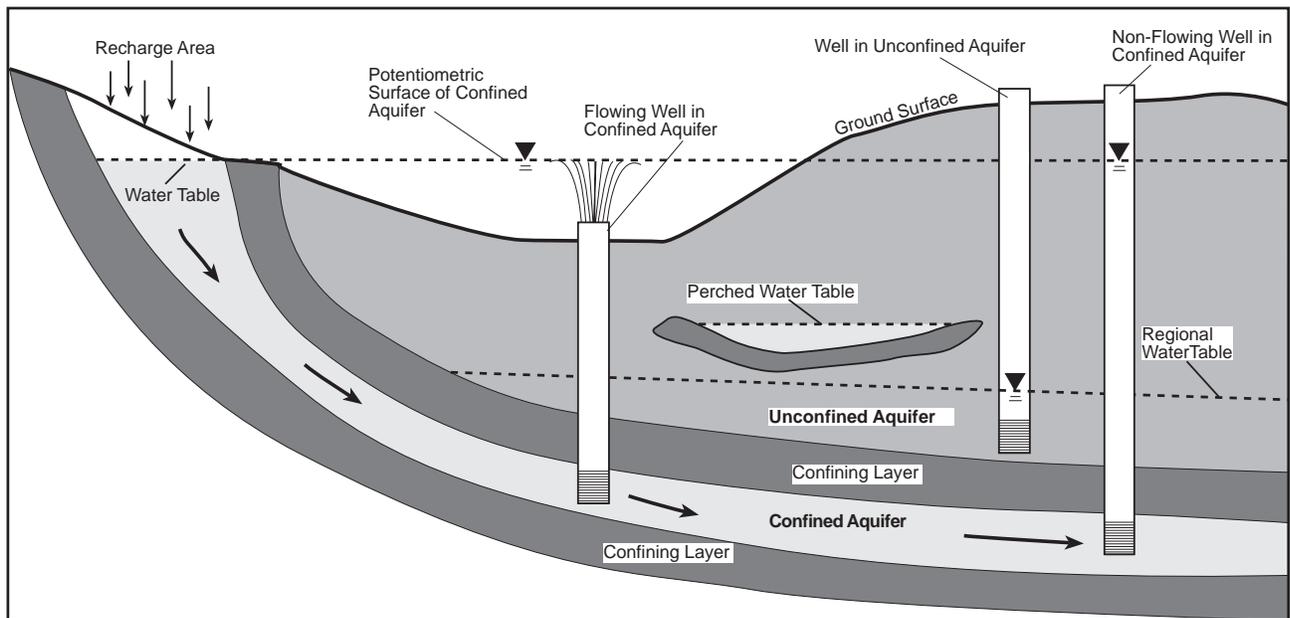
Some fractured or cavernous formations in Ohio may contain sediment that enters the well. Development procedures may be unable to entirely clear the sediment from these fractures, therefore it may be necessary to use settling tanks or low flow devices to prevent the entrance of sediment into the water system.

### Wells Developed in Unconfined Aquifers

**Unconfined aquifers** occur where the ground water in the geologic formation is open to the atmosphere through openings in the overlying materials (Figure 8). The water level in the aquifer is referred to as the water table. These formations are readily recharged by precipitation, and are often hydraulically connected to surface water bodies.

#### Casing

A minimum of 25 feet of casing is recommended, with no less than 15 feet of casing where shallow aquifers are present.



coarse grade bentonite products using the

### **Screens**

*For maximum yield in an unconfined aquifer, the screen should penetrate 30-50% of the formation.*

### **Grout**

*Wells should be grouted from either the bottom of the casing or the top of the filter pack to the surface using the grouting method recommended for the method of drilling.*

### **Geologic Issues**

*Due to their typically shallow nature, wells completed in unconfined aquifers may need a greater isolation distance from known or suspected sources of contamination.*

## **Wells Developed in Confined Aquifers**

A **confined aquifer** occurs when the aquifer is separated from the atmosphere at the point of discharge by a relatively impermeable geologic formation (Figure 8). Pressures in a confined aquifer are greater than atmospheric pressures. The water level in a well penetrating a confined aquifer will rise to a level equivalent to the pressure head, or elevation within the aquifer. If this elevation is greater than the land surface, then the well will flow.

### **Casing**

*The casing length should be a minimum of 25 feet and should extend to the bottom of the confining layer.*

### **Screens**

*For maximum yield in a confined aquifer, the screen should penetrate 70-80% of the formation. The screen should be sealed at the bottom.*

### **Grout**

*The well should be grouted from either the bottom of the casing or the top of the filter pack (where present) to the ground surface. All annular spaces adjacent to the confining layer should be grouted to maintain the integrity of the confining layer.*

### **Filter Pack/Formation Stabilizer**

*Filter pack or formation stabilizer should not extend significantly into the confining layer, and should not be placed across a confining layer allowing the interconnection of two aquifers along the annular space.*

### **Geologic Issues**

*The integrity of the confining layer should be maintained in all aspects of the well construction and materials to prevent mixing of water between aquifers.*

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### **Wells Penetrating Multiple Aquifers**

A variety of geologic conditions can lead to the presence of multiple aquifers. In the glaciated areas of the state, sand and gravel lenses may overlie bedrock formations with both formations providing adequate yields to wells. In eastern and southeastern Ohio, wells are typically completed as open boreholes penetrating cyclic interbedded sandstone, limestone, shale and coal sequences in order to obtain adequate well yields. Wells that penetrate multiple aquifers may allow the mixing of waters having different water quality or the loss of water to another zone due to differences in hydraulic heads between the aquifers. Consideration should be given to the well yield required, the relative thickness of the aquifers, the presence of multiple confining layers, and the hydraulic interconnection between the aquifers. In some areas, shallow zones of poorer water quality may exist that will need to be cased off to prevent contamination of other aquifers.

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#### **Casing**

*The casing length should be a minimum of 25 feet and should extend to the bottom of the confining layer. Known zones of poor water quality or contamination should be cased off and properly grouted to prevent contamination of other aquifers.*

#### **Grout**

*The well should be grouted from the bottom of the casing or top of the filter pack/formation stabilizer to the ground surface.*

#### **Liners**

*Perforated liner casing may be used to maintain the integrity of the borehole where formations are prone to collapse, but perforations must not occur within 25 feet of the ground surface. Liners should terminate within sight of the bottom of the pitless adapter or the ground surface. Liners should not be open to more than one aquifer if water quality and hydraulic head vary between aquifers.*

#### **Geologic Issues**

*To prevent the interconnection of two water-bearing zones having different water quality, completing wells in multiple aquifers is not recommended. Wells completed in multiple aquifers may also allow the thieving or loss of water to a lower zone due to differences in hydraulic heads between the aquifers. Exceptions to multiple aquifer completions occur where it is necessary to penetrate multiple zones to obtain adequate yields, particularly in areas of thin-bedded, cyclic formations (see Figures 9a and 9b).*

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## **Special Geologic Conditions**

Other types of special geologic conditions occur across the state that may significantly impact well drilling and construction procedures. Special care must be taken in these areas to prevent ground water contamination and/or the loss of hydraulic head in confined or semi-confined aquifers.

### **Flowing Wells**

Flowing wells occur where the hydraulic head in a confined aquifer is at an elevation greater than the land surface. Flowing wells can cause problems related to the drilling of the well when attempting to set casing and perform grouting. Flowing wells are common in some areas of northwestern Ohio, and in glaciated areas of the state where relatively impermeable glacial till overlies productive sand and gravel aquifers.

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#### **Casing**

*Casing should be installed through the confining layer into the top of the aquifer that is producing flowing conditions. The selection of casing materials must take into account any hydraulic pressures on the casing that will occur due to the flowing aquifer conditions.*

#### **Grout**

*The well must be properly grouted from either the bottom of the casing or the top of the filter pack (where present) to the land surface.*

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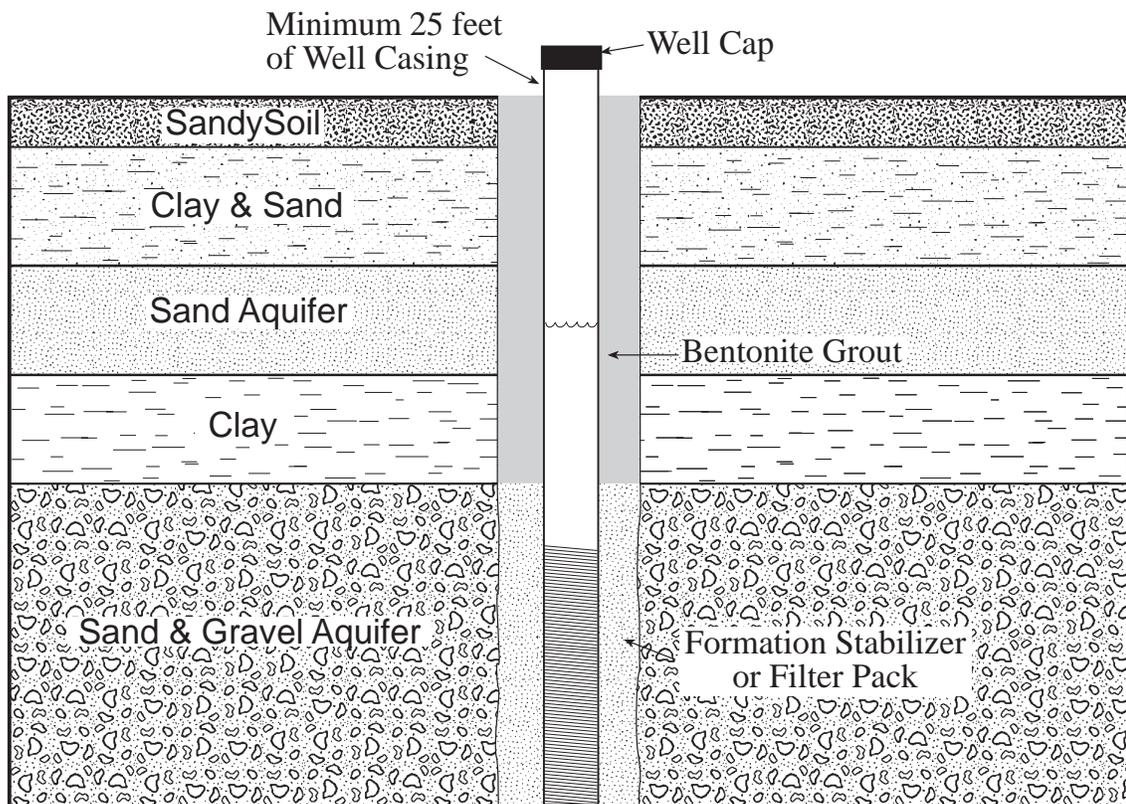


Figure 9a. Recommended well construction for wells penetrating multiple unconsolidated aquifers.

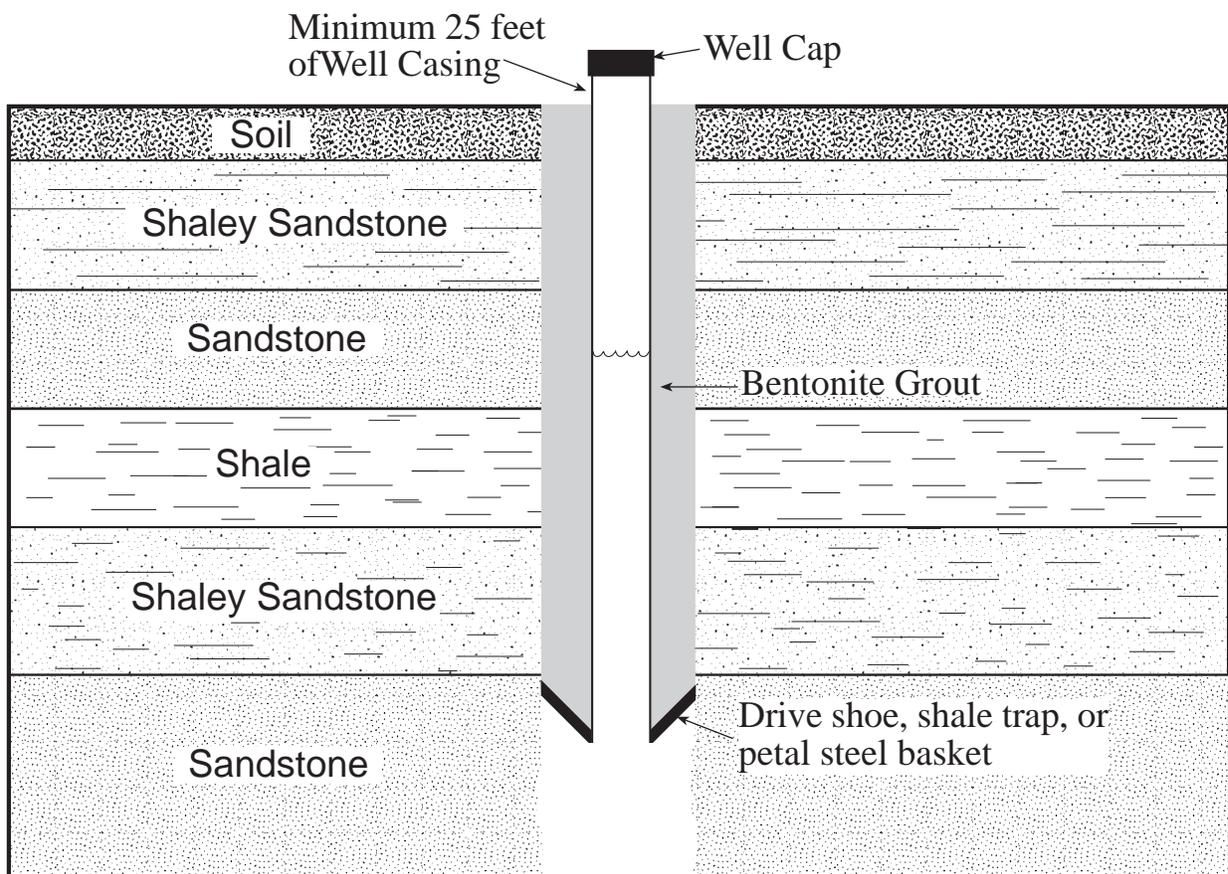


Figure 9b. Recommended well construction for wells penetrating multiple consolidated aquifers.

Grouting may be performed using several methods depending on the method of drilling and the rate of flow. Where flows are not excessive, double weight bentonite grout may be tremied into the annular space to prevent flow up the annular space in the borehole. The well may also be pumped to lower the water level in the borehole to allow the placement of a filter pack and the installation of double weight bentonite grout. Where flows are excessive, an upper enlarged borehole should be installed into the confining layer and pressure grouted. If the confined aquifer is consolidated, the inner casing should be driven or a smaller diameter borehole drilled and the casing set firmly into the bedrock. The annular space around the lower casing can then be pressure grouted using a double weight bentonite slurry (Figures 10a and 10b). If the confined aquifer is unconsolidated, then a smaller diameter borehole should be drilled, with the casing and screen installed into the confined aquifer. The well should be double cased and the annular space pressure grouted using a double weight bentonite slurry (Figures 11a and 11b). Another method that may be used to control flowing conditions is to set a surface casing, install a packer at the bottom of the casing, install the inner casing, and pressure grout through the packer between the two casings.

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### **Well Completion**

*Flows from the well should be restricted if possible to prevent the loss of hydraulic head in the aquifer. An air gap should be used to prevent backflow into the well, and should be a minimum of 8 inches above the surrounding grade. A backflow prevention assembly with a double check valve may be installed, in lieu of the air gap, if necessary. The air gap should be a minimum of 8 inches above the ground, with a minimum of 2 inches of air space, or a minimum of 2 pipe diameters. Overflows discharging into a drainage channel or catch basin should have a minimum air gap of 2 overflow pipe diameters above the flood rim of the receiving basing. Overflow should not be discharged to a septic system.*

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### **Cavernous or Highly Fractured Formations**

Cavernous and highly fractured formations are present in limestones and dolomites in northwestern and mid-central Ohio. Cavernous zones form where ground water has dissolved the limestone or dolomite and enlarged fractures or bedding planes to form large voids in the subsurface. The presence of these cavernous or highly fractured zones can affect the ability to properly grout the well, and may be a source of sediment or poorer quality water, especially if these zones are interconnected to the land surface. If the water from the well becomes turbid after a significant precipitation event the well may be under the direct influence of surface water and may be contaminated with bacteria. Where cavernous or highly fractured zones are encountered during drilling, the use of a **downhole camera** or **caliper log** may be useful to identify the exact depths and nature of these zones to facilitate proper grouting and casing of the well.

---

### **Casing**

*A minimum of 25 feet of casing is recommended. Any cavernous or highly fractured zones that are not being used as a source of ground water for the well should be cased off.*

### **Grout**

*The well must be properly grouted from the bottom of the casing to the land surface. Any casing installed through cavernous zones must be properly grouted. If the cavernous or highly fractured zone is below 25 feet from the ground surface, then the zone can be filled with cuttings or clean gravel, and then pressure grouted to the surface (Figures 12 and 13).*

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A shale basket, petal steel basket or rubber packer may be used to seal off cavernous or highly fractured zones. Where the cavernous or fractured zone is to be used as the source of water, these devices may be installed at the top of the zone and annular space can be pressure grouted from the top of the zone to the ground surface. Where cavernous or fractured zones are to be cased off, these devices must be installed at the top and bottom of the zone, and the well cased and pressure grouted. In some cases, it may be possible to pull the tremie pipe above the cavernous or fractured zone and then continue with pressure grouting.

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### **Screens**

*A well screen may be installed adjacent to water-producing cavernous zones to stabilize the borehole and to prevent sediment from entering the well.*

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### **Mine Shaft/Abandoned Mine Wells**

Wells penetrating abandoned underground mines often occur in areas of southeastern and eastern Ohio.

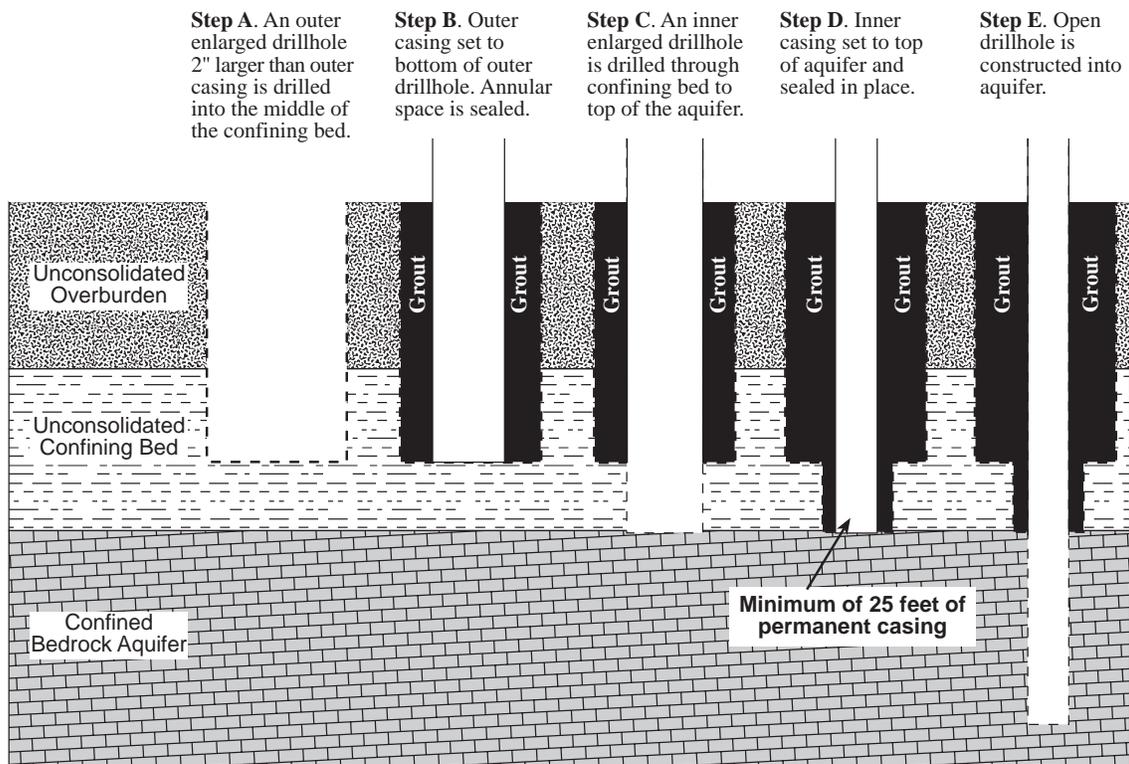


Figure 10a. Rotary method for flowing well construction-confined bedrock aquifer with an unconsolidated confining bed.

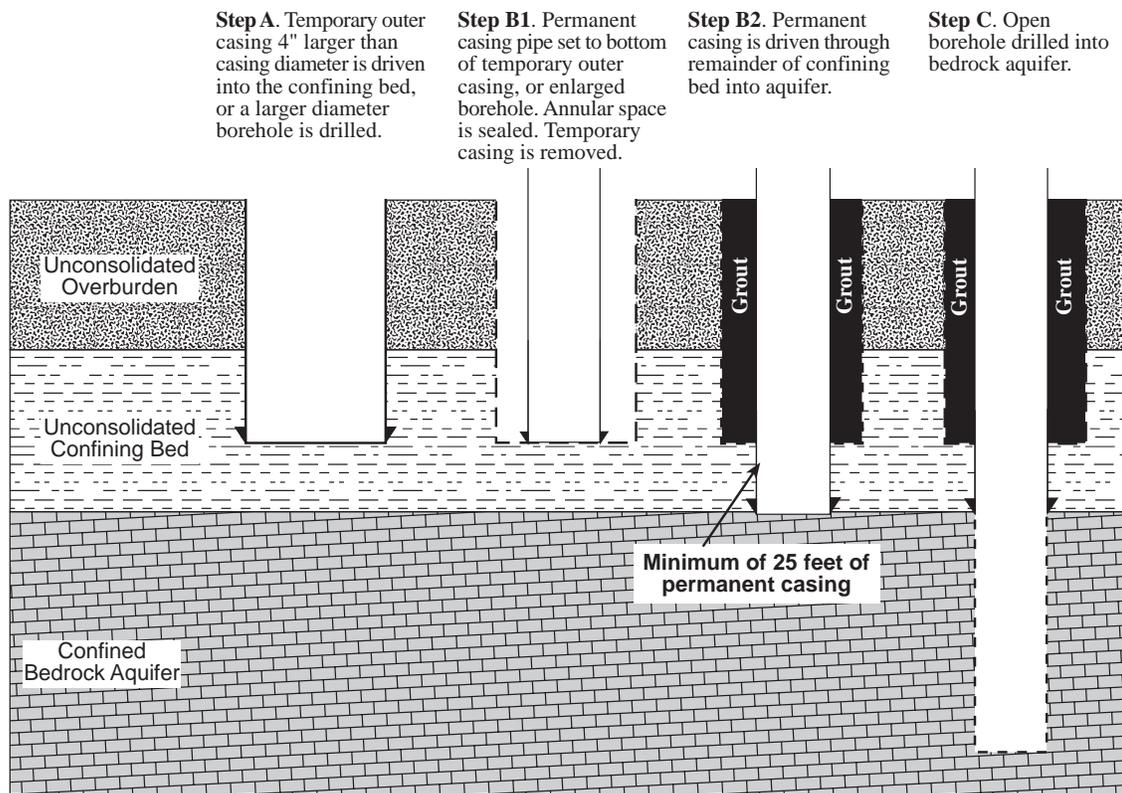


Figure 10b. Cable tool method for flowing well construction-confined bedrock aquifer with an unconsolidated confining bed.

**Step A.** An outer enlarged drillhole 2" larger than outer casing is drilled into the middle of the confining bed.

**Step B.** Outer casing set to bottom of outer drillhole. Annular space is sealed.

**Step C.** An inner enlarged drillhole is drilled through confining bed into the aquifer.

**Step D.** Inner casing (25' minimum) and screen are set into aquifer.

**Step E.** Filter pack/formation stabilizer placed around screen, and annular space is then sealed from top of pack/stabilizer to surface.

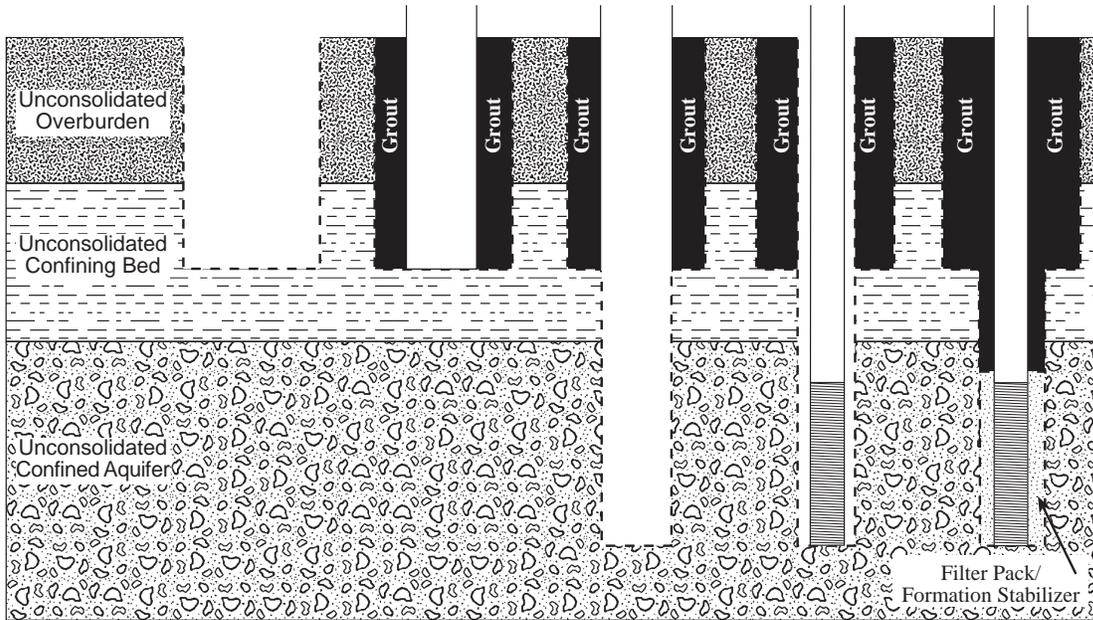


Figure 11a. Rotary method for flowing well construction where both confining bed and aquifer are unconsolidated-double casing construction.

**Step A.** Temporary outer casing 4" larger than casing diameter is driven into the confining bed, or a larger diameter borehole is drilled.

**Step B1.** Permanent casing pipe set to bottom of temporary outer casing, or enlarged borehole. Annular space is sealed. Temporary outer casing is removed.

**Step B2.** Permanent casing is driven through remainder of confining bed into aquifer.

**Step C.** Screen installed, casing pulled back to expose screen.

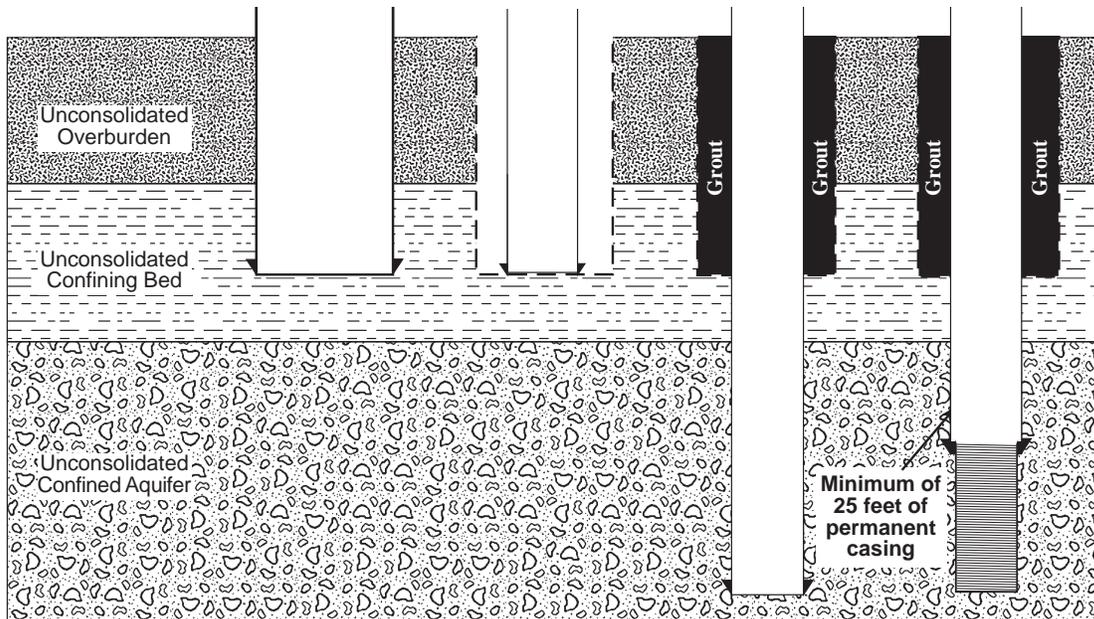


Figure 11a. Cable tool method for flowing well construction-confined unconsolidated aquifer with an unconsolidated confining bed.

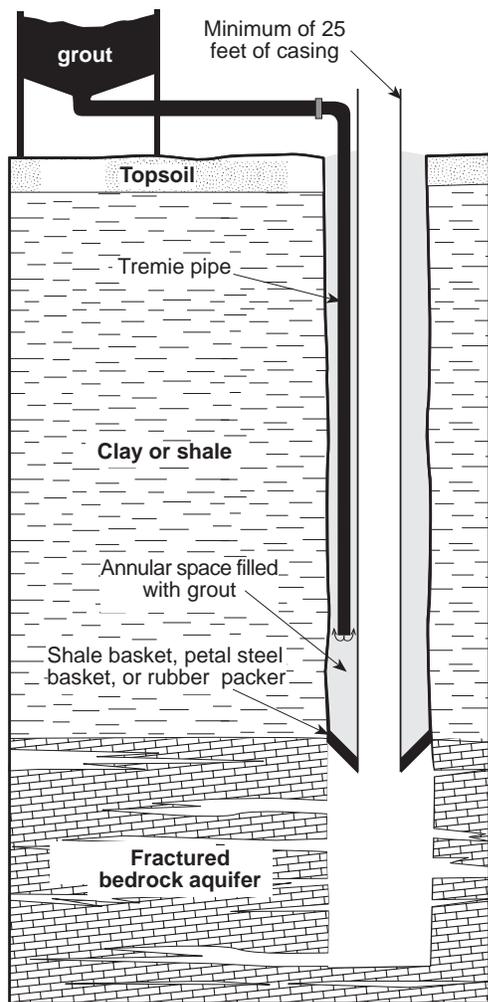


Figure 12. Recommended grouting procedures for wells penetrating fractured or cavernous formations.

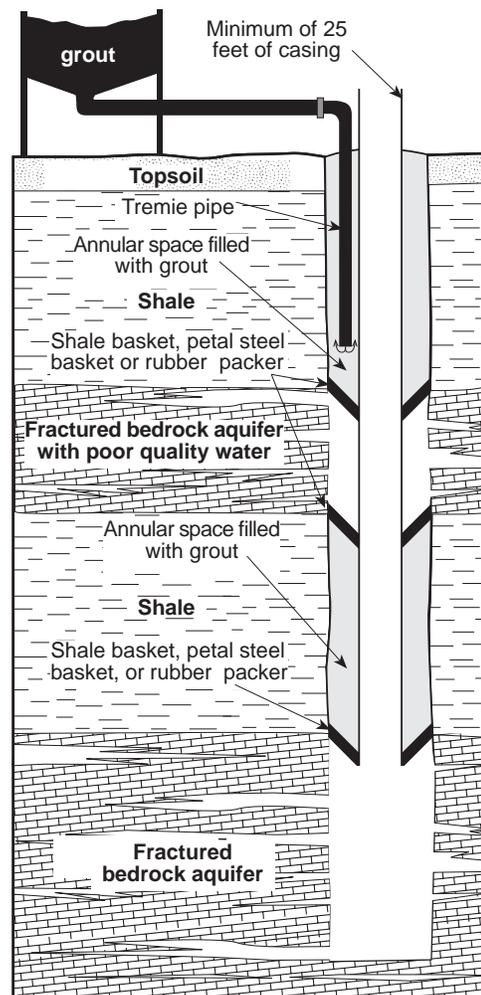


Figure 13. Recommended grouting procedures for wells penetrating fractured or cavernous formations where an upper fractured or cavernous zone has been sealed off.

Water quality can vary, but is often poor depending on whether or not the entire seam is submerged. Wells completed in mines encounter conditions during drilling and construction similar to those found in cavernous formations.

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### **Casing**

*A minimum of 25 feet of casing is recommended. Any mines that are not being used as a source of ground water for the well should be cased off.*

### **Grout**

*The well must be properly grouted from the bottom of the casing to the land surface. Any production casing installed through mines must be properly grouted.*

---

A shale basket, petal steel basket or rubber packer may be used to seal off mines. Where the mine is to be used as the source of water, these devices may be installed at the top of the opening and the annular space can be pressure grouted from the top of the zone to the ground surface. Where mines are to be cased through, these devices must be installed at the top and bottom of the void, and the well cased and pressure grouted.

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### **Screens**

*A well screen may be installed in water-producing mines to prevent sediment from entering the well.*

---

## **Brine-Producing Formations**

Brine-producing zones may be encountered in some areas of eastern, northeastern, southeastern, and southwestern Ohio counties. These zones may occur due to the presence of natural brine in the formation, or contamination from oil and gas drilling, or abandoned oil and gas wells.

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### ***Geologic Issues***

*When these zones are encountered in a well, the well should be plugged back to an elevation where the brine producing zones are not present. Plugging materials that are not adversely affected by the brine water (e.g. Hole Plug) should be used to seal back the borehole. If a brine-producing zone cannot be successfully sealed off, then the entire well should be properly sealed.*

---

## **Gas-Producing Formations**

Geologic formations that naturally produce methane gas can be found in confined bedrock formations and some unconsolidated sand and gravel formations, especially in northeastern Ohio. The primary issue with gas-producing wells is the need to properly vent the methane gas to prevent explosive conditions from occurring in basements or other confined spaces. The installation of a holding tank may be necessary to allow for volatilization of the gas to occur before the water is allowed to enter a building or home. Formations that produce methane gas should be cased off and the annular space properly grouted where other water-bearing formations are present.

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### ***Well Completion***

*Wells producing methane gas should be properly vented to the atmosphere to prevent the accumulation of vapors and resulting explosive conditions. In some cases, a shroud may be installed around the intake of the pump to force the separation of the gas from the water.*

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## **Well Development Procedures**

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*All wells should be properly developed until turbidity in the well is minimized. Water produced during development should not be discharged to a stream unless a NPDES permit is obtained, and controls are in place to prevent erosion and the discharge of turbid water. Smaller diameter wells will require an average of 1 hour of development per foot of screen.*

---

Most of the drilling techniques used today can be classified as destructive drilling techniques. The formation immediately around the drilled hole becomes compacted, drilling mud invasion and the formation of a mud cake on the borehole wall may occur, and/or fines may be driven into the formation during the drilling process, all of which result in the loss of permeability in the formation. In consolidated rock formations, similar compaction may occur in poorly cemented rocks, and cuttings or drilling mud can be forced into fractures and bedding planes that produce water. This in turn will cause the well to be very inefficient, especially if the intake portion of the well is not brought back to the original values of aquifer porosity and permeability before the drilling process was started. All wells should be properly developed and cleaned to reverse the damage caused by drilling to the maximum extent possible and to develop the well to maximize well yield and design life.

The purpose of well development is to reduce the compaction and intermixing of grain sizes that occurs during the drilling process, to remove any drilling muds from the borehole walls and the formation, or any mud cakes that may have formed, to increase the porosity and permeability of the formation adjacent to the screen or in the open borehole, and to create a graded zone of formation materials to prevent fines from entering the borehole (Driscoll, 1986).

The methods and techniques used during this process will be determined by the type of well completion used, the type of screen and screen openings, the filter pack thickness (if present), the formation type, and the equipment available for the application. The methods are divided into two major categories: mechanical techniques and chemical techniques. All mechanical methods with the exception of high velocity jetting rely on the introduction of energy to disturb the natural formation or filter pack to remove the fines and allow them to be drawn into the well, with the remaining coarser materials settling and supporting the screen. Mechanical techniques are typically divided into the following classifications: mechanical surging, air surging or air lifting, overpumping and backwashing, high velocity jetting, bailing, and hydrofracturing. Chemical techniques include acidizing and the use of non-phosphorus-containing dispersants.

## Mechanical Techniques

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### **Mechanical Surging**

*Initial mechanical surging should be gentle, working 3 foot sections of the screen or open borehole at a time. Sediment in the well should be bailed out or removed periodically to prevent fine materials from reentering the aquifer.*

---

This is the most commonly used development method for a cable tool rig and is the method that requires the least amount of equipment. A surge block is made to fit the inner diameter of the casing and can be either solid or with a flapper valve. The block is made of layers of hard material with leather washers between them to effectively seal against the inner diameter of the casing. By raising and lowering the block in the casing above the screen, a two-way washing action is created through the screen openings. This gentle surging action breaks up muds and removes fine materials from behind the screen, or cuttings and fine materials that may be trapped in fractures in an open bedrock borehole. This material should be periodically removed by a flapper-type bailer, a sand pump, or by air lifting. For fine formations and /or shallow wells, the surging action must be started slowly to avoid any wash out alongside the casing. Alternate surging and bailing should continue and gradually increase in vigor until the well is sand-free.

### **Air Surging or Air Lifting**

*Air surging should be conducted at 1 to 2 times the design capacity of the well. Fine materials should be periodically removed by air lifting when the water becomes turbid. The well should be developed in 5 foot sections starting near the top of the screen or open borehole. Do not inject air into the screen. This method should be used cautiously with low-yielding wells.*

---

Compressed air may be used to develop wells in both consolidated and unconsolidated formations. The air surging method uses compressed air injected into the well to lift water to the surface. The air is then turned off, allowing the column of aerated water to fall back into the well, reversing flow back into the aquifer. This operation is performed repeatedly until the water is turbid; then the fine material must be bailed or airlifted from the well. The same two-way washing action achieved by mechanical surging can be performed with this system. The discharge produced from airlifting is dependent on the air volume available, the total lift required, the percent of submergence of the air line, and the annular area of the well. Several criteria must be met for successful air surging/lifting and the airline and eductor pipes must be sized correctly. The airlift will only operate with minimum percentage submergence, generally 60% for wells with 100 to 200 feet of total lift required (Driscoll, 1986). Sufficient uphole velocities must be maintained to discharge water and fine materials from the well. Driscoll (1986) lists the recommended pipe sizes for airlift pumping. Air surging/lifting can be performed as a single pipe system open or closed to the atmosphere, or as a two-pipe system (U.S. EPA, 1975). Caution must be used when using the casing as the eductor pipe. Air should not be injected into the screens as this may cause the formation or gravel pack to be lifted upwards out of place on the outside of the screen. Do not place the air outlet at the bottom of the well to flush out the fines before the well has been thoroughly developed and the formation has settled on the outside of the screen. In low yield wells with high static levels, the hole should not be blown at the start of the development procedure. This will blow all the water out of the well, creating a large pressure differential. There will be no support from the inside of the well to hold the loose formation slumping down, causing premature well failure to occur with the collapse of the casing or the screen.

### **Overpumping and Backwashing**

*Overpumping and backwashing should be used alternately to achieve maximum development of the well. Overpumping should be performed in steps up to 1.5 times the design capacity of the well.*

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The extra high velocities created by overpumping will cause the fine material to be washed in through the screen. This method results in a one-way flow and may lead to bridging or packing against the screen, which will limit the amount of development that can be performed by restricting the flow of fines into the well. Most of the development will also only occur in the permeable zone adjacent to the screen. These high velocities are achieved by pumping the well with a pump that has a capacity of more than 10 times the anticipated flow rate of the well when in production. Overpumping is often combined with backwashing to prevent bridging and compaction of the fine materials. This is achieved by switching off the pump and allowing the water in the column to flow back down into the well. The non-return valve in the pump must be removed to allow the backwashing action to occur.

There are obvious limitations to this system. There has to be enough head of water in the column to generate enough pressure for sufficient backwashing to occur. If the pump to be permanently installed in the well is to be used for development, then it must be set above the screen in the casing to avoid being damaged by all the fine sand coming into the well. A bailer or sand pump will need to be used to remove the fine material and sand after the backwashing and overpumping.

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### **High Velocity Water Jetting**

*High velocity water jetting should be performed simultaneously with air lift pumping. The outside diameter of the jetting tool should be 1 inch less than the screen inside diameter. The minimum exit velocity of the water should be 150 feet/second. The tool should be rotated at a speed less than one rpm, should concentrate on one 4-5 inch area of the screen at a time, working over a 3 foot section of screen. Jetting should proceed from the bottom of the screen to the top, with pumping from the well occurring at 15-25 percent more than the rate of jetting.*

---

High velocity water jetting involves forcing water through the screen openings, agitating and rearranging the formation materials. Water enters the screen openings at the jets and reenters the well above and below the jets carrying the fine materials into the well. Jetting is often combined with air lifting to then remove the fines from the well. High velocity water jetting works most effectively on highly stratified, unconsolidated formations and consolidated bedrock formations such as sandstones. This system is one of the most successful methods that can be used for development with a continuous slot or wire wrapped screen. It is 100% controllable and can be accurately used to ensure that the entire intake portion of the well is developed.

A jetting tool is connected to the drill string, with the nozzles in the tool sized to suit the pressures and volumes required for the application. The diameter of the tool must be correctly sized to the diameter of the screen used. The pumps and availability of water required must be taken into consideration. The high pressure water jets can be directed at all parts of the formation by rotating and raising and lowering the tool. A screen with the optimum open area must be used to allow the water jets to be able to reach all of the formation. This technique needs to be carefully controlled and caution must be used to avoid jetting for too long a period at a time. This will cause water to flow from inside the well to the outside, and will force all of the fine material to remain in the formation. To avoid this, the well should be pumped at the same time as the jetting is done. The pumping rate should be 15 to 25 percent higher than the injection rate used for jetting. Alternatively, the jetting could be done for a limited period of time, and then the well pumped for at least 30% longer than the jetting time used.

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### **Bailing**

*Bailing should be used to alternately create a pumping and backwashing action to effectively develop the well. Initial development action should be gentle and increase to higher bailing speeds as development proceeds. Fine materials must be removed periodically.*

---

Bailing can be a reasonably effective system to use for low yield, small diameter, or shallow wells. The bailer is used to alternately create a pumping and backwashing action, and then used to remove fines from the well. Initial bailing and surging should be slow, then increased with vigor to effectively create the two-way washing action. Fine material should be removed periodically from the well. The bailer size is very important as it has to be able to remove a suitable amount of water on each stroke without becoming too heavy to operate for the equipment being used. The bailer must be sized to suit the diameter of the casing and the screen. For telescopic screens, caution must be used when running the bailer into the smaller diameter screen.

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### **Hydrofracturing**

*Hydraulic pressure applied rapidly in a focused fashion can be used to open existing fractures in low-yielding bedrock aquifers. Proper use of this method requires knowledge of the well's construction and experience with the type of lithology comprising the aquifer.*

---

Hydrofracturing is accomplished by applying hydraulic pressure to a sealed zone in the well. Typically, water is pumped into a well at pressures between 1000 and 3000 psi using a high-pressure piston pump. The zone of interest is sealed by a packer assembly. Single or straddle packer assemblies can be used, although the single packer method is more common. The force of the injected water will open any preexisting fractures in the bedrock, thus increasing yield to the well (ADITC, 1997).

## Chemical Techniques

Chemical techniques are used in conjunction with the mechanical techniques to enhance the effectiveness of the development process and to decrease the amount of time necessary for development. The most common chemical additives for well development are **dispersing agents** and acids.

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### **Dispersing Agents**

*Non-phosphorus-containing dispersing agents should be used only when necessary and should be pre-mixed and used according to the manufacturer's recommendations. Chlorine should be added to the mix water to prevent bacterial growth.*

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By adding dispersing agents to the well or the jetting water, the clays and fine materials are broken down and washed out of the formations and the gravel packs more easily than with plain water. Dispersing agents will break down the mud cakes on the wall of the well and increase the effectiveness of the development technique used. The most commonly used dispersing agents are polyphosphates. However, the phosphorus in these compounds attaches to the clays, and serves as nutrition for any biofouling microflora present. These phosphorus-containing compounds are usually not developed out sufficiently to avoid biofouling. Instead, manufacturers have developed polyacrylamide and other non-phosphorus-containing dispersants to eliminate problems with biofouling (NGWA, 1998 and Mansuy, 1999).

Dispersing agents should be used **only when absolutely necessary**; typically, they are used for an extraordinarily bad interbedded clay situation, or because of poor drilling mud control. Chlorine is often added to the water to minimize the occurrence of bacterial growth; yet in some cases, chlorination may encourage bacterial growth by breaking down long-chain polymers and making phosphorus more available as a nutrient (Smith, pers. comm., 1999).

These dispersing agents only work on contact with the clays and muds. The mechanical surging and jetting allows the dispersants to operate effectively. Excessive doses and high concentration mixes should not be used. Dispersants should not be left in the well for prolonged periods of time without agitation and or mixing as the full benefit of the contact with the muds will not be achieved. Dispersants should not be used in formations that have thinly bedded clays and sands; the chemicals tend to make the clays unstable near the borehole, causing mixing with the sand and reduction in the permeability of the formation.

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### **Acids**

*Acids should be used as necessary and according to the manufacturer's instructions. Proper pH must be maintained in the borehole to ensure the effective action of the acid.*

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The use of acids in certain formations, such as limestones, dolomites, and sandstones with calcium carbonate-based cement, will often increase the effectiveness of well development due to their ability to remove carbonate. These acids should be high-quality (NSF-rated or equivalent) HCl, not muriatic grades. The treatment should be light; that is 15% or less in solution (Smith, pers. comm., 1999). Acids only work on contact; therefore, they should not be used until all clays have been removed during the initial cleaning with the dispersing agents. Acids must be used with extreme caution; the fumes often are more lethal than the product itself. Proper ventilation is vital and protective clothing must be used. The pH must be monitored and maintained in the well to preserve the effectiveness of the acid. The acid solution must be neutralized before discharging from the well.

## Well Testing

### Testing For Quantity

After a well is completed and developed, a test should be performed to determine the rate at which water can be reliably produced. Simple tests that can be performed while the drilling rig is still over the well are usually sufficient to estimate the capacity of a well drilled for domestic uses. For larger capacity supplies, pumping tests should be conducted to determine (1) the performance characteristics of the well and (2) the hydraulic characteristics of the aquifer. The level of effort and degree of sophistication required for these pumping tests should be based on the quantity of water that will be used and the resource potential of the aquifer. In certain situations, more careful testing may be necessary regardless of the size of the supply if the desired well capacity is at or near the limit of the reasonable expectation for that hydrogeologic setting.

Pumping test data, taken under controlled conditions, give a measure of the productive capacity of a completed well and will provide information needed for the selection of pumping equipment. An accurate

test of a well before the pump is selected pays for itself by assuring that the pump will perform efficiently and reliably. Many times, unsatisfactory pump performance is due to an improperly selected pump rather than a problem with the well itself. Long term reliability of the system can be ensured when the performance characteristics of the pump are appropriately matched to the performance characteristics of the well.

Another purpose of pumping tests is to provide data from which the principal factors that govern aquifer performance can be determined. This type of test is called an aquifer test because it is primarily the aquifer characteristics that are being determined, even though the well performance characteristics can also be calculated. Aquifer tests can be used to predict or estimate (1) the effect of new withdrawals on existing wells, (2) the drawdown in a well at future times and at different pumping rates, (3) the radius of the cone of influence for individual or multiple wells, and (4) the amount of recharge potentially available. Aquifer tests are necessary for larger systems and where the dynamics of multiple wells and pumping centers add complexity to the hydrogeologic setting.

The pumping test method selected depends on the type and classification of well to be tested along with the type of information the tester wishes to obtain from the test. The purpose of this section is to provide a classification for wells based on design capacity, and recommend pump test methods suitable for a particular classification of well.

Data from a pumping test should be thoroughly analyzed by a ground water professional prior to determining the design pumping rate. Data from a pumping test using the step-drawdown tests and aquifer tests should be analyzed by a professional hydrogeologist.

### Guidelines For Quantity Testing Requirements

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*Two types of pumping tests are used for potable water wells. Well tests are used to determine the performance of a particular well. Step-drawdown pumping tests and constant rate pumping tests are the primary methods for evaluation of well performance. Aquifer tests are used to determine the hydraulic characteristics of the aquifer being tested. Selection of the type of test conducted depends on the data one wishes to obtain from the test and the well classification being tested.*

*For the purpose of these guidelines, wells are classified into four types based on estimated well production in gallons per day. The classifications are very low use (domestic), low use, medium use and high use as indicated in the table below.*

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Table 2. Well Use Classification

CLASSIFICATION	AVERAGE DAILY USAGE (GPD)
Very low use (domestic)	<1000
Low use	1000 to < 10,000
Medium use	10,000 to 100,000
High use	>100,000

In developing a potable ground water supply system, the well driller or designer must consider both the capacity of the proposed well and the user's estimated water demand needs. Well capacity can be defined as the volume of water per unit time that can be discharged from a well without pumping the well dry or damaging the aquifer. An estimate of the users average daily water demand needs can be determined using historical usage data (meter readings), fixture counts, or calculation using information contained in Table 1, found in Appendix III. Once the average daily water demand has been estimated, peak hourly demand can be calculated using the following equation:

$$\text{Average Daily Demand} \times 10 = \text{Peak Hourly Demand}$$

Public water systems utilizing a hydropneumatic pressure system must have sufficient well capacity to meet peak hourly water demand. Failure to meet peak hourly demand with a single well may require either additional wells to be developed, or installation of a water storage tank. Private (domestic) water systems must have sufficient capacity to meet the intended user's water demand needs.

In most cases, if the well driller or designer thinks that the well capacity meets or exceeds the estimated peak hourly demand, a pumping test conducted at the peak hourly demand rate for a predetermined duration would be sufficient. Unfortunately, many wells do not have sufficient capacity to sustain a peak hourly flow rate. These guidelines will establish criteria for pump testing wells that cannot sustain or are not designed to meet peak hourly demands.

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**Very low use (domestic)**

*For very low use (< 1000 GPD) domestic wells, well tests utilizing the bailing test method, the air blow test method, the air lift test method or the variable pumping rate method are recommended.*

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Guidance for conducting these types of well tests will be discussed in the Simple Tests To Estimate Well Performance section of Appendix III.

The method selected should be based on the driller's experience, equipment capability, site specific conditions, and accuracy required to make reliable judgements as to well yield and pump size needed. In some circumstances it may be necessary to perform more elaborate pumping tests on domestic wells, if more precise data is required to determine a reliable well yield. Pumping tests on domestic and public supply wells are sometimes used to evaluate the capability of an area to support the development of a subdivision that will rely on individual wells. Pumping tests should be designed to reflect the hydrogeologic conditions of the area.

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**Low use**

*For low use wells ( 1000 to < 10,000 GPD), a well test utilizing the constant rate pumping method is recommended.*

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A constant rate pump test can be conducted at the peak hourly demand rate (10 times the daily average demand). A constant rate pump test at this rate for the duration the well may be in operation would demonstrate that the well could sustain peak flows under all service conditions. In cases where the well cannot sustain peak hourly flow for the entire period of normal operation, the constant rate pump test should be conducted at 1.5 times the user's needed design capacity for the duration the well may be in operation. Testing should be related to the well's intended use.

For example:

A high school with 500 students & 20 staff members wishes to drill a new well. The school is normally open 12 hours per day. The existing system does not include a water meter, thus no historical data exists and the average daily demand must be estimated using Table 1 in Appendix III.

500 students @ 20 gpd/student	10,000 GPD
20 staff members @ 20 gpd/staff	<u>+ 400 GPD</u>
	= 10,400 GPD (7.2 gpm)

Using equation 1, calculate the peak hourly demand:  $7.2 \text{ gpm} \times 10 = 72 \text{ gpm}$

At this point, a step test with at least three steps can be used to extrapolate pumping levels at higher pumping rates. Or, it would also be possible to use the "variable pumping rate method" described in Appendix III. If the results from either test indicate that the proposed well can sustain the peak hourly rate of 72 gpm for 12 hours, this should be the minimum rate and duration that the constant rate pumping test is conducted. If the test results indicate that the well cannot sustain the peak hourly rate for 12 hours, a design capacity for the well must be determined, and the constant rate pumping test conducted for 12 hours at 1.5 times the design capacity. The need for additional wells or water storage to meet the peak hourly demand of 72 gpm must then be evaluated.

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**Medium use**

*For medium use wells (10,000 to 100,000 GPD), a well test utilizing the constant rate pumping method should be conducted for a minimum 24 hour period at 1.5 times the design well capacity or at the estimated peak hourly demand rate, whichever is attainable in the well driller or designer's judgement.*

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A proposed well utilizing a hydropneumatic pressure system must meet the peak hourly demand unless additional wells or water storage is available. A step-drawdown pumping test should be utilized to collect

additional information on well performance which can assist the well designer in determining optimum pumping rate and pump-setting depth. In complex hydrogeologic settings, pumping centers with multiple wells, and/or areas where desired capacity approaches the resource potential, aquifer tests should be conducted under the supervision of a professional hydrogeologist. Again, testing should be related to the design capacity of the well or its intended use.

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**High use**

*For high use wells (> 100,000 GPD), an aquifer test is recommended. As stated above, aquifer tests should be conducted under the supervision of a professional hydrogeologist.*

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A step-drawdown pumping test should be utilized to collect information on well performance and efficiency which can assist the well designer in determining optimum pumping rate and pump-setting depth. Upon determination of a design well capacity from data obtained in the step-drawdown test, a constant rate pump test at 1.5 times the design well capacity should be conducted for a minimum 24 hour period.

A more detailed discussion of the testing methodology recommended here can be found in Appendix III.

## Testing For Quality

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**Private water systems wells**

*Private water systems (domestic) wells should be sampled for total coliform bacteria as a general indicator of the presence or absence of bacteria in the system. When the well tests positive for total coliform after a minimum of 3 successive chlorination attempts, then the well should be sampled and tested for e-coli. Wells should also be tested for nitrates. In certain geologic formations across the state, naturally occurring constituents may be present, such as arsenic, barium, strontium, or radioactivity. If these constituents are known or suspected to exist in the ground water, then wells should also be tested for their presence. In areas of known man-made contamination, wells should be tested for volatile organic compounds (VOC s) which may include BTEX (benzene, toluene, ethylene, xylene), semi-volatile organic compounds (SVOC s) or as deemed appropriate by the regulating state agency. At a minimum, homeowners should test their well(s) once a year for total coliform.*

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Raw water samples should be collected and analyzed after all traces of development and disinfectant chemicals have been completely flushed from the well and the plumbing system. If the well is being sampled after alterations or rehabilitation on the well has been performed, it is critical that all mineral encrustation and bacterial slimes have been effectively removed from the well as they may provide a substrate for coliform bacterial growth. The presence of nonpathogenic heterotrophic bacteria in the subsurface that are attached to these substrates can contribute to total positive coliform results. After well alteration or rehabilitation has been completed, the well should be completely flushed by pumping to remove at least 2-3 borehole volumes of water, or ideally, a pumping test could be performed.

Appendix IV describes correct procedures for water sample collection. If sample collection is made at the tap, then chlorination of all plumbing, tanks, etc., must occur prior to sample collection. To sample the water from the well only, the sample should be collected at a point in the line or system before it reaches the pressure tank. At least 2-3 borehole volumes of water should be removed from the well prior to sampling to ensure that the water collected is coming from the aquifer.

If laboratory analysis of coliform bacteria test shows the raw water sample as unacceptable (coliform positive), disinfection of the entire system should be performed and sampling should be repeated. If the samples results are still coliform-positive, chlorination should be repeated and the subsequent sample collected from the well at a point prior to the pressure tank to determine whether the source of contamination is in the well or the plumbing system. Chlorinate the well and/or system again as necessary and collect a subsequent sample. Contact the local health department to perform an investigation if three sets of unacceptable samples are obtained. If more than three unacceptable samples are obtained, then sampling for e-coli to determine speciation should be performed to help determine the source of contamination. Assume a structural problem if total coliform positives persist. Look for indications of routes for contamination to reach a well (e.g., a broken sewer cleanout near a swale where a well is completed in shallow bedrock). Conduct a borehole TV survey and repair problems if possible, or plug the well and redrill in a safe location.

Other chemical constituents the intended water user may wish to have the well sampled for can include mineral content or hardness. Mineral content and hardness have little effect on the potability of water, but their removal from the potable water may be necessary for aesthetic and economic reasons. Depending on the intended use of the well, the user may want other tests performed if specific water quality parameters are required.

### **Public water system wells**

*All new potable water wells developed to serve a public water system must be sampled for total coliform bacteria and chemical parameters as required by the director of the Ohio EPA.*

Contact the appropriate district office of the Ohio EPA, Division of Drinking and Ground Waters for sample collection procedures and a list of required analysis for new wells to be used by public water supplies. All microbiological and chemical analyses conducted on a public water system water source must be analyzed by a laboratory certified for such analysis by the Ohio EPA.

### **Chemical sampling**

Collection, preservation and analysis of any additional raw water samples should be conducted in accordance with guidelines found in the latest edition of *Standard Methods For the Examination of Water and Wastewater*. Contact an appropriate contracting laboratory for information and guidance.

### **Well Completion**

The proper completion of the well is as important as the proper construction. The well must be completed so that it is protected from surface contamination and physical damage. Well completion involves the finished height of the well casing above grade, the installation of a pitless device, vent pipe, and the well cap. Physical protection for the exposed well casing should be a consideration in areas of high traffic. Installation of the pump and associated equipment is also part of the completion process, but it will not be addressed in this guidance.

#### **Pitless Devices**

*Pitless devices, whether adaptors or pre-assembled units, should be installed by an experienced contractor below the frost line (typically 32" below the ground surface or greater, depending on local conditions, or use 48" if frost line is unknown). These devices should meet PAS97 Standards established by the Water Systems Council.*

Buried well seals and well pit installations are not considered satisfactory for adequately protecting the well from contamination. A pitless device will protect the well by allowing the pump to discharge through the side of the well casing while preventing the intrusion of potentially contaminated water from the ground surface. Pitless devices must be installed whenever the pump discharge piping exits the casing below grade (see Figure 14).

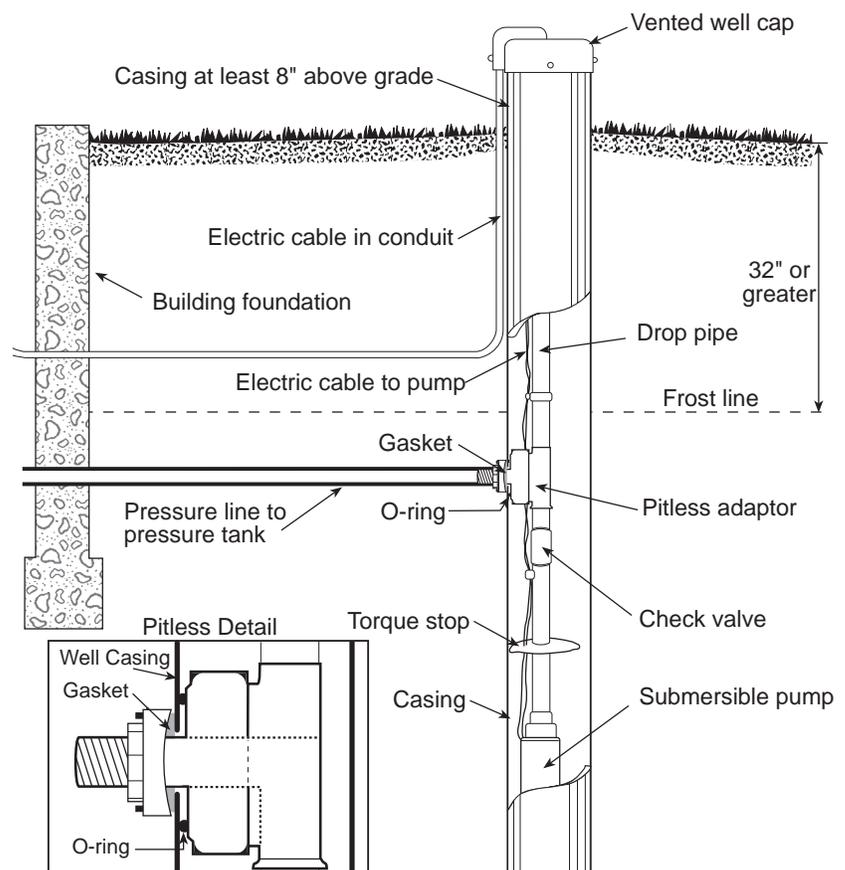


Figure 14. Example of pitless adapter installation.

Pitless devices are constructed so that they seal tightly against the sides of the well casing. Therefore, the hole made in the casing for the installation of the pitless device should be cut with a hole saw or other tool capable of making a clean and uniform hole to allow proper sealing. A cutting torch is not recommended for creating the hole, as this method can easily lead to irregular or oversized holes that have rough surfaces.

The pitless device must be installed below the frost line to protect from freezing. Frost line data can be obtained from county soil surveys, or, lacking that information, a minimum depth of 32-48 inches is recommended as a working standard.

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**Non-pitless Devices**

*A pitless device may not be necessary if an above-ground discharge is used. Seals and vents should be used to provide physical protection from potential damage, adverse weather conditions, and contamination. There should also be a convenient access to measure water levels.*

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In this situation, an above-ground well seal could be used in place of a pitless device and the well cap. Easy access for water level measurements should always be provided, especially if a steel plate is permanently welded to the top of the well casing.

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**Distribution Line**

*All plumbing materials used for the distribution line from the pitless adaptor to the pressure tank should be in compliance with AWWA or NSF standards.*

**Sample Tap or Port**

*Sample taps or ports should be installed prior to the pressure tank at a reasonable height to facilitate the collection of water samples. No drainback frost-free hydrants should be used for this purpose. If an outside or wellhead tap is needed, use blowout type sampling hydrants designed for this purpose.*

**Casing Termination and Surface Completion**

*The casing height above finished grade should be a minimum of 12" for all wells, but localized conditions may necessitate the use of more casing if the well is located in an area prone to flood events. For all wells, drainage away from the well casing is recommended.*

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The top of the casing at its finished height should be cut so that its surface will fit flush with the well cap and properly seal the top of the casing. The portion of the casing that extends above the ground surface must be of a size so that standard well caps will fit properly. Large diameter excavated wells should be finished with an impermeable surface seal sloping away from the well and extending beyond the edges of the excavation. Drive point wells should be fitted with a tee to facilitate access to the well.

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**Well Caps**

*All well caps/seals should form an insect-tight seal with the top of the casing to prevent entry of insects or other pests and meet the standards of PAS-97. Caps/seals should be secured with screws or other appropriate hardware. Well caps used on wells located in floodplains or areas subject to flooding should form watertight seals with the casing.*

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Well caps should be secured to discourage unauthorized removal and the entry of insects and pests. Well caps should meet standards set by the Water Systems Council under PAS-97.

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**Vents**

*All types of wells should be vented. Vent piping should be self-draining and screened with a noncorroding, 24 mesh (.043") minimum size screen that prevents the entry of insects. For wells located in a floodplain, the vent must extend 3' above the 100-year flood elevation.*

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Venting of all wells is essential to maintain equalized air pressure and prevent increased dissolved gas introduction into the well. Vent pipes for wells in floodplains should be turned down and reinforced or attached to a stable object to reduce damage during flood events.

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**Physical Protection**

*Well casing should be physically protected when the well is located in a high traffic area.*

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Physical protection for the well casing should be considered when a well is located where it may be subject to damage. Damage to the exposed casing could allow surface contaminants to reach the aquifer. Barriers, such

as guard posts or a well house, should be considered when a well is located near a high traffic area. The use of concrete pads is discouraged, unless the likelihood of cracking and heaving can be alleviated.

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### ***Super Chlorination (Shock Disinfection)***

*A well should be chemically disinfected by calculating the amount and concentration of chlorine necessary for complete disinfection based on well depth and volume of water in the borehole. Initial chlorine concentrations equivalent to 250 mg/l (or ppm) for new wells and 500 mg/l for existing wells should be maintained for a minimum contact time of 8 hours unless the pH of the water in the well is controlled. Always exercise caution when using chlorine in its various forms; follow handling instructions on the label carefully. When using bleach products, use only unscented varieties.*

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A properly constructed drilled well is regarded as the most sanitary type of private water system. A well should be maintained in a sanitary manner through all stages of the construction process to protect public health and the ground water resource. All equipment should be cleaned and disinfected periodically while the well is under construction and the well chemically disinfected upon completion. All equipment and well construction materials should be kept off of the ground to prevent contamination by soil and pathogenic bacteria.

Sodium hypochlorite (liquid) or calcium hypochlorite (granular or pellet form) are readily available products that can be used for the disinfection of wells. Concentrations of 500 mg/l are recommended for disinfection of existing wells in Ohio due to the presence of bacterial slime, iron, manganese, total organic carbon, and variability in pH. A disinfectant solution of 250 mg/l is recommended for new wells. Actual chlorine concentrations will vary over the period of disinfection due to the presence of these constituents and variable water chemistry in the borehole. The addition of chlorine products to a well causes a rise in the pH of the water in the well. The biocidal activity of the chlorine is reduced with increasing pH, with minimal biocidal capability at a pH equal to or greater than 9. Where pH levels are greater than 8, a buffering agent or mild acid will need to be added to reduce pH levels from 6 to 7.5 to ensure maximum effectiveness of the chlorine. Buffering agents can include mild acids such as acetic (vinegar), citric acid, or commercially available buffering solutions. When pH levels are controlled, chlorination contact time can be reduced to 30 minutes. Chlorine concentrations in the well may decline over time as the chlorine reacts with these constituents reducing the free available chlorine. Concentrations of 500 mg/l will also help ensure that proper disinfection will occur over the estimated contact time even if some of the chlorine reacts with other constituents in the well. Theoretically, the contact time needed to complete disinfection at this concentration should be only moments after contacting the microorganism. However, since the chlorine must actually contact all microorganisms, the solution should remain in the well and plumbing for at least several hours to help ensure uniform dispersal of the chlorine solution and provide the greatest opportunity to kill all microorganisms.

The gallons of water to be disinfected should be determined by calculating the total amount of water stored in the well and all related storage, or pressure tanks, existing plumbing and attached fixtures. When calcium hypochlorite is used for disinfection, the tablets or granules should be completely dissolved in water prior to placement into the well. Sodium hypochlorite solutions should be used within the manufacturer's posted expiration date. Sodium hypochlorite solutions with fragrance additives should not be used for disinfection. Sodium hypochlorite and calcium hypochlorite should not be mixed with other chemicals for disinfection purposes and all manufacturer's directions must be followed.

An appropriate amount of disinfectant to make a 250 or 500 mg/l chlorine solution, as calculated from Tables 2 and 3, should be placed into the well. Calcium hypochlorite should not be used on wells completed in limestone aquifers, or where the water has high levels of dissolved calcium due to the formation of calcium hydroxide or calcium carbonate precipitates in the well that may cause well yield losses. The water in the well should be agitated or surged to ensure even dispersal of the disinfectant throughout the entire water column. Chlorinated water in the well should be recirculated to wash down the sides of the well casing for a minimum of ten minutes. Chlorinated water should then be circulated through the distribution system and the plumbing within the dwelling or building.

In some instances, where traditional disinfection methods do not appear to be sanitizing the water system, more stringent procedures can be employed. This may include the use of a surge block or jetting tool, or an inflatable packer to help force the chlorine solution back into the formation. The addition of a slug of chlorine solution 1 to 2 times the well bore volume into the well can also be performed to try to

Table 3. Volume of Water in Well

Diameter of Well (inches)	Gallons per Foot of Water
3	0.37
4	0.65
5	1.0
6	1.5
8	2.6

Table 4. Amount of Chlorine Added to 100 Gallons of Water for Disinfection

Chlorine concentration (parts per million or mg/l)	Gallons of 5.25% sodium hypochlorite liquid bleach	Pounds of dry calcium hypochlorite	Minimum contact time
250mg/l	0.5 gallons	0.38 pounds	8 hours
500mg/l	1 gallons	0.75 pounds	8 hours

force chlorinated water into the formation. Increasing the concentration above 1000 mg/l will not improve the chances of sanitizing the well. The key to successful chlorination is to actually force the sterilant into contact with all surfaces that need disinfection. In some older wells and water systems bacteria may be protected by mineral scale and/or the formation of bacterial slime layers over their surfaces. These bacterial havens can be removed by agitation, physical surging, or the use of well rehabilitation acids to dissolve and remove scale before disinfection. Any acids used to remove mineral scale or bacterial slimes must be completely removed from the well prior to the addition of chlorine to prevent the development of toxic gases.

The removal of protective bacterial slime layers has been a subject of much discussion. There is some indication that slime layer thickness may actually increase with increased chlorination. Therefore, the casing may need some sort of scrubbing to physically remove the protective barrier prior to chlorination treatments. Old plumbing can present problems, especially where work has been done that leaves dead ends that the chlorine cannot reach. In these cases, the dead ends in the plumbing system should be eliminated prior to another shock treatment.

After the appropriate amount of chlorine has been added to the well, and any mechanical procedures, such as agitation, surging, scrubbing, etc., have been performed, pump to waste until clear, then turn on all of the spigots in the building until chlorine is detected by smell and immediately shut off. The water softener should not be bypassed because the resin bed may be harboring microbiological growth. The softener should receive the same disinfection treatment as the rest of the system, even though there is a chance of slightly reducing the life of the resin bed. The chlorine solution is generally left in the well and plumbing for a minimum of 8 hours and no more than 24 hours and then disposed of properly. Chlorinated water from the well and plumbing should not be discharged to the septic system or local streams or rivers without dechlorination. It is better to wait until a few days after this process to take a water sample to allow time for the remaining chlorine to dissipate. The water should be tested for a chlorine residual just prior to sampling. A water sample should never be taken from a well if there is any chlorine residual remaining in the well.

## Well Maintenance

*Effective well maintenance requires the selection of well materials and design that will retard and/or prevent corrosion and biofouling, regular monitoring of well performance and water quality as indicators of possible deterioration, good record keeping of well performance and maintenance, and preventative treatments to prevent well deterioration in the early stages. Any chemicals or additives used for well maintenance should meet NSF Standard 61.*

Well maintenance is a scheduled process of testing, inspection, repair and treatment to maintain well performance and water quality. Effective well maintenance will delay the need for extensive and expen-

sive well rehabilitation and may make rehabilitation unnecessary. Preventative maintenance will serve to limit or retard well deterioration over time, and is more effective and less costly than well rehabilitation due to crisis conditions.

Proper selection of well drilling and construction materials is necessary to minimize **corrosion**, other types of casing failure, or **biofouling**. Particular care should be made in the selection of steel casings, collars, fittings, and screens to prevent or minimize the development of galvanic corrosion due to contact between unlike metals. See NGWA (1998) for specific guidance in material selection.

Regular monitoring of well performance and water quality is essential to detect the early stages of well deterioration. Well testing using continuous or variable rate tests are commonly performed after the well is drilled. Information on the date of the test, test rate and duration, yield and drawdown should be carefully recorded on the well log and, if the test is more comprehensive, on appropriate pumping test forms. Benchmark step tests permit valid assessment of performance changes later in aquifer loss, well loss, and pump efficiency (Helweg et al., 1983, and Borch et al., 1993). Depending on the extent of the data collected, **specific capacity** and **well efficiency** can be calculated. Similar performance tests conducted at later dates can be compared with the original values obtained after the well was first drilled. Modest variations in these values can be an indicator of well deterioration. Significant deterioration (variations greater than 10 to 15%) indicate the need for aggressive well rehabilitation (Driscoll, 1986). Smaller capacity wells, such as domestic wells, should be tested at least once every several years, whereas large capacity wells should be tested on a yearly basis or even more frequently (Gass, et al., 1980). Testing for water quality should also be conducted on a relatively frequent basis depending on the well use. Water quality testing on a regular basis will indicate contamination and the beginning stages of biofouling. A total coliform test is an indicator of the presence of contamination which suggests a pathway for contaminants to enter a well. Total coliform tests will not detect the large majority of biofouling organisms. The use of a combination of available cultural (e.g. BART) and microscopy-based (e.g. Standard Methods Section 9240) indicator tests must be used to detect biofouling. Microscopy alone is not sufficient. Smith (1992 and 1996) offers protocols for maintenance water quality testing. Chemical analysis for iron, manganese, pH, total organic carbon, total phosphorous, and nitrogen (as ammonia-N, nitrate-N and organic-N) in addition to conductivity, and total dissolved solids can be used as important indicators that conditions favor well deterioration (Smith, 1998).

Accurate records should be kept of all aspects of well construction, testing, maintenance and/or rehabilitation. A well log and drilling report must be accurately and completely recorded for each well. Testing and maintenance results, dates, and the contractor who performed the work should also be carefully recorded and kept in a safe and accessible place. This information can be very critical when trying to diagnose future well problems.

Preventative well treatments should be applied on a regular schedule and consist of a lighter form of treatment than is typically used for well rehabilitation. Where light biofouling has occurred, shock chlorination methods described in Appendix V of this document may be used. **Chelating agents** and organic acids may also be employed with surging and agitation to retard and/or remove more significant biofouling and encrustation. Any maintenance and or rehabilitation techniques beyond simple chlorination should be performed by a qualified and knowledgeable well contractor.

## Well Alterations

Well alterations can consist of changes made to the well above the ground surface or below. According to the Ohio Department of Health's Private Water Systems rules (Ohio Administrative Code Chapter 3701-28), an alteration "means a major change in the type of construction or configuration of a private water system, including but not limited to adding a disinfection or treatment device, converting a water well with a buried seal to a well with a pitless adapter or well house installation; extending a distribution system; converting a well using a well pit to a well with a pitless adapter or well house type of construction; extending the casing above ground; deepening a well; changing the type of pumping equipment when that requires making new holes or sealing or plugging existing holes in the casing or wall of a well; repairing, extending or replacing any portion or the inside or outside casing or wall, or of the walls of a spring or cistern that extend below ground level." For the Ohio Department of Natural Resources, Division of Water (Ohio Revised Code Section 1521.05), altering any type of well defined in this section of the ORC "means changing the configuration of a well, including, without limitation, deepening a well, extending or replacing any portion of the inside or outside casing or wall of a well that extends below ground level, plugging a portion of a well back to a certain depth, and reaming out a well to enlarge its original diameter."

## Reporting Requirements

The Ohio Department of Health requires that a permit be obtained for alterations prior to the start of work, except in the case of emergencies. A completion form must be filed with the department within 15 days of the completion of the alteration. Within 30 days of the completion of the alteration, a copy of the well log and drilling report submitted to the Ohio Department of Natural Resources (ODNR) must be filed with the department. The ODNR, Division of Water requires that a well log and drilling report be filed within 30 days of the completion of any of the alterations described in its definition. The Ohio Environmental Protection Agency requires that plans be submitted for any substantial change to a public water system and must be approved by the Director. Any public water supply system should contact the appropriate Ohio EPA district office regarding alterations to the system.

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### **Above-Ground Alterations**

*All couplings should be welded, threaded, or solvent welded to connect the existing well casing to the extension piece, and should form a watertight seal.*

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Above-ground alterations include casing extension to its required height above grade (12" minimum), addition or replacement of a pitless device, and installation of a surface seal for above-ground discharge. When extending the casing above grade, the mechanical coupling should not be used to connect the existing well casing with the extension piece. Instead, the coupling should be welded, threaded, or solvent welded to provide structural integrity. The coupling should form a watertight seal between the two casings. Information on pitless devices and surface seals can be found in the section on **Well Completion**. After all alterations have been completed, the well should be disinfected using the procedures described in the section on **Well Disinfection**.

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### **Below-Ground Alterations**

*All couplings, including mechanical, threaded, or welded, must maintain the structural integrity of the casing and/or liner and maintain a watertight seal. All liners must meet a minimum wall thickness of SDR 26 for PVC casing or ASTM A53, A589, or API Specification 5L. All couplings, threads, or solvents must meet related ANSI/NSF, ASTM or API standards. For public water supply wells, all couplings should comply with the requirements of ANSI/AWWA Standard A100.*

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Below-ground alterations include deepening a well, plugging back a well, reaming out a well, adding a liner, or extending buried casing above ground. Liners should be watertight to a depth of 25 feet and meet NSF Standard 61 or similar requirements. The minimum wall thickness of any liner installed should be equivalent to SDR 26, and may need to be thicker, depending on its use. Typically, liners are used either to repair casing or to keep the borehole open in friable consolidated formations. A liner should extend to the bottom of the pitless adapter so that it will be visible from the ground surface. When extending buried casing above ground, couplings used should be welded, threaded, or solvent cemented to ensure structural integrity. Mechanical couplings can be used if they are able to maintain structural integrity and are suitable for pressure pipe applications. The coupling seal should be watertight. For information on materials that should be used to plug back a well, refer to the *State of Ohio Technical Guidance Document for Sealing Unused Wells*, published in 1996. As mentioned above, once the alterations have been completed, the well should be disinfected before use.

## Temporary Wells and Other Types of Subsurface Installations

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*The design of temporary wells and subsurface installations must be protective of the ground water resources and prevent the infiltration of surface water and/or the mixing of water of different quality between multiple aquifers. Temporary wells and subsurface installations should follow the recommendations for well construction materials and installation procedures described previously in this document. Exceptions are described below.*

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A temporary well installation is a boring or well that is to be installed and used for **less than one year**. These typically include dewatering wells and a variety of test borings. Other types of subsurface structures may also be installed on a permanent basis that penetrate into aquifers but are not necessarily used for withdrawing or recharging water. These include elevator shafts, cathodic protection wells, ground wells, and open and closed loop vertical geothermal wells. It is critical that these permanent structures be properly designed and installed to prevent surface water contamination of aquifers, the leakage of oils or other chemicals from these structures, and intermixing of different quality ground waters when multiple aquifers

are penetrated. Wells installed for temporary sampling or withdrawal of ground water **must be properly abandoned and sealed** (for further information, refer to *State of Ohio Technical Guidance Document for Sealing Unused Wells*, published in 1996). Key issues and exceptions to the recommended procedures are described in the following discussions of each type of well and/or subsurface structure.

## Dewatering Wells

Because dewatering wells are often used to withdraw shallow ground water for construction purposes, grouting of the annular space can be minimized. Cuttings or clean gravel may be used to fill the annular space to within 5 feet of the ground surface. A minimum of 5 feet of grout must be placed in the annular space to the ground surface. Casing length required is dependent on the target zone to be dewatered, but casing length should be no less than 5 feet. Where dewatering of deeper aquifers is required, casing and proper grouting through the vadose zone and any upper aquifers should be installed. Dewatering wells should be properly capped during use. Dewatering wells installed in unique geologic conditions described previously in this document should follow the appropriate recommendations. These wells should be immediately sealed using methods described in the *State of Ohio Technical Guidance for Sealing Unused Wells* after dewatering has ceased.

## Test Borings

The installation of test borings should follow procedures identified in ASTM Standards D1452-80 (1995), D2113-83 (1993), D6151-97, and D5784-95. Test borings should not penetrate multiple aquifers and allow the mixing of water between aquifers. If multiple aquifers are to be penetrated, then casing and grouting should be installed and removed upon completion and sealing of the test boring. Test borings installed in unique geologic conditions described previously in this document should follow the appropriate recommendations. Proper sealing of test wells must be performed either according to the State of Ohio Technical Guidance for Sealing Unused Wells or ASTM Standard D-5299.

## Geothermal Wells

The installation of permanent open and closed loop vertical geothermal wells should follow the recommended materials and installation procedures described previously in this document for water wells. Closed loop vertical geothermal wells should be grouted the entire length of the borehole and only non-toxic transfer fluids should be used.

## Cathodic Protection and Ground Wells

Cathodic protection and ground wells should follow the recommended materials and installation procedures described previously in this document for water wells. These wells should be properly cased and grouted. The bottoms of these wells should be sealed to prevent the intrusion of ground water into the borehole where it could contact materials used to fill these wells. Any fill materials used should be nontoxic.

## Elevator Shafts

Elevator shafts should follow the recommended materials and installation procedures for water wells described previously in this document. All casings, liners and joints should be water tight and properly grouted. The bottom of the shaft must be properly sealed and should not serve as the drain for the pit. Shafts should not allow cross-contamination between aquifers. Double wall cylinder shaft installations are recommended. If single wall cylinder shafts are installed, then the borehole should be cased to the bottom of the excavation. Shafts completed in bedrock may have two casings, a surface casing set into the rock, and an inner casing set to the bottom of the shaft. The annular space between these casings should be grouted according to recommendations described previously in this document. Protection from leakage of hydraulic fluid can be achieved by either attaching a watertight cap or plate to the bottom of the casing and surrounding the casing with grout, by grouting the inside of the casing with at least two feet of neat cement or grout, or by encasing the cylinder in a Schedule 30 plastic outer pipe or sleeve with the bottom of the pipe or sleeve capped and the top extending above the pit floor. The plastic casing is not structural but serves as a container to catch any leaked hydraulic fluids.

## Conclusions

Since 1990, 143,385 well log and drilling reports were filed with the Department of Natural Resources, Division of Water for domestic, irrigation, monitoring, municipal, and other water supply wells drilled in Ohio. Consequently, an average of 15,932 potential conduits for ground water contamination have been

created each year during the 1990's. Considering the fact that about 40% of Ohio's population relies on ground water for its drinking water (Ohio EPA, 1987), it is essential that all newly installed wells be properly sited, constructed, developed, and tested to ensure the safety of our ground water resources. To reach that goal, consistent state standards are needed. This guidance was developed to set those standards in the form of recommendations.

The recommendations given in this document are general, and not intended to cover every conceivable contingency. Rather, they should serve as a guide to handling unique situations when they arise. Geologic conditions vary across the state, and may dictate changes in recommended procedures. Any questions as to the suitability of a particular procedure for certain conditions should be directed to the appropriate regulatory agency.

These recommendations do not constitute a guarantee or any implied guarantee regarding the performance of any well that has been drilled, altered or rehabilitated according to the recommendations in this document.

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## **Listing of American Society for Testing and Materials (ASTM) Standards Referenced**

A53	Standard Specification for Pipe, Steel, Black and Hot-Dipped, Zinc-Coated, Welded and Seamless
A106	Standard Specification for Seamless Carbon Steel Pipe for High-Temperature Service.
A500	Standard Specification for Cold-Formed Welded and Seamless Carbon Structural Tubing in Rounds and Shapes
A589	Standard Specification for Seamless and Welded Carbon Steel Water-Well Pipe
C150	Standard Specification for Portland Cement
C478	Standard Specification for Precast Reinforced Concrete Manhole Sections
C913	Standard Specification for Precast Concrete Water and Wastewater Structures
C990	Standard Specification for Joints for Concrete Pipe, Manholes, and Precast Box Sections using Preformed Flexible Joint Sealants
D1452	Standard Practice for Soil Investigation and Sampling by Auger Borings
D2113	Standard Practice for Diamond Core Drilling for Site Investigation
D5092	Standard Practice for Design and Installation of Ground Water Monitoring Wells in Aquifers
D5299	Standard Guide for Decommissioning of Ground Water Wells, Vadose Zone Monitoring Devices, Boreholes, and Other Devices for Environmental Activities
D5784	Standard Guide for Use of Hollow-Stem Augers for Geoenvironmental Exploration and Soil Sampling
D6151	Standard Practice for Using Hollow-Stem Augers for Geotechnical Exploration and Soil Sampling
F480	Standard Specifications for Thermoplastic Well Casing Pipe and Couplings Made in Standard Dimension Ratios (SDR) SCH40 and SCH80.

## **Listing of American Petroleum Institute (API) Standards Referenced**

Spec 5L	Line Pipe, Forty-First Edition, April 1, 1995
RP 5B1	Threading, Gauging, and Thread Inspection of Casing, Tubing, and Line Pipe Threads, Fourth Edition, December, 1996

## **Listing of National Sanitation Foundation (NSF) Standards Referenced**

NSF Standard 14	Plastic Piping System Components and Related Materials, 10/28/96
NSF Standard 61	Section 1 through 9 Drinking Water System Components, 9/25/97

## **Listing of Water Systems Council Standards Referenced**

PAS-97	Performance Standards and Recommended Installation Procedures For Sanitary Water Well Pitless Adaptors, Pitless Units, and Watertight Well Caps
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## Glossary

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<b>Annular seal:</b>	an impermeable material placed between the outside of the casing and the borehole, or between two casings, to prevent movement of fluids from the surface or between formations.
<b>Aquifer:</b>	a consolidated or unconsolidated geologic formation or series of formations that have the ability to receive, store, or transmit water to wells or springs.
<b>Artificial pack:</b>	filter pack materials placed directly around the screen.
<b>Backwashing:</b>	the surging effect or reversal of water flow in a well during the development process.
<b>Biofouling:</b>	biological growth in a well and/or the surrounding formation that interferes with the performance of a well.
<b>Borehole:</b>	a hole in the earth made by a drill; the uncased drill hole from the ground surface to the bottom of the well.
<b>Caliper log:</b>	simple logging device used to determine the diameter of a borehole, the presence of such features as swelling clays or fractures in limestones or sandstones, and the amount of borehole erosion.
<b>Casing:</b>	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.
<b>Chelating agents:</b>	substances that have the ability to sequester metal ions in solution and prevent them from combining chemically with other ions, used for well maintenance and rehabilitation.
<b>Cone of influence:</b>	the area, circular or elliptical in shape, in the ground water table or potentiometric surface affected by a pumping well.
<b>Confined aquifer:</b>	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.
<b>Corrosion:</b>	the act or process of dissolving or wearing away metals.
<b>Density:</b>	the mass or quantity of a substance per unit volume, usually expressed in grams per cubic centimeter.
<b>Dispersing agents:</b>	substances that have the ability to remove clays occurring naturally in the formation, and those introduced into the borehole as part of the drilling fluid, typically used during well development.
<b>Drawdown:</b>	the distance between the static water level and the pumping level.
<b>Effective grain size:</b>	the 90-percent-retained size of a sediment as determined from a grain-size analysis.
<b>Entrance velocity:</b>	speed at which water moves into a well screen, should not exceed 0.1 ft/sec.
<b>Filter pack:</b>	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.
<b>Gravity emplacement:</b>	material installation by free-fall into desired position.
<b>Ground water:</b>	any water below the surface of the earth in a zone of saturation.
<b>Hydrated:</b>	the incorporation of water into the chemical composition of a mineral.

<b>Hydrogeologic setting:</b>	a mappable unit with common hydrogeologic characteristics.
<b>Intake:</b>	screened or open borehole portion of a well that allows water to enter.
<b>Leaching:</b>	removal of mineral salts by solution.
<b>Mesh:</b>	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.
<b>Microannulus:</b>	the space between the sealing material and the casing and/or the formation.
<b>Mud balance:</b>	a scale that measures a specific volume of grout slurry (density) and is expressed in pounds per gallon.
<b>Natural pack:</b>	created when the formation is allowed to collapse around the screen.
<b>Plasticity:</b>	the capability of being deformed permanently without rupture.
<b>Permeability:</b>	the property or capacity of porous rock, sediment, or soil for transmitting a fluid.
<b>Porosity:</b>	the percentage of the bulk volume of a rock or soil that is occupied by interstices, whether isolated or connected.
<b>Primary pack:</b>	part of an artificial pack, extends from the bottom of the borehole to the top of the screen.
<b>Private water system:</b>	any water system for the provision of water for human consumption, if such a system has fewer than fifteen service connections and does not regularly serve an average of at least twenty-five individuals daily at least sixty days out of the year.
<b>Public water system:</b>	a system for the provision to the public of piped water for human consumption, if such a system has at least fifteen service connections or regularly serves an average of at least twenty-five individuals daily at least sixty days out of the year.
<b>Recharge:</b>	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.
<b>Reverse circulation:</b>	any methodology involving injection of drilling fluid, water, or water/solids mixture into an annulus and returning it to the surface through the well casing or drill rod.
<b>Screen:</b>	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.
<b>Secondary pack:</b>	part of an artificial pack, placed directly on top of the primary pack to prevent the infiltration of the annular seal into the primary pack.
<b>Specific capacity:</b>	a measure of the productivity of a well, typically expressed by dividing the rate of discharge (usually gallons per minute) by the drawdown (usually in feet).
<b>Strength:</b>	the limiting stress that a solid can withstand without failing by rupture or continuous plastic flow.
<b>Surface protection:</b>	protective casing and surface seal used to safeguard well casing against physical damage and surface water infiltration.
<b>Temporary well installation:</b>	a boring or well that is to be installed and used for less than one year
<b>Tremie pipe:</b>	small diameter plastic or metal tubing used to emplace sealants or filter pack materials.
<b>Unconsolidated formation:</b>	consists of rock and mineral fragments that have been deposited in layers but are not cemented or are only partially cemented together.

**Uniformity coefficient:** a measure of how well or poorly sorted a sediment is, expressed as the ratio of the sieve size on which 40 % of the material is retained to the sieve size on which 90% of the material is retained.

**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, excluding subsurface drainage systems installed to enhance agricultural crop production or urban or suburban landscape management or to control seepage in dams, dikes or levees; 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, excluding horizontal trenches that are installed for water source heat pump systems.

**Well efficiency:** the ratio of actual drawdown in a well versus theoretical drawdown, usually expressed as a percentage.

# Appendix I

## Well Drilling Methods Used in Ohio

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There are three commonly used methods of well construction in Ohio: digging (by hand or backhoe), driving and drilling. 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), and are constructed by digging with a backhoe or by hand. Casing installed in dug wells can vary from concrete pipe and vitrified tile to cobbles and bricks. In some cases, dug wells are improperly used as cisterns for roof runoff or hauled water.

Driven wells, for the purposes of this document, will refer to well points exclusively. Well points are installed only in unconsolidated formations. Well points are typically small diameter, shallow wells used to supply water for a single household. Many of these wells are installed by the homeowners themselves. Well points consist of a well screen with a hardened point on the end of the screen which is hammered into place (by hand or machine) using a large weight. Sections of pipe are added to the screen in order to advance the screen to the desired depth.

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 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 could be 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 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. 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 a 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 (sometimes called "spudder") rigs operate by repeatedly lifting and dropping a string of drill tools into the hole. The drill bit at the bottom of the drill tools breaks or crushes the formation and when 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 the hole will remain open. When the desired depth has been reached, the casing can be pulled back to expose a screen, if one is to be installed. Otherwise, the casing is driven until a solid rock formation is encountered, and the casing is set a few feet into the bedrock. 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 Ohio own cable tool rigs.

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 should 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 through. The air, in combination with water or foam, lifts the cuttings out of the hole. Hole sizes can range from 4 1/8" to 30" (Ingersoll-Rand Co., 1988). Usually a well will be drilled with mud through the 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.

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 up through the drill rods. The fluid and cuttings are deposited into a mud pit, where the cuttings settle out and the fluid is recirculated. The resulting large diameter borehole allows easy installation of filter pack and well screens, which are necessary to properly develop high capacity wells in unconsolidated formations. Reverse rotary drilling can also be used in most consolidated formations (Driscoll, 1986).

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.

# Appendix II

## Grouting Materials

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*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 the annular space around a well casing 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 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 one 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  $1 \times 10^{-7}$  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 anhydrite to control setting time.

When Portland cement is mixed with water (producing neat cement), several chemical reactions occur. Heat is generated as the mixture cures and changes from a slurry to a solid. This is referred to as the heat of hydration and results in a temperature increase in the formation material at the cement/borehole interface and the well casing (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 PVC plastic well casing (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.

#### 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.

Table 1. Grout Properties

	<b>Advantages</b>	<b>Disadvantages</b>
<b>CEMENT-BASED GROUTS</b>	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
	<b>BENTONITE-BASED GROUTS</b>	Suitable Permeability With High Solids Grouts
Non-Shrinking & Self-Healing		Difficult Mixing
Hard-Positive Seal		High Density Results in Loss To Formations
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		Usage Instructions Vary For Each Product

Table 2. Permeability of Various Sealing Materials

<b>Sealing Material</b>	<b>Permeability (K) in cm/sec</b>
Neat Cement (5.2 gal water - 6 gal water maximum/94 lb sack)	10 <sup>-7</sup>
Bentonite Grout (20% Bentonite)	10 <sup>-8</sup>
Bentonite Pellets	10 <sup>-8</sup>
Granular Bentonite	10 <sup>-7</sup>
Granular Bentonite/Polymer Slurry (15% Bentonite)	10 <sup>-8</sup>
Coarse Grade Bentonite	10 <sup>-8</sup>

(From American Colloid Co, and N.L. Baroid/N.L. Industries, 1989)

Table 3. Cement Curing Time Required

<b>Grout Type</b>	<b>Curing Time</b>
Neat Cement - Type I	48 Hours
Concrete Grout - Type I	48 Hours
Neat Cement w/2% CaCl <sub>2</sub>	24 Hours
Hi-Early Cement - Type III	12 Hours
Concrete Grout - Type III	12 Hours

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 circumstances, such as for sealing the annular space in flowing wells, wells with natural gas or methane present, and 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.

## 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

Table 4. Grout Slurry Densities

Product	Water Ratio	Minimum Density lbs/gal	Volume ft <sup>3</sup> /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 & CaCl (accelerator)	6.0 gal./sack of cement CaCl - 2 to 4 lbs. sack of cement	15.0	1.28
Concrete Grout	1 sack of cement and an equal volume of sand per 6 gallon 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)

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.

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

Bentonite products developed specifically for well grouting are widely available. 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 suppress 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**

Granular bentonites are generally manufactured from high-yield, non-drilling grade sodium 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.

Dry granular bentonite can be used to grout driven casing. Called the dry driven grout method, the granular bentonite is poured around the top of the casing as it is driven. The vibrations from the driving process, along with the couplings on the casing, cause the bentonite to follow the casing down into the ground. The bentonite will then form a seal around the casing as it hydrates in place. (See pp. 56-57 for more information.)

Granular bentonite slurries are typically used to grout wells with significant annular space. 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 solids 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 downhole 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. As with coarse grade bentonite, water should be poured on top of any pelletized bentonite above the water table.



## Ohio Department of Natural Resources

Fact Sheet 93-19

# Dry Driven Grout Method

**D**rilling contractors are genuinely concerned about maintaining and preserving the quality of ground water—our most valuable natural resource. Dry grouting while driving casing for the construction of wells using a cable tool drilling rig is one way to protect our water supply. Although grouting casing while driving is not new to the water well construction industry, its application should be more widespread, and for very good reasons. Dry grouting while driving well casing requires little effort, yet it provides many benefits.

### Resource Protection

The primary reason for grouting a driven well casing is the same as for other types of well construction. The driving of the casing into the ground creates a “micro” annular space between the casing and the geologic material. By placing an impervious layer of material in the annulus (space between the casing and borehole), the probability of surface water intruding the aquifer is minimized. When the annulus is properly sealed, water is restricted from flowing from one aquifer to another. Proper grouting techniques result in the best well construction possible. This fact sheet, and others pertaining to well construction, will help you learn how to protect everyone’s ground water.

The methods used to grout and drive well casing may vary, but the following procedures cover the basic technique.

### Techniques

Initially, a 3-foot-deep borehole should be drilled approximately four to five inches wider than the drill pipe being used. Next, the casing is placed into the borehole and the annulus is filled with a dry grouting material. As drilling continues, the well casing is then driven into the ground approximately 12 feet while grouting material is continually placed around the drill pipe at the surface. The grouting material simply moves down the annulus along the casing. As additional well casing is driven, each coupling drags and pulls the grout down along the exterior of the casing filling the annulus.

Water used for drilling operations may spill onto the area where the dry grout is being placed. This makes the grout swell, creating a temporary seal at the surface. This is corrected by shoveling off the thin top layer of the moistened grout and exposing the underlying dry grout. If the grout bridges during driving operations and no longer moves down the annulus, it is necessary to pull the well casing back two or three feet. By pulling the well casing back, the bridging of the grout is eliminated, and drilling and driving procedures may continue.

### Grout Material

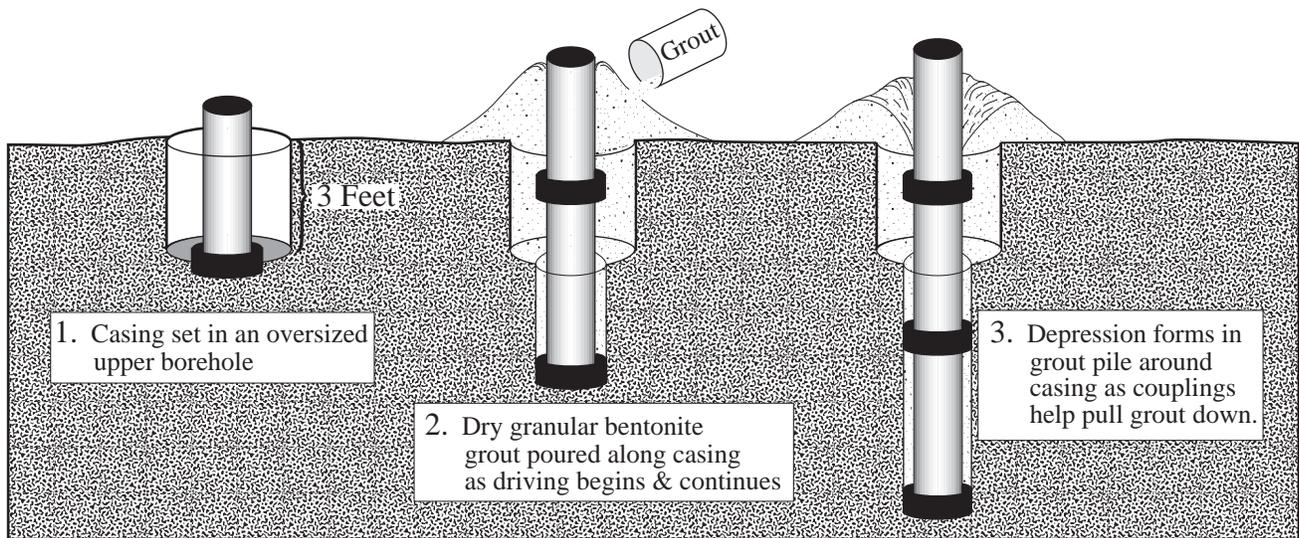
The type of grouting material used directly affects the quality of the grout job. Bentonite is advantageous to use because it incorporates the most important properties of the various grouting materials available.

Two different kinds of bentonite are suggested for use with this method. The most popular bentonite is the granular form. Experience has shown this type of bentonite readily fills the annulus with minimal bridging and blocking. The average cost is \$12.00 per 50 pound bag. The other type of bentonite is the drilling mud type of bentonite that comes in a powdered form. This type of bentonite comes in 100-pound bags and has an average cost of \$5.75 per 50 pounds of material.

Powdered bentonite, however, tends to swell rapidly when exposed to water and thus placement may be restricted due to bridging and premature swelling. The only advantage of using powdered bentonite rather than granular bentonite is lower cost.

### Cost

The cost of dry grouting while driving well casing must also be considered. The cost of grouting is contingent upon the size of the well casing, type of grouting material used and the geologic formations encountered. The average cost of material to properly grout a 5+ inch well constructed in glacial till is 72 cents per foot. This cost is based on using granular bentonite grout and an application rate of 150 pounds per 50 feet of hole.



**Advantages**

The cost of grouting driven well casing is minimal in relation to the advantages. Most Ohioans express a concern for the quality of their ground water and are not reluctant to pay the additional expense when the benefits of grouting are explained to them.

**Bentonite Seals**

The most obvious benefit of grouting a well is that the probability of surface water or any other substance entering the aquifer is minimized. Grouting also helps prevent cross-contamination or mixing between aquifers with different water quality. There are other benefits to the consumer and driller from using this grouting technique.

**Bentonite Lubricates**

Bentonite grout enables well casing to move more freely in the hole. Well screen installation in a cable tool drilled well requires that the well casing move freely so that the driller can pull the casing up to expose the screen. By using the bentonite grout method it is easier to pull back the well casing. Bentonite also allows casing to be driven to greater depths and in significantly less time.

**Bentonite Protects**

Another benefit of using this grouting technique is the way in which the outside of the well casing is protected from corrosion. By placing an inert material around the

casing, corrosive elements are kept from direct contact with the casing, preventing break down of the molecular structure of the well casing.

Dry grouting while driving well casing can help to preserve ground water resources and provide efficient construction. Current Health Department rules require dry grouting of cable tool wells. We strongly urge all drilling contractors to implement a grouting program directed at preserving our most valuable natural resource.

*(Edited and reprinted from Drill Bits, Winter 1989, Brad Ulery author)*

For more information on well construction methods and other water related topics contact:

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 Division of Water, Water Resources Section  
 1939 Fountain Square

Columbus, OH 43224-1336

Voice: (614) 265-6740 Fax: (614) 265-6767

E-mail: [water@dnr.state.oh.us](mailto:water@dnr.state.oh.us)

Web site: <http://www.dnr.state.oh.us/odnr/water/>



OR

The Ohio Department of Health  
 Private Water System Program  
 (614) 466-1390

OR Your Local Health Department

# Appendix III

## Well Quantity Testing

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### Quantity Testing Methodology

Testing methodology encompasses many elements. Factors to be considered include water level measurement procedures, type of flow rate measurement, simple preliminary tests for estimating well yield, types of pumping tests to evaluate well performance, types of pumping tests to evaluate aquifer characteristics, and data collection and record-keeping. The first factor discussed here will be water level measurement procedures.

The accuracy and reliability of data obtained from a pumping test depends largely on the accuracy of measurements taken before and during the test. The method of measuring water levels in the well and discharge rates while conducting the pumping test is often determined by the type of data the driller wishes to obtain. This section identifies some common measurement devices used in the well drilling industry with some of the advantages and disadvantages of each device.

### Electrical tape method

The electrical tape method utilizes an electrode suspended by insulated wires connected to an ammeter, electric sounder, or indicator light. When the electrode touches the water surface, the ammeter or indicator light indicates a closed circuit. Depth to water level is determined by reading the calibrations on the insulated wires. Care must be taken to ensure that depth markers not printed on the tape do not slip or move on the tape. The accuracy of electric tapes should be checked periodically with a calibrated steel tape to insure the tape has not stretched, kinked, or that markers are accurate.

A primary advantage of this method is that, unlike the wetted tape method, the electrical tape does not require complete withdrawal each time a measurement is taken. Disadvantages include inaccurate readings resulting from wet well casings and kinks or nicks in the insulated wire. Where cascading water in open rock boreholes is likely to preclude satisfactory measurements with an electric tape, a one inch drop pipe should be installed in the well to the top of the pump in which accurate measurements can be made.

### Wetted tape method

This is the most accurate method of measuring water levels. The wetted tape method utilizes a calibrated steel tape with a weight attached to the end of the tape. The lowest 2 to 3 feet of the tape is coated with carpenter's chalk. Water level measurements are obtained by noting the length of tape dropped into the water and subtracting this from the reading of the tape held at the measuring point (usually the top of casing). Disadvantages of this method include:

- 1) Water depths below 100 feet are difficult to measure because the amount of tape to be withdrawn each time becomes cumbersome.
- 2) Because initial water level readings are typically one minute apart, frequency of dropping and removing the tape is also cumbersome.
- 3) Cascading water in wells can distort accuracy of reading on chalked portion of the tape.

### Airline method

The airline method involves installation of a small diameter tube (airline) in the well which is pressurized by a small air compressor or tire pump. By knowing the length of the tube and reading the pressure gauge at various times during the pump test, relatively accurate readings of water level in the well can be calculated. Pressure gauges calibrated in feet of water are available and are recommended for best results.

The dependability of measurement varies with the accuracy of the pressure gauge and the care at which the airline is installed in the well. The airline must be vertical without kinks or coils and must be airtight to ensure as accurate readings as possible. The airline should be purged each time a measurement is taken to ensure accuracy.

The operation of an airline is shown on Figure 1. The airline itself is a small diameter metal or plastic tube installed below the maximum pumping level (usually down to or near the pump intake), fitted at the surface with a Schrader (tire) valve and pressure gage. In operation, air (or an inert gas) is pumped into the airline until a maximum pressure is reached on the gage, at which point the air will be bubbling out the bottom of the airline. The pressure at the gage is then equal to the distance from the water level in the well to the bottom of the airline and, by knowing the length of the airline, this distance can be subtracted from

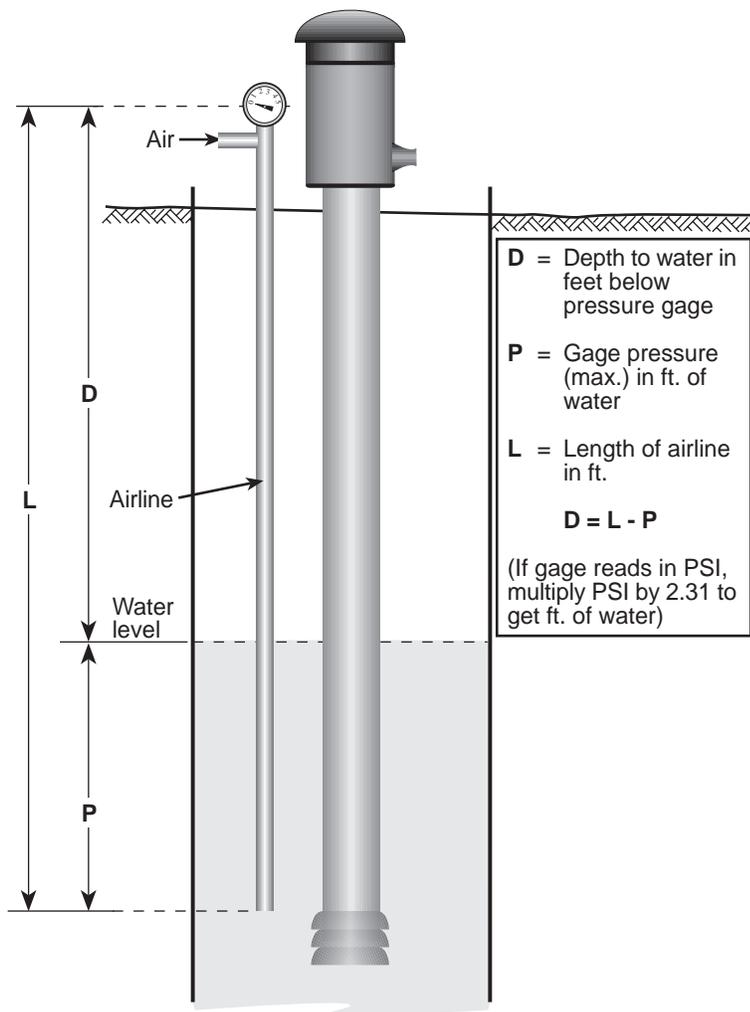


Figure 1. Example of airline setup and operation.

16 inch thick around the circumference of the hole and should be fastened against the outer end of the discharge pipe so that the orifice is centered on the pipe. The end of the pipe must be squarely cut so that the plate is vertical. The bore of the pipe must be smooth and free of obstructions that would cause turbulence. The discharge pipe must be straight and level for a distance of 6 feet from the orifice. The pipe wall should be tapped midway between the top and bottom with a 1/4 inch hole exactly 24 inches from the orifice plate. Any burrs inside the pipe from drilling and tapping the hole should be filed off.

A manometer tube should be fitted to the hole with a 1/4 inch nipple in order to measure the head of water in the discharge pipe. The manometer tube should be clear plastic tubing about 5 feet long. The nipple, which is screwed into the hole, must not protrude inside the discharge pipe. A scale divided in inches should be fastened to the pipe or securely fastened to a stake driven into the ground so that the head from the center of the discharge pipe can be measured directly. The water level in the manometer tube indicates the pressure head caused by the orifice plate when water is pumped through the discharge pipe.

For any given size of orifice/discharge pipe, the rate of flow at various pressure heads can be determined from standard tables available in numerous references. This method of measurement of flow rates is recommended for most circumstances.

### Commercial water meters

A commercial water meter is a reliable means of measuring large discharge rates. Its primary disadvantage results from the delay in obtaining values at the start of the test when the pumping rate is being adjusted to the desired level. Another disadvantage is that it is a precision instrument which must be cared for, and could become inaccurate if mishandled or abused. Meters used routinely should be calibrated or

that length to obtain the depth to water below the gage. If the gage reads in psi it must first be converted to feet by multiplying by 2.31. During falling water level conditions (drawdown) it is usually not necessary to keep adding air for each measurement because the expanding air continues to evacuate the line; during rising water levels (recovery) it is necessary to re-pressure the line for each observation. The source of air must have sufficient pressure to blow all the water out of the airline. A typical manual tire pump cannot usually develop more pressure than about 40 psi (or about 90 feet); for airlines submerged to greater depths it may be necessary to use a motor-driven compressor, or a tank or cylinder of compressed air or nitrogen, to obtain a true reading.

### Flow Rate Measurement

#### Circular orifice weir

A circular orifice weir is the device used most often to measure the discharge from a pumping test. The advantage of this method is its simplicity and the ability to quickly and accurately determine pumping rates and make adjustments to hold a constant rate.

Figure 2 is an illustration of the dimensional requirements to construct an orifice weir. The orifice is a round hole with clean, square edges in the center of a circular steel plate. The plate should be 1/

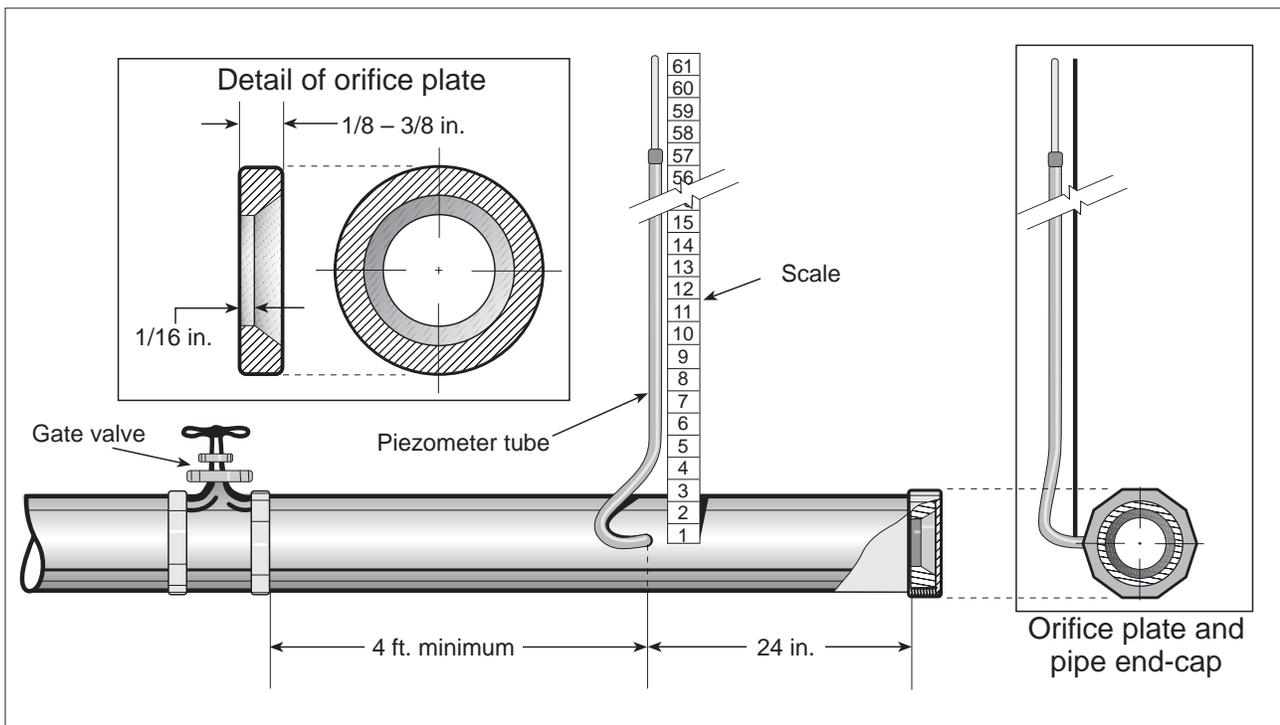


Figure 2. Detail of orifice weir construction.

checked regularly. The advantage of this method is the ability to record the total pumpage during a test period, particularly if maintaining a constant rate is difficult due to test conditions.

### Container/timed method

The container/timed method involves the use of a container of known volume and a timing device. To determine the pump discharge rate, one observes the time it takes to fill a container of known volume. The volume divided by the time gives the discharge rate. While the container/timed method is a practical means to determine discharge rate, it is generally useful only for low pumping rates. The disadvantage of this method is that instantaneous readings cannot be obtained and it is difficult and time consuming to use this method to change or adjust pumping rates.

### Weirs and flumes

This method can be used to measure flow from a well by constructing a constriction in a discharge channel originating at the wellhead. The specifications and methods for use of weirs and flumes are available in numerous references. The accuracy of these discharge rate measurement devices can vary from plus or minus 10% or better. Great care must be taken in the construction and installation of these devices to ensure the best possible accuracy.

## Simple Tests To Estimate Well Yield

### Bailing test method

A bailer of known volume that is only slightly smaller than the well casing should be used. The static level of the water in the well should be measured accurately. The well should then be bailed until the water level can no longer be lowered and the bailing line should be marked with paint at a point level with the top of the casing when the bottom of the bailer is just touching the water, (a fast falling bailer makes an audible sound when it hits the water surface). A second mark should be made one bailer length above the first. Rhythmically bailing, the driller should lower the line precisely to the second mark on the cable each time, noting the elapsed time per round trip. The bailer should be full each time as it emerges from the well. If the bailer is not full, it should not be lowered deeper; rather, the rate of bailing should be slowed until the bailer comes out full each time. The bailing rate in gallons per minute (gpm), equals the volume of the bailer divided by the time per round trip. The bailing rate and the drawdown (water level repre-

sented by first mark on the bailing line minus the static level) should be recorded on the well log.

When there is less depth of water in the well than the length of the bailer, it is impossible to follow the above procedure. Instead, the amount of water in the bailer should be measured and related to a timed interval of one minute for each time the bailer leaves the bottom of the well. An alternative method for a well that can be bailed dry is to measure the rate of recovery after the well is bailed down. By calculating the volume of water in the casing or borehole after 10 or 15 minutes of recovery and dividing by the time of recovery, the maximum rate that the well will produce can be estimated.

### **Air blow test method**

Using this method the well should be tested for 30 minutes by introducing air in sufficient quantity to blow the water out of the well. The discharge of the air should be at the bottom of the hole through the drill stem. A deflector should be placed at the top of the well casing to deflect the water downward outside the well. A dike should be constructed around the well to contain the deflected water, and a discharge pipe should be placed near the top of the dike and the water allowed to discharge through it. A container of known volume should be used to collect the water from the discharge for a measured period of time and the rate (gpm) should be calculated from this information and recorded on the well log.

A disadvantage of this method is that it is impossible to get an accurate drawdown measurement. However, the water level should be measured as quickly as possible after shutting off the air flow to allow for estimation of the amount of drawdown that was associated with the flow rate. An alternative method for low yielding wells is to blow the well for 30 minutes and measure the recovery for 10 or 15 minutes. The maximum rate that the well can produce can be estimated by dividing the recovery time into the volume of water that has filled the casing or borehole.

### **Air lift test method**

Using this method, air should be introduced through an airline with upward pointing jets inside of an eductor pipe placed at the bottom of the well. The submergence (length of the eductor pipe from the lower end to the pumping level as related to the total length of the eductor pipe) should be at least 60 percent. Drawdown in the well in which the airlift pump is working can be measured between the eductor pipe and the well casing by any of the conventional methods. A deflector should be placed at the top of the well to deflect the water downward outside of the well. A dike should be constructed around the well and the flow rate should be measured as described for the air-blow test method. The advantage of airlift over the air-blow test method is the ability to accurately measure drawdown.

### **Variable pumping rate method**

A test pump that can produce more than the desired pumping rate should be set at the depth of the lowest producing zone in the well and the well should be pumped until the pump breaks suction. The rate then should be slowly decreased until the pumping level stabilizes approximately 2 feet above the pump intake for a period of at least 5 minutes. The pumping rate then should be decreased by 5 percent and the well should be pumped at this rate until the pumping level stabilizes for 1 hour. The discharge rate and drawdown thus established should be maintained for at least 4 hours. This pumping rate can be considered the available production rate of the well, and the observed pumping level during the test can be considered the production pumping level for the well.

## **Pumping Test To Evaluate Well Performance**

### **Step-drawdown tests**

The step-drawdown test typically is used to examine the performance of wells by theoretically separating drawdown into components produced by laminar (aquifer loss) and turbulent (well loss) flow. Step tests are the single most useful pumping test tool for benchmarking and then assessing well performance changes over time. It is important that subsequent tests be run at comparable discharge rates to make comparisons on values such as specific capacity. If personnel are running a test that will be evaluated by a hydrogeologist not a the test and supervising, it is necessary to provide all drawdown data and not just final drawdown points in a step (Driscoll, 1986 and NGWA, 1998). The well should be pumped at several successively higher pumping rates and the drawdown for each rate, or step, is recorded. The incremental rate increases should be approximately the same and the time duration for each step should be one hour, but this might vary from 30 minutes to 2 hours for a particular well depending upon how fast pumping levels stabilize after each rate increase. The number of steps may be from as few as 3 to as many as 8.

Step tests are sometimes used to determine or verify the depth of significant water producing zones in rock boreholes. The same stepwise incremental increase of equal rate and pumping time is used until the pump breaks suction or the maximum pump capacity is reached. Disproportionate increases in drawdown indicate water producing zones and once the pumping level is lowered below a major producing zone, the drawdowns accelerate significantly. Upon shutdown of the pump, depth to water zones can be accurately identified by listening to cascading water in the borehole and noting the water level when the sound changes or stops during recovery.

## **Constant rate tests**

### **Preparation**

A test pump should be selected that is capable of producing at least 1.5 times the desired or anticipated well capacity at the maximum pumping level in the well. Provisions should be made at the wellhead to facilitate easy access for measuring water levels. A control valve should be installed at the wellhead in the discharge line before the flow measuring device to provide for making adjustments to the pumping rates. Provisions should be made to ensure uninterrupted pumping during the test. If direct current is used, the appropriate switches or automatic controls within the circuit should be locked out to preclude an inadvertent shutdown of power. If an electric generator or direct drive power unit is used to operate the test pump, provisions must be made to ensure timely refueling and continued operation of the system for the duration of the test. Discharge piping should be provided to convey the water to a natural point of drainage away from the well. Depending upon the hydrogeologic setting, special provisions may be required to ensure that discharge water is not recirculated and give a false response to water level changes due to pumping. Ideally, the flow measuring device should be near the control valve and wellhead. If a long discharge line is required, it should be free of leaks, and if the flow measuring device must be placed at the end of the discharge line, special provisions may be required to ensure timely and accurate adjustments to the flow rate.

### **Test Rate**

A pumping rate should be selected that will stress the well during the pumping test more than it will be stressed during normal operation. Typically, the test rate should be about 1.5 times the planned or desired well capacity. For sand and gravel wells this is consistent with well development objectives, i.e. pumping the well at least 50 percent above design rate to remove fines from the screened area to ensure complete development. For rock wells, the test rate should be selected that will maintain pumping levels above the major water producing zone(s) during the test. Step test data can be used to determine the most appropriate rate for a constant rate test. If step test data is not available, a pump trial should be performed to establish a feasible pumping rate for the constant rate test to preclude a rate change due to failure to select the proper test rate. It is essential that the pumping rate be held constant so that water level changes can be analyzed correctly.

### **Test Duration**

Typically a pumping test of a minimum 24 hours in duration is required (depending on the aquifer, a much longer test may be needed, e.g. unconfined alluvial systems) to conclusively evaluate the performance characteristics of a well and enable reliable predictions of long term time-drawdown relationships and sustainable well yield. However, for some low use requirements or for well performance evaluations, properly run and analyzed shorter tests (6, 8, or 12 hours) may be sufficient. The determination of an appropriate length of time for a pumping test under these circumstances should be based on the required pumping rates and operating time necessary to meet the anticipated daily demand.

### **Recovery Data**

Whenever practical, recovery data should be collected to verify the accuracy of pumping data. Often, the recovery data will be more consistent and reliable if it has not been possible to maintain a constant rate during the test. Recovery measurement should be measured at the same frequency and for the same duration as the pumping period. If the drawdown data collected during the test is considered reliable, recovery data is less important and not essential.

### **Pumping Tests To Evaluate Aquifer Characteristics**

Pumping tests to evaluate aquifer characteristics require more elaborate preparation, data collection, and analysis. Typically, the test duration for confined (artesian) conditions will be 24 hours in duration and

tests of aquifer systems under unconfined (water table) conditions will be 72 hours in duration. These tests usually involve the installation of several observation wells in various configurations (depth and spacing) with respect to the pumping well. Collection of background data is usually very important in order to evaluate natural trends and fluctuations of ground water levels before, during, and after the pumping test. Additional data to be collected may include barometric pressure changes, river levels, precipitation, and any changes in pumpage that may affect ground water levels in the pumping well and observation wells.

### **Data Collection And Record Keeping**

Before starting a pumping test, the complete program for depth-to-water measurements should be laid out. When using multiple observation wells it is not necessary to make measurements in all wells simultaneously, but watches used for timing the measurements should be synchronized so that the time of each reading can be referenced to a common start time. The date, clock time, elapsed pumping time, and depth to water should be recorded for each measurement. Any readings and calculations made to determine depth to water such as used for the wetted tape method or corrections for tape length should be recorded to preclude errors in field calculations. Water level measurements should be made to the nearest 0.01 foot. Field forms should be provided with columns for each type of data recorded. Other data such as pumping rates, the size of the orifice weir, manometer hose readings, air line length, height and description of measuring points, and personnel collecting the data should be recorded on the forms. Preprinted pumping test forms for pumping tests longer than 8 hours in duration are available from the Ohio Department of Natural Resources, Division of Water. The measurement intervals are similar to those shown below (especially for the first 60 minutes). These forms can be obtained free of charge by contacting the Division of Water's Water Resources Section at 614-265-6739.

Early test data is extremely important and as much information as possible should be obtained in the first 10 minutes of pumping. The following time intervals are recommended for water level measurements:

<b>Time After Pumping Started or Stopped (in minutes)</b>	<b>Time Interval Between Measurements (in minutes)</b>
0-10	0.5-1
10-15	1
15-60	5
60-120	10
120-180	20
180-300	30
300-1440	30
1440-termination of test	240 (4 hrs.)

Table 1. Estimating Water Usage

Place	GPD per Unit	Occupancy Type
Apartments .....	250 .....	one bedroom
Apartments .....	300 .....	two bedroom
Apartments .....	350 .....	three bedroom
Assembly Halls .....	2 .....	per seat
Bowling Alleys (no food service) .....	75 .....	per lane
Churches (small) .....	4 .....	per sanctuary seat
Churches (large w/kitchen) .....	6 .....	per sanctuary seat
Country Clubs .....	50 .....	per member
Dance Halls .....	2 .....	per person
Drive-In Theaters .....	5 .....	per car space
Factories (no showers) .....	25 .....	per employee
Factories (w/showers) .....	35 .....	per employee
<b>Food Service Operations</b>		
Ordinary restaurant (no 24 hr) .....	35 .....	per seat
24-hr. restaurant .....	50 .....	per seat
Banquet rooms .....	5 .....	per seat
Restaurant along freeway .....	100 .....	per seat
Tavern (very little food service) .....	35 .....	per seat
Curb service (drive-in) .....	50 .....	per car space
Vending machine restaurants .....	100 .....	per seat
Homes in Subdivisions .....	400 .....	per dwelling
Hospitals (no resident personnel) .....	300 .....	per bed
Institutions (residents) .....	100 .....	per person
Laundries (coin operated) .....	400 .....	per std. size machine
Mobile Home Parks .....	300 .....	per mobile home space
Motels .....	100 .....	per unit
Nursing & Rest Homes .....	150 .....	per patient
Nursing & Rest Homes .....	100 .....	per resident employee
Nursing & Rest Homes .....	50 .....	per nonresident emp.
Office Buildings .....	20 .....	per employee
Recreational Vehicle Parks & Camps .....	125 .....	per trailer or tent space
Retail Store .....	20 .....	per employee
Schools-Elementary .....	15 .....	per pupil
Schools-High & Junior High .....	20 .....	per pupil
Service Stations .....	1000 .....	first bay or pump island
Service Stations .....	500 .....	additional bay or pump island
Shopping Centers (no food service or laundries) .....	0.2 .....	per sq. ft. of floor space
Swimming Pools (average) .....	4 .....	per swimmer
With hot water showers .....	6 .....	per swimmer
Travel Trailer Parks & Camps .....	125 .....	per trailer or tent space
Vacation Cottages .....	50 .....	per person
Youth & Recreation Camps .....	50 .....	per person

# Appendix IV

## Water Sample Collection

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### Coliform bacteria sampling

Water samples for bacteriological analysis should be collected in a sterile sample bottle provided by the laboratory that will perform the analysis. The sample bottle should not be rinsed prior to collection of the sample. Great care should be taken to prevent contamination of the sample that may produce erroneous results. The following is the recommended total coliform sampling procedure:

- (1) Select a tap such as a small valve to collect samples. Do not sample from hoses. Avoid taps that leak at the stem.
- (2) Sanitize the nozzle of the tap with a chlorine solution.
  - (a) Use a 5.25% sodium hypochlorite solution such as Clorox™ liquid bleach. Do not use chlorine solutions with special scents. To prepare a sanitizing solution that will contain about 400 mg/L of available chlorine from the 5.25% sodium hypochlorite, add one ounce of bleach to one gallon of water (or 1 tablespoon per half gallon). Store the mixed solution in a tightly closed screw capped container. The solution should be discarded and remade six months after preparation. Stronger solutions can be used; however, some tap discoloration may result.
  - (b) Open the sample tap long enough to flush water in the drop pipe. Close the valve.
  - (c) Apply the sanitizing solution to the nozzle. This can be accomplished by either using a spray bottle or a plastic bag.
    - i. Using a spray bottle, saturate the tap opening with sanitizing solution then wait at least two minutes before proceeding, or
    - ii. Place a bag over the nozzle and hold the top of the bag tightly on the tap. Alternately squeeze and release the bag to flush the solution in and out of the tap. Do this for two minutes. A fresh solution and bag must be used to sanitize each tap.
  - (d) Flush the tap. The sample to be collected is intended to be representative the water in the well. The tap must be fully open and the water run to waste for enough time (1-2 well bore volumes) to allow for adequate flushing of the drop pipe.
  - (e) Reduce the flow from the tap. This will allow the sample bottle to be filled without splashing.
  - (f) Remove the cap from the sample bottle.
    - i. Grasp the bottom of the sample bottle.
    - ii. Remove the cap and hold the exterior of the cap between your fingers while filling the sample bottle. Take care not to touch the mouth of the bottle or the inside of the cap with fingers or the sample could become contaminated.
    - iii. The bottle must be open only during the collection of the sample.
  - (g) Fill the sample bottle.
    - i. Do not rinse out the bottle before collecting the sample. Do not remove any pills from the bottle. The bottle contains a small amount of sodium thiosulfate to neutralize any chlorine that may be in the water.
    - ii. Do not touch the rim or mouth of the bottle during collection of the sample.
    - iii. Do not overflow the bottle. Fill the bottle to within 1 inch of the top.
  - (h) Immediately recap the sample bottle tightly.
  - (i) If there is any question as to whether a sample or bottle has become contaminated during collection of the sample, the bottle should be discarded and a new sample collected in a new sample bottle.
  - (j) All samples should be kept cool but not frozen. Deliver the sample to the laboratory as soon as possible. The laboratory must receive the sample within 30 hours after collection so analysis can be initiated. Samples greater than 30 hours old are considered invalid samples. Allow the laboratory adequate time to analyze the sample.

A bacterial sample report form is supplied with each sample bottle. The top half of the bacterial sample report should be filled out by the individual collecting the sample. Each completed bacterial sample report

should be attached to the respective finished sample by wrapping the report around the sample bottle with a rubber band.

As noted above, all microbiological analysis conducted on a public water system water source must be analyzed by a laboratory certified for such analysis by the Ohio EPA. Contact the appropriate district office of the Ohio EPA, Division of Drinking and Ground Waters for a current list of approved laboratories.

# Appendix V

## Well Disinfection

### Disinfection of a Drilled Well

1. Determine the amount of water in the well by multiplying the gallons per foot by the total depth of water in the well in feet. This information can be obtained by measuring the depth to the water level in the well, and subtracting this number from the total well depth (Example: Total well depth is 100 feet, depth to water from the ground surface is 40 feet, therefore  $100 - 40 = 60$  feet of water in the well). This is the total depth of water in the well. Table 1 provides the gallons of water per foot in a well based on the well diameter. For example, a well with a six inch diameter contains 1.5 gallons of water per foot. If there is 60 feet of water in the well, multiply 1.5 by 60 ( $1.5 \times 60 = 90$ ). If the total water depth cannot be obtained, assume a water depth of 100 feet.
2. For each 100 gallons of water in the well, use the amount of chlorine (unscented liquid or granules) indicated in Table 2. Mix the total amount of liquid or granules with about 10 gallons of water.
3. Pour the solution into the top of the well before the seal is installed.
4. Connect a hose from a faucet on the discharge side of the pressure tank to the well casing top. Start the pump. Spray the water back into the well and wash the sides of the casing for at least 15 minutes.
5. Systematically open every faucet and fixture in the system and let the water run until the smell of chlorine can be detected. Include both hot and cold water valves. Then close all the faucets and seal the top of the well.
6. Let stand for a minimum of 6-8 hours, preferably overnight.
7. After letting the water stand for the contact period, open the hose spigot and discharge water to the ground surface or a drainage ditch until the chlorine odor disappears. Turn on all remaining faucets and fixtures and let the water run until all odor of chlorine disappears. Adjust the flow of water from faucets or fixtures that discharge into septic tank systems to a low flow to avoid overloading the disposal system.

Table 1. Volume of Water in Well

Diameter of Well (inches)	Gallons per Foot of Water
3	0.37
4	0.65
5	1.0
6	1.5
8	2.6
10	4.1

Table 2. Amount of Chlorine Added to 100 Gallons of Water for Disinfection

Chlorine concentration (parts per million or mg/l)	Gallons of 5.25% sodium hypochlorite liquid bleach	Pounds of dry calcium hypochlorite	Minimum contact time
250mg/l	0.5 gallons	0.38 pounds	8 hours
500mg/l	1 gallons	0.75 pounds	8 hours

### Calculation and Examples

To determine the amount of liquid chlorine bleach needed to achieve a desired concentration, the following equation may be used:

### Sodium Hypochlorite (liquid bleach)

$$\text{Volume (gallons of disinfectant)} = \frac{\text{water volume (gallons in well)} \times \frac{8.33 \text{ lbs}}{\text{(weight of 1gal. water)}} \times \frac{\text{desired disinfectant concentration (mg/l in decimal)}}{\text{Disinfectant concentration (\% in decimal)}}}{8.33 \text{ lbs}}$$

Example: Desired concentration of 5.25% liquid bleach to disinfect a one hundred foot deep well with five inch casing and a static water level at sixty feet.

$$.38 = \frac{40 \times 8.33 \times \frac{0.005}{0.0525}}{8.33 \text{ lbs}}$$

Therefore V= .38 gallons of 5.25% liquid bleach needed to get a concentration of 500 mg/l in a 40 gallon column of water.

There are other methods that can be used to disinfect wells. Solid calcium hypochlorite tablets can be placed directly in the well so that the solid chlorine will sink to the bottom of the well and dissolve there. Chlorine tablets can also be placed in a mesh bag or perforated pipe and run up and down the water column until it is completely dissolved. Calcium hypochlorite used to disinfect wells will have a concentration of either 60, 65, or 70 per cent available chlorine. Below is an equation similar to the one used for liquid bleach can be used to determine the proper amounts of calcium hypochlorite to use in a well for shock disinfection.

$$\text{Weight in pounds of Calcium Hypochlorite} = \frac{\text{water volume (gallons in well)} \times \frac{8.33 \text{ lbs}}{\text{(weight of 1gal. water)}} \times \frac{\text{desired disinfectant concentration (mg/l in decimal)}}{\text{Disinfectant concentration (\% in decimal)}}}{8.33 \text{ lbs}}$$

### Disinfection of a Dug or Bored Well

1. Use Table 3 to calculate how much bleach (liquid or granules) to use.
2. To determine the exact amount to use, multiply the amount of disinfectant needed (according to the diameter of the well) by the total depth of water in the well. The total depth of water in the well can be calculated by subtracting the depth to the water measured from the ground surface from the total depth of the well. For example, a well 5 feet in diameter requires 6 cups of bleach per foot of water. If there is 30 feet of water in the well then multiply 6 by 30 to determine the total cups of bleach required (6 X 30 = 180 cups). There are sixteen cups in each gallon of liquid bleach (For the previous example this equals 180 cups/16 cups per gallon = 11.25 gallons).
3. Add this total amount of disinfectant to about 10 gallons of water. Splash the mixture around the wall or lining of the well. Be certain the disinfectant solution contacts all parts of the well.
4. Seal the top of the well.
5. Open all faucets and pump water until a strong odor of bleach is noticeable at each faucet. Then stop the pump and allow the solution to remain in the well overnight.

Table 3. Quantity of Bleach for a Bored or Dug Well (1000 ppm)

Diameter of Well (feet)	Amount of 5.25% laundry bleach per foot of water	Amount of 70% chlorine granules per foot of water
3	0.15 gallons (2.5 cups)	2 ounces
4	0.25 gallons (4 cups)	3 ounces
5	0.4 gallons (6 cups)	4 ounces
6	0.5 gallons (8 cups)	6 ounces
7	0.75 gallons (12 cups)	8 ounces
8	1 gallons	10 ounces
10	1.5 gallons	1 pound

6. The next day, connect a hose to an outside spigot and discharge water until the odor of chlorine disappears. Then turn on all faucets, continuing to discharge water until the chlorine odor disappears. Adjust the flow of water faucets or fixtures that discharge to septic systems to a low flow to avoid overloading the disposal system.

# Appendix VI

## Monitoring Well Design and Installation<sup>1</sup>

In order to collect representative ground water samples, it is necessary to construct monitoring wells to gain access to the subsurface. This chapter covers installation and construction of single-riser/limited interval wells, which are designed such that only one discrete zone is monitored in a given borehole. It is important that efforts focus on intervals less than 10 feet thick and be specific to a single saturated zone.

All monitoring wells should be designed and installed in conformance with site hydrogeology, geochemistry, and contaminant(s). While it is not possible to provide specifications for every situation, it is possible to identify certain design components. Figure 1 is a schematic drawing of a single-riser/limited interval well. The casing provides access to the subsurface. The intake consists of a filter pack and screen. The screen allows water to enter the well and, at the same time, minimizes the entrance of filter pack materials. The filter pack is an envelope of uniform, clean, well-rounded sand or gravel that is placed between the formation and the screen. It helps to prevent sediment from entering the well. Installation of a filter pack and screen may not be necessary for wells completed in competent bedrock. The annular seal is emplaced between the borehole wall and the casing and is necessary to prevent vertical movement of ground water and infiltration of surface water and contaminants. Surface protection, which includes a surface seal and protective casing, provides an additional safeguard against surface water infiltration and protects the well casing from physical damage.

### Design of Multiple-Interval Systems

It is often necessary to sample from multiple discrete intervals at a given location if more than one potential pathway exists or a saturated zone is greater than 10 feet thick. Multiple-interval monitoring can be accomplished by installing single-riser/limited interval wells in side-by-side boreholes (well clusters) or using systems that allow sampling of more than one interval from the same borehole (multilevel wells, well nests, or single-riser/flow-through wells).

#### Well Clusters

When monitoring multiple intervals at one location, single-riser/limited interval wells should be installed in adjacent, separate boreholes. These well clusters can be used to determine vertical gradients when distinct differences in head exist. They may be used to monitor discrete zones or evaluate chemical stratification within a thick zone. If flow direction has been determined prior to installation, the shallow well should be placed hydraulically upgradient of the deeper well to avoid the potential influence on its samples caused by the presence of grout in the annular space of the deeper well.

#### Multi-Level Wells

Multilevel wells allow sampling of more than one interval in a single borehole. Individual tubes run from sampling levels to the surface. These levels are isolated within the well either by packers or grout. Probes, lowered into the casing, can locate, isolate and open a valve into a port coupling to measure the fluid pressure outside the coupling or obtain a sample.

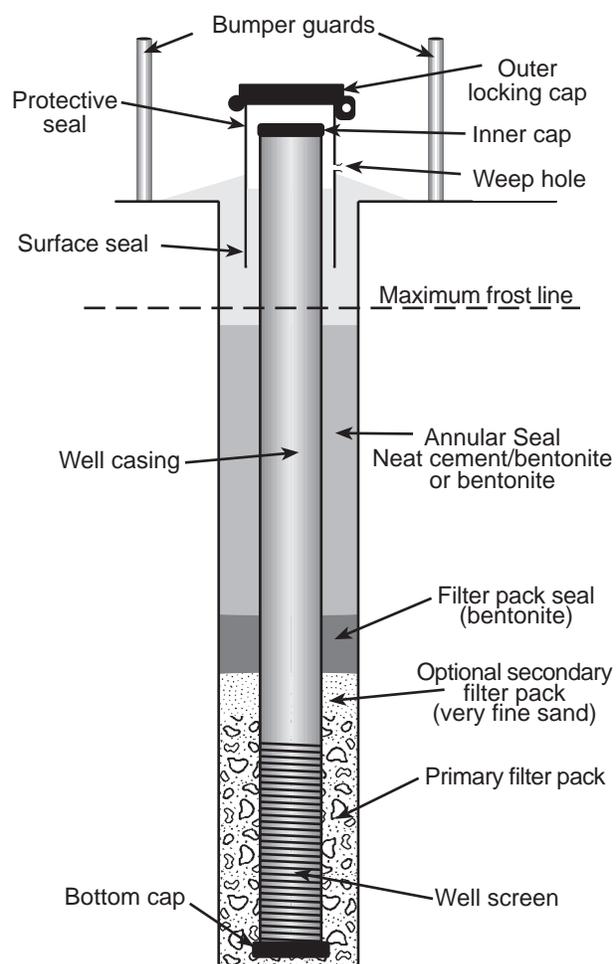


Figure 1. Cross-section of a typical single-riser/limited interval monitoring well.

<sup>1</sup> Modified from Chapter 7 of the Ohio Environmental Agency's "Technical Manual for Hydrogeologic Investigations and Ground Water Monitoring", 1995.

The use of multiple-level monitoring wells in Ohio has been limited due to: 1) cost of installation, 2) difficulty in repairing clogs, and 3) difficulty in preventing and/or evaluating sealant and packer leakage. Detailed work plans (including construction and installation, methods to measure water levels and obtain samples, references to situations where these types of wells have been used successfully, and advantages and disadvantages) should be submitted prior to installing multilevel systems. Until more site-specific data is available concerning their performance, multilevel wells should only be considered when a single zone having no to little vertical flow is being monitored at different depths.

## **Nested Wells**

Nested wells involve the completion of a series of single-riser wells in a borehole. Each well is screened to monitor a specific zone, with filter packs and seals employed to isolate the zones. Nested wells are not recommended because they are difficult to install in a manner that ensures that all screens, filter packs, and seals are properly placed and functioning. It is more efficient to install single-riser wells for each interval to ensure that representative samples can be collected. Aller et al. (1991) indicated that individual completions generally are more economical at depths less than 80 feet. According to Dalton et al. (1991), the cost of installing well clusters is usually only marginally higher than the cost for nested wells. Well clusters can enable savings on sampling and future legal costs that may be necessary to prove the accuracy of nested wells.

## **Single Riser/Flow-Through Wells**

Single riser/flow-through wells are monitoring wells that, in general, are screened across the entire thickness of a water-bearing zone. These wells are typically small in diameter and provide a “transparent” cross-section of the flow field (Aller et al., 1991). If purging is performed immediately before sampling, only composite water samples are yielded, which are not adequate for most monitoring studies. If natural, flow-through conditions can be maintained, and if a sampling device can be lowered with minimal disturbance of the water column, vertical water quality profiles potentially can be identified. To achieve and document the collection of such samples is very difficult, however, and the resulting data may be questioned. Furthermore, these wells are conducive to allowing cross-contamination between different zones and, therefore, should not be used in contaminated areas. Flow-through wells are not recommended.

## **Casing**

The purpose of casing is to provide access to the subsurface for sampling of ground water and measurement of water levels. A variety of casing has been developed. Items that must be considered during well design include casing type, coupling mechanism, diameter, and installation.

### **Casing Types**

There are three categories of casing commonly used for ground water monitoring, including fluoropolymers, metallics, and thermoplastics (Aller et al., 1991). All have distinctive characteristics that determine their appropriateness.

#### **Fluoropolymers**

Fluoropolymers are synthetic “plastics” composed of organic material. They are resistant to chemical and biological attack, oxidation, weathering, and ultraviolet (UV) radiation. They have a broad useful temperature range, a high dielectric constant, a low coefficient of friction, display anti-stick properties, and have a greater coefficient of thermal expansion than most other plastics and materials (Aller et al., 1991). A variety of fluoropolymers are marketed under various trademarks. Some manufacturers use one trade name to refer to several of their own materials, which may not always be interchangeable in service or performance (U.S. EPA, 1992). Standard properties of the various materials have been provided by Nielsen and Schalla (1991) and Aller et al. (1991).

The most common fluoropolymer used for monitoring wells is polytetrafluoroethylene (PTFE). It can withstand strong acids and organic solvents and, therefore, it is useful for environments characterized by the presence of these chemicals. It maintains a low tensile strength, which theoretically limits installation of Schedule 40 PTFE to an approximate depth of 250<sup>2</sup>. It is also very flexible, which makes it difficult to install with the retention of straightness that is needed to ensure successful insertion of sampling or measurement devices. Dablow et al. (1988) found that the ductile nature of PTFE can result in the partial closing of screen slots due to the compressive forces of the casing weight. This makes slot size selection very difficult. The inert nature of PTFE often

<sup>2</sup> The maximum depth for PTFE casing is dependent on site hydrogeology. If the casing largely penetrates unsaturated soils, the depth may be limited to approximately 100 feet. However, if the casing is placed mostly in water-bearing zones, then depth may be as great as 375 feet.

prevents the annular seal from bonding with the casing completely, which can allow infiltration of surface water. PTFE is costly, generally ten times more expensive than thermoplastics.

### **Metallics**

Metallic materials include low carbon, carbon, galvanized, and stainless steel. Metallics are very strong and rigid and can be used to virtually unlimited depths. Corrosion problems are the major disadvantage for low carbon, carbon, and galvanized casings. Electrochemical and chemical attack alters water sample quality. U.S.EPA (1992) has listed the following as indicators of corrosive conditions (modified from Driscoll, 1986):

- Low pH (< 7.0).
- Dissolved oxygen exceeds 2 ppm.
- Hydrogen sulfide in quantities as low as 1 ppm.
- Total dissolved solids (TDS) greater than 1000 ppm.
- Carbon dioxide exceeds 50 ppm.
- Chloride (Cl<sup>-</sup>), bromide (Br<sup>-</sup>), and fluoride (F<sup>-</sup>) content together exceeds 500 ppm.

According to Barcelona et al. (1983), flushing before sampling does not minimize the bias of low carbon steel due to the inability to predict the effects of disturbed surface coatings and corrosion products accumulated at the bottom of the well. Due to their high corrosion potential, all metallics except stainless steel are unacceptable for monitoring wells.

Stainless steel is manufactured in two common types, 304 and 316. Type 304 is composed of iron with chromium and nickel. Type 316's composition is the same as Type 304's, but includes molybdenum, which provides further resistance to sulfuric acid solutions. Stainless steel is readily available in a wide variety of diameters.

Stainless steel can perform quite well in most corrosive environments. In fact, oxygen contact develops an external layer that enhances corrosion resistance (Driscoll, 1986). Yet, under very corrosive conditions, even stainless steel can corrode and release nickel and chromium into ground water samples (Barcelona et al., 1983). Combinations and/or extremes of the factors indicating corrosive conditions generally are an indication of highly corrosive environments. For example, Parker et al. (1990) found that both 304 and 316 showed rapid rusting (<24 hrs.) when exposed to water containing chloride above 1000 mg/l. Like PTFE, stainless steel is relatively expensive in comparison with thermoplastics Nielsen and Schalla (1991) and Aller et al. (1991) provided additional information on the properties of stainless steel.

### **Thermoplastics**

Thermoplastics are composed of large, synthetic organic molecules. The most common type used for monitoring wells is polyvinyl chloride (PVC), while a material used less often is acrylonitrile butadiene styrene (ABS). These materials are weaker, less rigid, and more temperature-sensitive than metallics. Thermoplastics are very popular due to their light weight, high strength to weight ratio, low maintenance, ease of joining, and low cost.

Common, acceptable PVC types are Schedule 40 and Schedule 80. The greater wall thickness of Schedule 80 piping enhances durability and strength, provides greater resistance to heat attack from cement, and allows construction of deeper wells. Only rigid PVC should be used for monitoring wells. Flexible PVC is composed of a high percentage of plasticizers (30 - 50%), which tend to degrade and contaminate samples (Jones and Miller, 1988). All PVC casing should meet Standard 14 of NSF International. This standard sets control levels for the amount of chemical additives to minimize leaching of contaminants (NSF International, 1988). Additional specifications have been provided by Nielsen and Schalla (1991) and Aller et al. (1991).

Drawbacks of PVC include brittleness caused by ultraviolet (UV) radiation, low tensile strength, relative buoyancy in water, and susceptibility to chemical attack. It is immune to corrosion and is resistant to most acids, oxidizing agents, salts, alkalies, oils, and fuels (NWWA/PPI, 1981). Additionally, Schmidt (1987) showed that no degradation of PVC occurred after six months immersion in common gasolines. However, studies have shown that high concentrations (parts-per-thousand or percentage concentrations) of tetrahydrofuran, methyl ethyl ketone, methyl isobutyl ketone, and cyclohexane degrade PVC (Nielsen and Schalla, 1991). Barcelona et al. (1983) reported that low molecular weight ketones, aldehydes, amines, and chlorinated alkenes and alkanes may cause degradation. There is a lack of published information regarding the concentrations of these compounds at which deteriora-

tion is significant enough to affect either the structural integrity of casing or ground water sample quality.

### **Type Selection**

Many regulated parties choose PVC casing because of its lower cost; however, well integrity and sample representativeness are more important criteria. The high cost of analysis and the extreme precision of laboratory instruments necessitate the installation of wells that produce representative samples. Above all, the burden of proof is on the regulated party to demonstrate that casing is appropriate. The proper selection can be made by considering casing characteristics in conjunction with site conditions.

Casing characteristics include strength, chemical resistance and chemical interference potential. The strength must withstand the extensive tensile, compressive, and collapsing forces involved in maintaining an open borehole. Since the forces exerted are, in large part, related to well depth, strength often is important when planned depth exceeds the maximum range of the weakest acceptable material (100 to 375 ft. - PTFE). In these instances, either stainless steel or PVC should be chosen. Strength can be the overriding factor because the concern for chemical resistance and interference become insignificant if an open borehole cannot be maintained. Nielsen and Schalla (1991) provided specific strength data for commonly used materials.

The casing also must withstand electrochemical corrosion and chemical attack from natural ground water and any contaminant(s). Chemical resistance is most important in highly corrosive environments, when contaminants are present at extremely high levels, and when wells are intended to be part of a long-term monitoring program. For extended monitoring in corrosive environments, PTFE and PVC are preferred over stainless steel because of the potential for the metallic material to degrade. If high concentration of organics (parts per thousand) are present, either PTFE or stainless steel should be selected. U.S. EPA (1992) recommended that PVC not be used if a PVC solvent/softening agent is present or the aqueous concentration of a solvent/softening agent<sup>3</sup> exceeds 0.25 times its solubility in water. It is suitable in most situations where low (parts per billion to low parts per million) levels of most organic constituents are present (Nielsen and Schalla, 1991).

The casing also should not interfere with sample quality by adding (leaching) or removing contaminants. In most cases, the magnitude of this interference is a function of the ground water's contact time with the casing. The longer the contact, the greater the potential for leaching and sorption. Various studies have been conducted [Barcelona and Helfrich (1988), Curran and Tomson (1983), Gillham and O'Hannesin (1989), Jones and Miller (1988), Miller (1982), Parker and Jenkins (1986), Parker et al. (1990), Reynolds and Gillham (1985), Schmidt (1987), Sykes et al. (1986), Tomson et al. (1979), Hewitt (1992, 1994), Parker and Ranney (1994)] to compare the sorbing and leaching characteristics of the three favored materials. No conclusive results have been obtained to indicate that any one is best. Most of these studies involved contact lasting days, weeks, and even months and, therefore, the results cannot be correlated to field conditions where contact is often minimal because sampling is generally conducted soon after purging.

In many cases, concern about sorption or leaching may be exaggerated. Barcelona et al. (1983) and Reynolds and Gillham (1985) both concluded that the potential sorption biases for casing may be discounted due to the short contact after purging. Also, Parker et al. (1990) indicated that sorption of various constituents never exceeded 10 percent in the first 8 hours of their tests. They concluded that, on the basis of overall sorption potential for organic and inorganic compounds, PVC is the best compromise.

In summary, the appropriate casing should be determined on a case-by-case basis. PVC is acceptable when free product is not present and the solubility limits of organic contaminants are not approached (e.g., levels that exceed 0.25 times the solubility). Ohio EPA recognizes the difficulty inherent in establishing a "cut-off" level for when aqueous concentrations of organics cause failure of PVC. To be certain that casing will retain integrity, particularly when monitoring is planned for long periods of time (e.g., 30 years), Ohio EPA may require a more resistant casing when aqueous concentrations are relatively high but still below the criteria mentioned above.

### **Hybrid Wells**

Casing not in contact with the saturated zone generally is not subject to attack. Therefore, it may be possible to install less chemically resistant material above the highest seasonal water level and more inert material where ground water continually contacts the casing. Such a "hybrid well" commonly is installed for cost reduction reasons only. For example, when monitoring a zone with high concentrations of organic compounds, stainless steel or PTFE could be installed opposite the saturated materials, while PVC could

<sup>3</sup> Known PVC solvent/softening agents include: tetrahydrofuran, cyclohexane, methyl ethylketone, methyl isobutyl ketone, methylene chloride, trichloromethane, 1-1-dichloroethane, trichloroethene, benzene, acetone, and tetrachloroethene.

be used opposite the unsaturated materials. Thus, resistant, more expensive casing would be present where contact with highly contaminated ground water may occur, while less resistant, inexpensive casing would be present where contact does not occur.

Different varieties of steel never should be installed in the same well. Each type is characterized by its own electro-chemical properties. Installation of different types in contact can increase the potential for corrosion.

## **Coupling Mechanisms**

Casing sections should be connected using threaded joints that provide for uniform inner and outer diameters along the entire length of the well. Such “flush” coupling is necessary to accommodate the insertion of tools and sampling devices without obstruction and to help prevent bridging during the installation of the filter pack and annular seal. It should be noted that thread types vary between manufacturers and matching can be difficult. A union among non-matching joints should never be forced, otherwise structural integrity of the joint and the entire well could be compromised. To alleviate these problems, the American Society of Testing and Materials has developed Standard F 480-90 (1992) to create a uniformly manufactured flush-threaded joint. Most manufacturers now produce the F 480 joint, which is available in both PVC and stainless steel.

It is recommended that either nitrile, ethylene propylene, or Viton O-rings be used between sections to prevent the seal and/or affected water from entering (Nielsen and Schalla, 1991). Nielsen and Schalla (1991) indicated that Teflon tape can be used in place of O-rings, although it does not ensure as good a seal. Solvent cements should never be used because they are known to leach organics. Although welding stainless steel can produce a flush joint that is of equal or greater strength than the casing itself, this method is not recommended due to the extra assembly time, welding difficulty, corrosion enhancement, ignition danger, and the potential to lose materials into the well (Nielsen and Schalla, 1991).

Threaded steel casing provides inexpensive, convenient connections. It should be noted that threaded joints reduce the tensile strength of the casing; however, this does not cause a problem for most shallow wells. Also, threaded joints may limit or hinder the use of various sampling devices when thin-walled stainless steel (Schedules 5 and 10) is employed. Thin-walled casing is too thin for threads to be machined, so the factory welds a short, threaded section of Schedule 40 stainless steel pipe to the end of the thin-walled pipe. These joints are made to be flush on the outside, but not the inside.

If hybrid wells are installed, it is essential that the joint threads be matched properly. This can be accomplished by purchasing casing screen that is manufactured to ASTM F480-90 (1992) standard coupling.

## **Diameter**

Choice of casing diameter is also site-specific. Small wells are considered to be from 2 to 4 inches in diameter. The minimum diameter for use in monitoring wells is 2 inches. Advantages of small diameter wells are as follows:

- Water levels require less time to recover after purging.
- They produce a smaller volume of purged water that must be disposed.
- Construction costs are lower.

Some disadvantages of small diameter wells include:

- Access may be limited for sampling devices.
- Filter packs and seals are more difficult to install.
- They offer a lower depth capability due to lesser wall thickness.
- Development can be more difficult.
- Less ground water is pumped during a hydraulic test or a remediation extraction.
- The amount of available water may be too small for chemical analyses.

Further discussion of well diameter can be found in articles by Schalla and Oberlander (1983), Schmidt (1982), and Rinaldo-Lee (1983).

## **Installation**

Casing should be cleaned thoroughly before installation. Strong detergents and even steam cleaning may be necessary to remove oils, cleansing solvents, lubricants, waxes, and other substances. (Curran and Tomson, 1983; Barcelona et al., 1983). It is strongly recommended that only factory-cleaned materials be used for monitoring wells. Casing can be certified by the supplier and individually wrapped sections to retain cleanliness. If it has not been factory-cleaned and sealed, it should be washed thoroughly with a non-phosphate, laboratory grade detergent (e.g., Liquinox) and rinsed with clean water or distilled/deionized water as suggested by Curran and Tomson (1983) and Barcelona et al. (1983). The materials should be stored in a clean, protected place to prevent contamination by drilling and site activities.

When installing casing, it is important that it remain centered in the borehole to ensure proper placement and even distribution of the filter pack and annular seal. In addition, centering helps ensure straightness for sampling device access. If a hollow-stem auger is used, no additional measures are necessary because the auger acts as a centralizing device. If casing is installed in an open borehole, centralizers made of stainless steel or PVC can be used. They are adjustable and generally attached just above the screen and at 10 to 20 foot intervals along the riser. If centralizers are used, measures should be taken to prevent them from bridging the filter pack and seal material during their installation.

## **Intakes**

Although every well is unique, most have a screen and filter pack. Together, these comprise an “intake” Monitoring wells in cohesive bedrock may incorporate open borehole intakes.

## **Filter Pack**

Wells monitoring unconsolidated and some poorly consolidated materials typically need to have a screen (discussed later) surrounded by more hydraulically conductive material (filter pack). In essence, the filter pack increases the effective well diameter and prevents fine-grained material from entering.

### **Types of Filter Packs**

Filter packs can be classified by two major categories, natural and artificial. Natural packs are created by allowing the formation to collapse around the screen. In general, natural packs are recommended for formations that are coarse-grained, permeable, and uniform in grain size. According to Nielsen and Schalla (1991), they may be suitable when the effective grain size (sieve size that retains 90%, or passes 10%) is greater than 0.010 inch and the uniformity coefficient (the ratio of the sieve size that retains 40% and the size that retains 90%) is greater than 3. Ideally, all fine-grained particles are removed when the well is developed, leaving the natural pack as a filter to the surrounding formation.

Installation of artificial packs involves the direct placement of coarser-grained material around the screen. The presence of this filter allows the use of a larger slot size than if the screen were placed in direct contact with the formation. Artificial packs generally are necessary where: 1) the formation is poorly sorted; 2) the intake spans several formations and/or thin, highly stratified materials with diverse grain sizes; 3) the formation is a uniform fine sand, silt or clay; 4) the formation consists of thinly-bedded materials, poorly cemented sandstones, and highly weathered, fractured, and solution-channeled bedrock; 5) shales and coals that provide a constant source of turbidity are monitored; and 6) the borehole diameter is significantly greater than the diameter of the screen (Aller et al., 1991). Artificial packs generally are used opposite unconsolidated materials when the effective grain size is less than 0.010 inches and when the uniformity coefficient is less than 3.0 (Nielsen and Schalla, 1991).

An artificial pack may include two components. The primary pack extends from the bottom of the borehole to above the top of the screen. In some cases, it may be desirable to place a secondary pack directly on top of the primary pack. Its purpose is to prevent the infiltration of the annular seal into the primary pack, which can partially or totally seal the screen.

### **Nature of Artificial Filter Pack Material**

The artificial pack material should be well-sorted, well-rounded, clean, chemically inert, of known origin, and free of all fine-grained clays, particles and organic material. Barcelona et al. (1983) recommended clean quartz sand or glass beads. Quartz is the best natural material due to its non-reactive properties and availability. Crushed limestone should never be used because of the

irregular particle size and potential chemical effects. Materials should be washed, dried, and packaged at the factory, and typically are available in 100 lb. bags (approximately one cubic foot of material) (Nielsen and Schalla, 1991).

Selection of material should be based on the formation particle size. If chosen grains are too small, it is possible that loss of the pack to the formation can occur (Nielsen and Schalla, 1991), which could lead to the settling of the annular seal into the screened interval. On the other hand, if the grains are too large, the pack will not effectively filter fine-grained material, leading to excessively turbid samples.

The primary pack generally should range in grain size from a medium sand to a cobbled gravel. Most materials are available in ranges, such as 20- to 40-mesh (0.033 to 0.016 inches, Table 1). The grain size of the primary filter pack should be determined by multiplying the 70% retention size of the formation by a factor of 3 to 6 (U.S. EPA, 1975). A factor of 3 is used for fine, uniform formations; a factor of 6 is used for coarse, nonuniform formations (Figure 2). In situations where the material is less uniform and the uniformity coefficient ranges from 6 to 10, it may be necessary to use the 90% retention (10% passing) size multiplied by 6 (Nielsen and Schalla, 1991). This is to ensure that the bulk of the formation will be retained. The ratio of the particle size to the formation grain size should not exceed 6, otherwise, the pack will become clogged with fine-grained material from the formation (Lehr et al., 1988). If the ratio is less than 4, a smaller screen slot size will be necessary, full development of the well may not be possible, and well yield may be inhibited. When monitoring in very heterogeneous, layered stratigraphy, a type of pack should be chosen that suits the layer with the smallest grain size.

It is preferred that the filter pack be of uniform grain size. Ideally, the uniformity coefficient should be as close to 1.0 as possible and should not exceed 2.5 (Nielsen and Schalla, 1991, ASTM D5092-90, 1994). Uniform material is much easier to install. If nonuniform material is used, differing fall velocities cause the materials to grade from coarse to fine upwards along the screen. This can result in the loss of the upper fine-grained portion to the well during development.

The secondary filter pack material should consist of a 90% retention sieve size (10% passing) that is larger than the voids of the primary pack to prevent the secondary pack from entering the primary pack (Nielsen and Schalla, 1991). In general, the secondary 90% retention size should be one-third to one-fifth of the primary 90% retention size (Nielsen and Schalla, 1991).

Table 1. Common filter pack characteristics for typical screen slot sizes. (From Nielsen and Schalla, 1991)

Size of screen Opening [mm (in.)]	Slot No	Sand Pack Mesh Size	1% Passing Size (D1) (mm)	Effective Size (D10) (mm)	30% Passing Size (D30) (mm)	Range of Uniformity Coefficient	Roundness (Powers Scale)	Fall Velocities* (cm/s)
0.125(0.005)	5	40-140	0.09-0.12	0.14-0.17	0.17-0.21	1.3-2.0	2-5	6-3
0.25 (0/010)	10	20-40	0.25-0.35	0.4-0.5	0.5-0.6	1.1-1.6	3-5	6-6
0.50 (0.020)	20	10-20	0.7-0.9	1.0-1.2	1.2-1.5	1.1-1.6	3-6	14-9
0.75 (0.030)	30	10-20	0.7-0.9	1.0-1.2	1.2-1.5	1.1-1.6	3-6	14-9
1.0 (0.040)	40	8-12	1.2-1.4	1.6-1.8	1.7-2.0	1.1-1.6	4-6	16-13
1.5 (0.060)	60	6-9	1.5-1.8	2.3-2.8	2.5-3.0	1.1-1.7	4-6	18-15
2.0 (0.080)	80	4-8	2.0-2.4	2.4-3.0	2.6-3.1	1.1-1.7	4-6	22-16

\* Fall velocities in centimeters per second are approximate for the range of sand pack mesh sizes named in this table. If water in the annular space is very turbid, fall velocities may be less than half the values shown here. If a viscous drilling mud remains in the annulus, fine particles may require hours to settle.

### Dimension of Artificial Filter Pack

The distance between the casing and the borehole wall should be at least 2 to 4 inches to allow for proper placement of the filter pack and annular seal. Therefore, the filter pack thickness should be 2 to 4 inches. It is important that the thickness not be excessive, otherwise the potential for effective development is reduced.

The primary pack should extend from the bottom of the screen to at least 2 feet above its top. In deeper wells (i.e., >200 feet), the pack may not compress initially. Compression may occur

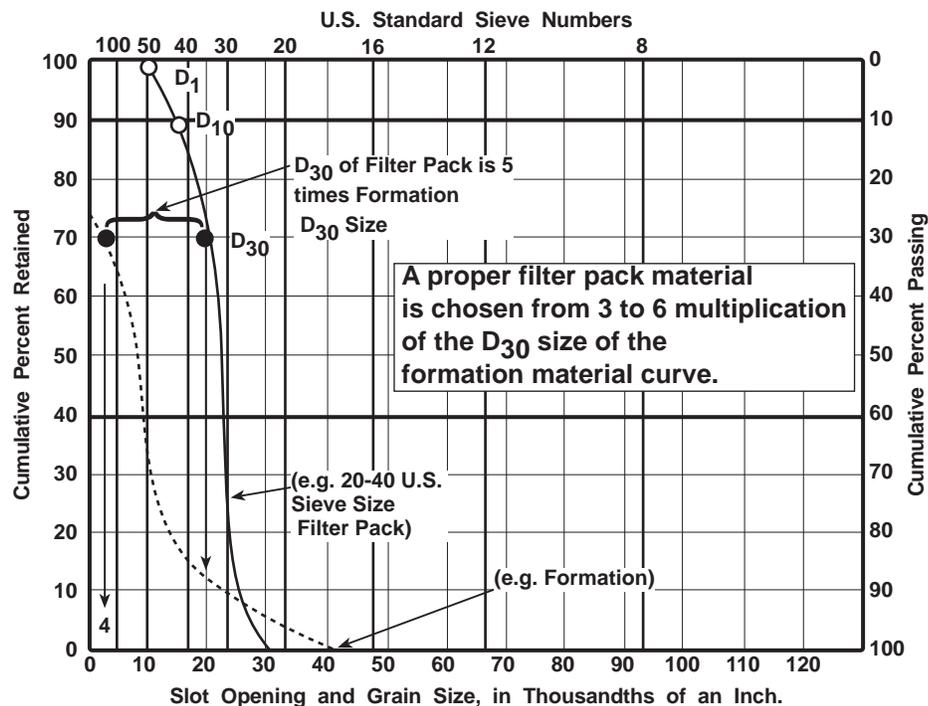


Figure 2. Artificial filter pack design criteria (Source: Design and Installation of Ground Water Monitoring Wells by D.M. Nielsen and R. Schalla, Practical Handbook of Ground Water Monitoring, edited by David M. Nielsen, Copyright 1991 by Lewis Publishers, an imprint of CRC Press, Boca Raton, Florida. With permission.)

after installation of the annular seal, which may allow the seal to be in close contact with the screen. Therefore, additional pack material may be needed to account for settling and, at the same time, provide adequate separation of the seal and the screen. However, extension of the pack should not be excessive because it enlarges the zone that contributes ground water to the well, which may cause excess dilution. The length of the secondary pack should be one-foot or less.

### Artificial Filter Pack Installation

Methods that have been used for artificial pack installation include tremie pipe, gravity emplacement, reverse circulation, and backwashing (Nielsen and Schalla, 1991). The material must be placed in a manner that prevents bridging and particle segregation. Bridging can cause the presence of large voids and may prevent material from reaching the intended depth. Segregation can cause a well to produce turbid samples. During installation, regular measurements with a weighted tape should be conducted to determine when the desired height has been reached, and also act as a tamping device to reduce bridging. The anticipated volume of filter pack should be calculated.<sup>4</sup> Any discrepancy between the actual and calculated volumes should be explained.

The preferred method for artificial pack installation is to use a **tremie pipe** to emplace material directly around the screen. The pipe is raised periodically to help minimize the risk of bridging. The pipe generally should be at least 1.5 inches ID, but larger diameters may be necessary where coarser-grained packs are being installed. When driven casing or hollow-stem augering is used to penetrate non-cohesive formations, the material should be tremied as the casing and auger is pulled back in one to two foot increments to reduce caving effects and ensure proper placement (Nielsen and Schalla, 1991). When installing wells through cohesive formations, the tremie pipe can be used after removal of the drilling device.

**Gravity emplacement** is accomplished by allowing material to free-fall to the desired position around the screen. Placement by gravity should be restricted to shallow wells with an annular space greater than 2 inches, where the potential for bridging or segregation is minimized (Nielsen and Schalla, 1991). For low-yielding formations, it may be possible to bail the borehole dry to facilitate placement; however, segregation is generally only a problem for deep wells with shallow water levels. Also, segregation is generally not a problem if the pack has a uniformity coefficient of 2.5 or less. Gravity placement also can cause grading if the material is not uniform. In addition,

<sup>4</sup> Anticipated filter pack volume can be calculated by determining the difference in volume between the borehole and casing (using outside diameter of the well) from the bottom of the borehole to the appropriate height above the well screen.

formation materials are often incorporated during placement, which can contaminate the pack and reduce its effectiveness. For most cases, gravity placement is not recommended.

Reverse circulation involves the insertion of a sand and water mixture through the annulus. Sand is deposited around the screen as the water returns to the surface through the casing. Due to the potential water quality alteration, this method generally is not recommended.

Backwashing is accomplished by allowing material to free-fall through the annulus while clean water is pumped down the casing. The water returns up the annulus carrying fine-grained material with it. This creates a more uniform pack; however, the method is not commonly used for monitoring well installation and generally is not recommended due to the potential for alteration of ground water quality. Nonetheless, it is sometimes used for placing packs opposite non-cohesive heaving sands and silts.

## Screen

The screen is the final link to retaining the borehole and keeping unwanted formation particles out of ground water samples.

### Screen Types

Recommended screen compositions are stainless steel, PTFE, and PVC. The same discussion and concerns for casing material apply to screens. Only manufactured screens should be used, since these are available with slots sized precisely for specific grain sizes. Field-cut or punctured screen should never be used, due to the inability to produce the necessary slot size and the potential for the fresh surface to leach or sorb contaminants. A bottom cap or plug should be placed at the base of the screen to prevent sediments from entering and to ensure that all water enters the well through the screen openings.

Slotted and continuous slot, wire-wound screen are the common types used for monitoring wells. In deep wells, slotted screen generally retains structural integrity better than wire-wound; however, continuous slot, wire-wound screens provide almost twice the open area of slotted casing. More open area per unit length enhances well recovery and development. A slot type should be chosen that provides the maximum amount of open area in relation to the effective porosity of the formation. Driscoll (1986) recommended that the percentage of open area should be at least equal to the effective porosity of the formation and filter pack. In common situations with 10 to 30 percent effective porosities, continuous slot screens are preferred, although not required (Nielsen and Schalla, 1991).

### Slot Size

When selecting a screen slot size for an artificially filter-packed well, a sieve analysis should be conducted on the pack material. The selected size should retain at least 90% of the pack. In many situations it is preferable to retain 99% (Nielsen and Schalla, 1991 and ASTM D 5092-90, 1994) (Figure 3). See Table 1 for a guide to the selection of slot sizes for various packs.

For naturally-packed wells, the screen should retain from 30 to 60% (Aller et al., 1991). As a rule of thumb, a 50% retention may be adequate (based on Wisconsin Administrative Code, 1990). With small diameter (4-inch or less), low yield wells, development may not be effective to remove a sufficient amount of fines and a 60 to 70% retention size may be more desirable. For additional information on pack and screen selection, see Aller et al. (1991), Nielsen and Schalla, (1991), and ASTM D 5092-90 (1994).

It should be noted that if a PTFE screen is used in a deep well, a slightly larger slot size than predicted should be selected due to the material's lower compressive strength, which allows the openings to compress (Dablow et al., 1988).

### Length

Screen length should be tailored to the desired zone and generally should not exceed 10 ft. A 2 to 5 ft. screen is desirable for more accurate sampling and discrete head measurements. Longer screens produce composite samples that may be diluted by uncontaminated water. As a result, concentrations of contaminants may be underestimated. Furthermore, the screen should not extend through more than one water-bearing zone to avoid cross-contamination. When a thick formation must be monitored, a cluster of individual, closely spaced wells, screened at various depths, can

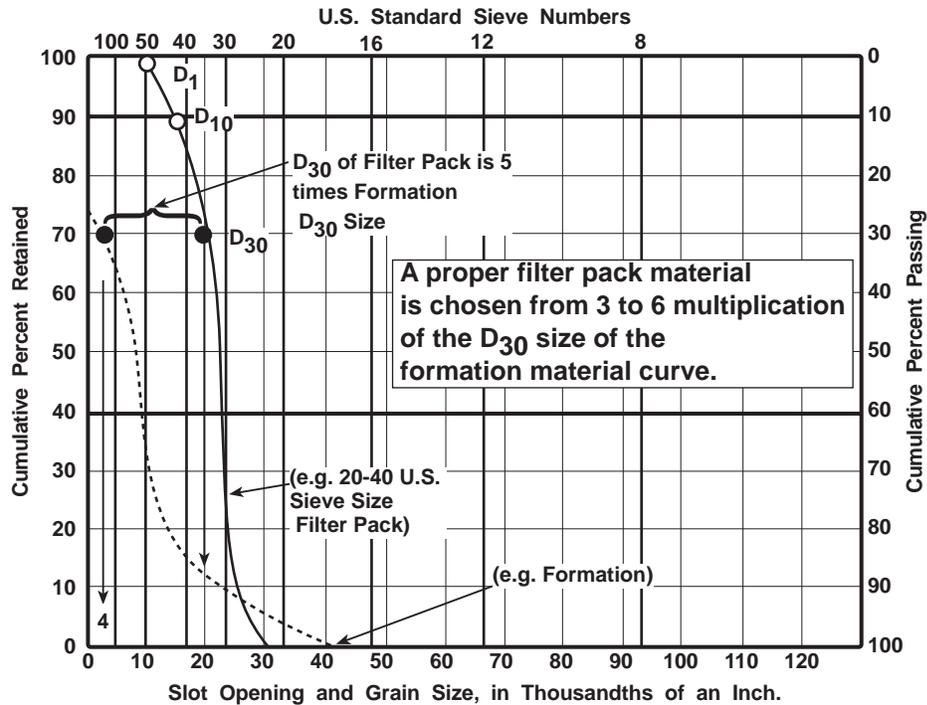


Figure 3. Selection of screen slot size based on the filter pack grain size. (Source: Design and Installation of Ground Water Monitoring Wells by D.M. Nielsen and R. Schalla, Practical Handbook of Ground Water Monitoring, edited by David M. Nielsen, Copyright 1991 by Lewis Publishers, an imprint of CRC Press, Boca Raton, Florida. With permission.)

be installed to monitor the entire formation thickness. The length of screens that monitor the water table surface should account for seasonal fluctuation of the water table.

### Open Borehole Intakes

When constructing monitoring wells in competent bedrock, an artificial intake is often unnecessary because an open hole can be maintained and sediment movement is limited. Installing a filter pack in these situations may be difficult due to loss of material into the surrounding formation. In some cases, however, intakes are a necessary component of bedrock wells. A screen and filter pack should be installed in highly weathered, poorly cemented, and fractured bedrock (Nielsen and Schalla, 1991). They are usually necessary when monitoring the unconsolidated/consolidated interface in Ohio.

Open hole wells often are completed by casing and grouting the annulus prior to drilling into the monitoring zone. In cases where the zone has been drilled prior to sealing the annulus, a bridge (cement basket or formation packer shoe) must be set in the hole to retain the grout/slurry to the desired depth (Driscoll, 1986).

If an open hole well is installed, the length of open hole generally should not exceed 10 feet to prevent sample dilution. To maintain a discrete monitoring zone in consolidated formations, the casing should be extended and grouted to the appropriate depth to maintain the 10 foot limit. Driven casing may be necessary to avoid loss of the annular seal into the surrounding formation.

### Annular Seals

The open, annular space between the borehole wall and the casing must be sealed properly to: 1) isolate a discrete zone, 2) prevent migration of surface water, 3) prevent vertical migration of ground water between strata, and 4) preserve confining conditions by preventing the upward migration of water along the casing. An effective seal requires that the annulus be filled completely with sealant and the physical integrity of the seal be maintained throughout the lifetime of the well (Aller et al., 1991).

## Materials

The sealant must be of very low permeability (generally  $10^{-7}$  to  $10^{-9}$  cm/sec), capable of bonding with casing, and chemically inert with the highest anticipated concentration of chemicals expected. Cuttings from the existing borehole, no matter what the type of materials, should never be used. They generally exhibit higher permeability and cannot form an adequate seal.

The most common materials used are bentonite and neat cement grout. Each has specific, unique, and desirable properties. These materials are discussed briefly here. Additional information can be found in Gaber and Fisher (1988), ASTM Method C-150 (1992), and Nielsen and Schalla (1991).

### Neat Cement Grout

Neat cement grout is comprised of portland cement and water, with no aggregates added. It is a hydraulic cement produced by pulverizing cement clinker consisting essentially of hydrated calcium silicates, and usually containing one or more forms of calcium sulfate as an interground addition. Several types of portland cements are manufactured to accommodate various conditions that may be encountered. Table 2 lists the types as classified by ASTM C150-92 (1992). Type I is most commonly used for monitoring wells.

Table 2. ASTM Cement Designation (modified from Gaber and Fisher, 1988)

Type I	General purpose cement suitable where special properties are not required.
Type I	Moderate sulfate resistance. Lower heat of hydration than Type I. Recommended for use where sulfate levels in ground water are between 150 to 1500 ppm.
Type III	High early strength. Ground to finer particle size, which increases surface area and provides faster curing time period before drilling may resume from 48 hours to 12 hours. 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 designated for applications where the rate and amount of heat generated by the cement must be kept to a minimum. Develops strength at a lower rate than Type I.
Type V	Sulfate-resistant cement for use where ground water has a high sulfate content. Recommended for use when levels in ground water exceed 1500 ppm.
Type IA, IIA, and IIIA	Air entraining cements for the same use as Types I, II, and III. Not recommended for monitoring well construction.

Air-entraining portland cements have been specially processed to form minute air bubbles within the hardened structure. The air-entraining materials are added during the grinding of the clinker. The finished product is more resistant to freeze-thaw action. Air-entraining cements are designated with an "A" after the ASTM cement type. They have been used to construct water supply wells; however, they are less desirable than standard cements because of their greater permeability. Therefore, air-entraining varieties are not recommended for subsurface sealing of monitoring wells.

Water added to the neat cement should be potable and contain less than 500 ppm total dissolved solids (Gaber and Fisher, 1988). Low chloride and sulfate concentrations also are desirable (Campbell and Lehr, 1973). As the water to cement ratio increases, the compressive strength of the cement decreases and shrinkage increases. The American Petroleum Institute recommends a ratio of 5.2 gallons of water per 94 pound sack of cement. Additional water makes it easier to pump, but adversely affects the grout's sealing properties. Excess water can cause shrinkage and separation of the cement particles, which compromises seal integrity (Nielsen and Schalla, 1991).

The major disadvantages of neat cement are its heat of hydration, shrinkage upon curing, and its effect on water quality. During curing, heat is released, which is generally of little concern; however, generally if large volumes of cement are used or the heat is not rapidly dissipated, the resulting high

temperatures can compromise the integrity of PVC casing. However, the borehole for most monitoring wells is small, and heat significant enough to cause damage generally is not created.

Shrinkage is undesirable because it causes cracks and voids. To reduce cracking, 3 percent bentonite by weight can be added (Smith, 1994). Bentonite should not be pre-mixed with water, but should be added dry to the cement/water slurry (ASTM 5092-90, 1994). The addition of bentonite also retards settling time and reduces peak temperatures. Other additives, such as accelerators (e.g., calcium chloride) and retarders, are commercially available but are not recommended due to their potential to leach (ASTM Method 5092-90, 1994).

Upon settling, neat cement grouts often lose water into the formation and affect water quality. Neat cement typically ranges in pH from 10 to 12; therefore, it is important to isolate the annular seal from the screen and filter pack.

## Bentonite

Bentonite is composed of clay particles that expand many times their original volume when hydrated. The most acceptable form is a sodium (Na) rich montmorillonite clay that exhibits a 10 to 12-fold expansion when hydrated. Other types, such as calcium (Ca) bentonite, are less desirable because they offer lower swelling ability and surface area to mass ratios. However, other types should be considered if Na bentonite is incompatible with the formation or analyses of concern. For example, the capability of bentonite may be adversely affected by chloride salts, acids, alcohols, ketones, and other polar compounds. Ca bentonite may be more appropriate for calcareous sediments.

Bentonite is available in a variety of forms, including pelletized, coarse grade, granular and powder. **Pellets** are uniform in size and consist of compressed, powdered Na montmorillonite. They typically range from 1/4 to 1/2 inch in size. Pellets expand at a relatively slower rate when compared to other forms. **Coarse grade**, also referred to as crushed or chipped, consists of irregularly shaped, angular particles of montmorillonite that range from 1/4 to 3/4 inches in size. **Granular** particles range from 0.025 to 0.10 inches in size. **Powdered** bentonite is pulverized montmorillonite, factory-processed after mining. Powdered and granular forms are generally mixed with water to form a slurry. Risk of losing a slurry to the underlying filter pack and surrounding formation should be considered. High-solids, bentonite (>30% clay solids) has been developed specifically for monitoring well construction and provides an effective seal.

## Seal Design

It is important that the design of annular seals prevent infiltration into the filter pack. Contact with the seal can cause sampled ground water to be artificially high in pH. Additionally, bentonite has a high cation exchange capacity, which may affect the chemistry of samples (Aller et al., 1991). In the saturated zone, a 2-foot pure bentonite seal can minimize the threat of infiltration. Above the bentonite seal, neat cement, bentonite, or neat cement/bentonite grouts should be placed in the remainder of the annulus to within a few feet of the surface. Because bentonite requires a sufficient quantity and quality of water in order to achieve and retain hydration, bentonite generally, should only be used in the saturated zone. Where saturated conditions do not exist, neat cement-bentonite should be used.

## Seal Installation

It is important that annular seals are installed using techniques that prevent bridging, which may cause gaps, cracking or shrinking. Surface water and/or contaminants potentially can migrate through any voids created. The 2 foot bentonite seal above the filter pack is commonly installed by placing granular bentonite, bentonite pellets, or bentonite chips around the casing by dropping them directly down the annulus. If feasible, this practice is acceptable for wells less than 30 feet deep if a tamping device is used. However, for wells deeper than 30 feet, coarse-grained bentonite should be placed by means of a tremie pipe.

The bentonite should be allowed to hydrate or cure prior to sealing the remainder of the annular space. This will help prevent invasion of grout into the screened interval. If a two foot bentonite seal is desired in the unsaturated zone, granular material should be used. It should be added and hydrated in stages using water that is potable and free of analytes of concern.

For the remainder of the annulus, sealants should be in slurry form (e.g., cement grout, bentonite slurry) and should be placed with a tremie pipe (Figure 4). The bottom of the pipe should be equipped with a side discharge deflector to prevent the slurry from jetting a hole through the filter pack<sup>5</sup>. The seal

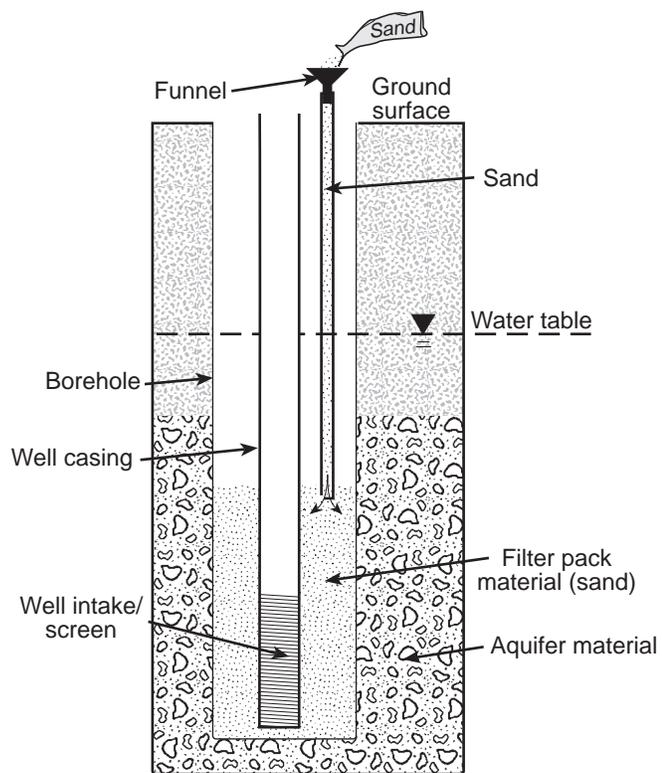
<sup>5</sup>Side discharge deflectors may not be necessary when a bentonite seal has been placed properly.

should be allowed to completely hydrate, set, or cure in conformance with the manufacturer's specifications prior to completing the surface seal and developing the well.

## Surface Seal/Protective Casing Completions

### Surface Seal

A neat cement or concrete surface seal should be placed around a protective casing to a depth just below the frost line (3-5 ft.). If the same material was used in the annular seal, the surface seal can be a continuation; otherwise, the surface seal is installed directly over the annular seal after settling and curing. The surface seal should slope away from the well and extend beyond the edge of the borehole to divert surface water. Air-entraining cements may be desirable in cold climates to alleviate cracking caused by freezing and thawing.



### Above-Ground Completions

Whenever possible, monitoring wells should extend above the ground surface to prevent surface water from entering and to enhance visibility. From the frost line upward, a steel protective casing should encompass the well. The protective casing should be at least two inches larger in diameter than the inner casing, extend above it, and have a locking cap. The lock should be protected by plastic or rubber covers so the use of lubricants to free and maintain locking mechanisms can be avoided. A small drain or "weep hole" should be located just above the surface seal to prevent the accumulation of water between the casings (See Figure 1). This is especially useful in cold climates, where the freezing of trapped water can damage the inner casing. A permanent reference point on the well inner casing must be surveyed to the nearest 0.01 ft. This permanent marker should be used for all water level measurements. Additionally, the well identification number or code should be marked permanently and clearly.

Bumper or barrier guards should be placed beyond the edge of the surface seal or within 3 to 4 feet of the well (See Figure 1). These guards are necessary to reduce and prevent accidental damage from vehicles. Painting the guard posts yellow or orange and installing reflectors can increase visibility and help prevent mishaps.

### Flush-to-Ground Completions

Flush-to-ground completions are discouraged because the design increases the potential for surface water infiltration; however, they are occasionally unavoidable. This type of completion should be used only when the location of a well would disrupt traffic areas such as streets, parking lots, and gas stations, or where easements require them (Nielsen and Schalla, 1991).

If flush-to-ground completion is installed, very careful procedures must be followed. A highly secure subsurface vault generally is completed in the surface seal, allowing the well casing to be

Figure 4. Tremie pipe emplacement of annular seal material. (Source: Design and Installation of Ground Water Monitoring Wells by D.M. Nielsen and R. Schalla, Practical Handbook of Ground Water Monitoring, edited by David M. Nielsen, Copyright 1991 by Lewis Publishers Division, an imprint of CRC Press, Boca Raton, Florida. With permission.)

cut below grade (Figure 5). An expandable locking cap on the casing and a waterproof gasket should be installed around the vault lid to prevent surface water infiltration. The completion should be raised slightly above grade and sloped away to help divert surface water. It should be marked clearly and locked to restrict access. This is especially important at gas stations to prevent the misidentification of wells as underground tank filling points.

## Documentation

During monitoring well installation, pertinent information should be documented, including design and construction, the drilling procedure, and the materials encountered. Accurate “as-built” diagrams should be prepared that, in general, include the following:

- Date/time of start and completion of construction.
- Boring/well number.
- Drilling method and drilling fluid used.
- Borehole diameter and well casing diameter.
- Latitude and longitude.
- Well location (+ 0.5 ft.) with sketch of location.
- Borehole depth (+ 0.1 ft.).
- Well depth (+ 0.1 ft.).
- Casing length and materials.
- Screened interval(s).
- Screen materials, length, design, and slot size.
- Casing and screen joint type.
- Depth/elevation of top and bottom of screen.
- Filter pack material/size, volume calculations, and placement method.
- Depth/elevation to top and bottom of filter pack.
- Annular seal composition, volume (calculated and actual), and placement method.
- Surface seal composition, placement method, and volume (calculated and actual).
- Surface seal and well apron design/construction.
- Depth/elevation of water.
- Well development procedure and ground water turbidity.
- Type/design of protective casing.
- Well cap and lock.
- Ground surface elevation (+ 0.01 ft.).
- Surveyed reference point (+ 0.01 ft.) on well casing.
- Detailed drawing of well (include dimensions).
- Point where water encountered.
- Water level after completion of well development.

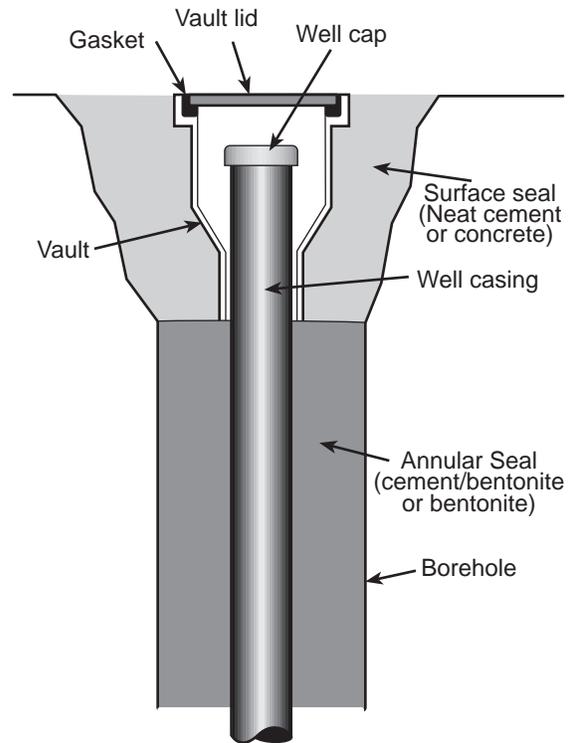


Figure 5. Typical flush-to-ground monitoring well completion. (Source: Design and Installation of Ground Water Monitoring Wells by D.M. Nielsen and R. Schalla, Practical Handbook of Ground Water Monitoring, edited by David M. Nielsen, Copyright 1991 by Lewis Publishers Division, an imprint of CRC Press, Boca Raton, Florida. With permission.)

In addition, the following should be documented in work plans (when appropriate) and reports:

- Selection and rationale materials for selection of casing and screen.
- Selection and rationale for well diameter, screen length, and screen slot size.
- Filter pack selection and emplacement.
- Annular sealant selection and emplacement.
- Security measures.
- Locations and elevations of wells.
- Well development.

A complete, ongoing history of each well should be maintained. This can include sample collection dates, dates and procedures for development, water level elevation data, problems, repairs, personnel, and methods of decommissioning. This information should be kept as a permanent on-site file, available for agency review upon request.

On July 18, 1990, Ohio House Bill 476 went into effect. This bill requires that all logs for monitoring wells drilled in Ohio be submitted to the Ohio Department of Natural Resources, Division of Water (ODNR). The ODNR can be contacted for further information.

## **Maintenance**

The condition of wells must be maintained to keep them operational and insure that representative samples can be obtained. Maintenance consists of conducting inspections and periodic checks on performance. Proper documentation (see previous section) is needed to serve as a benchmark for evaluation. Maintenance includes, but is not limited to, the following:

- Ensuring visibility and accessibility
- Inspecting locks for rusting
- Inspecting surface seals for cracking.
- Checking survey marks to insure visibility.
- Determining depth.
- Removing sediments (if needed).
- Evaluating performance by doing hydraulic conductivity tests.
- Evaluating turbidity and redeveloping or replacing well if turbidity increases.

Routine inspections generally can be conducted during sampling. Additional evaluation can be conducted by comparing new ground water quality data with previous data. If the maintenance check indicates a problem, rehabilitation should be conducted.

## **Appendix VII**

### **Contact Agencies**

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#### **Ohio Department of Agriculture (ODA), Pesticide Regulation Section**

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

#### **Ohio Department of 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.

#### **Ohio Department of Health, Division of Quality Assurance**

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 and 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 Ground water 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 well log and drilling reports be filed by drilling contractors for wells drilled in the state. Well sealing reports also must be filed with the Division of Water for any type of well sealed in Ohio. Again, this authority comes from Section 1521.05 of the Ohio Revised Code. Requests for copies of well log and drilling reports and well sealing reports on file can be made by calling 614-265-6740. Well log and drilling report forms and well sealing report forms can be obtained from the Division by calling 614-265-6739.

**\*Note:** The Division of Mines and Reclamation and the Division of Oil and Gas have recently been combined to create the Division of Mineral Resources Management.

## **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. 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.

