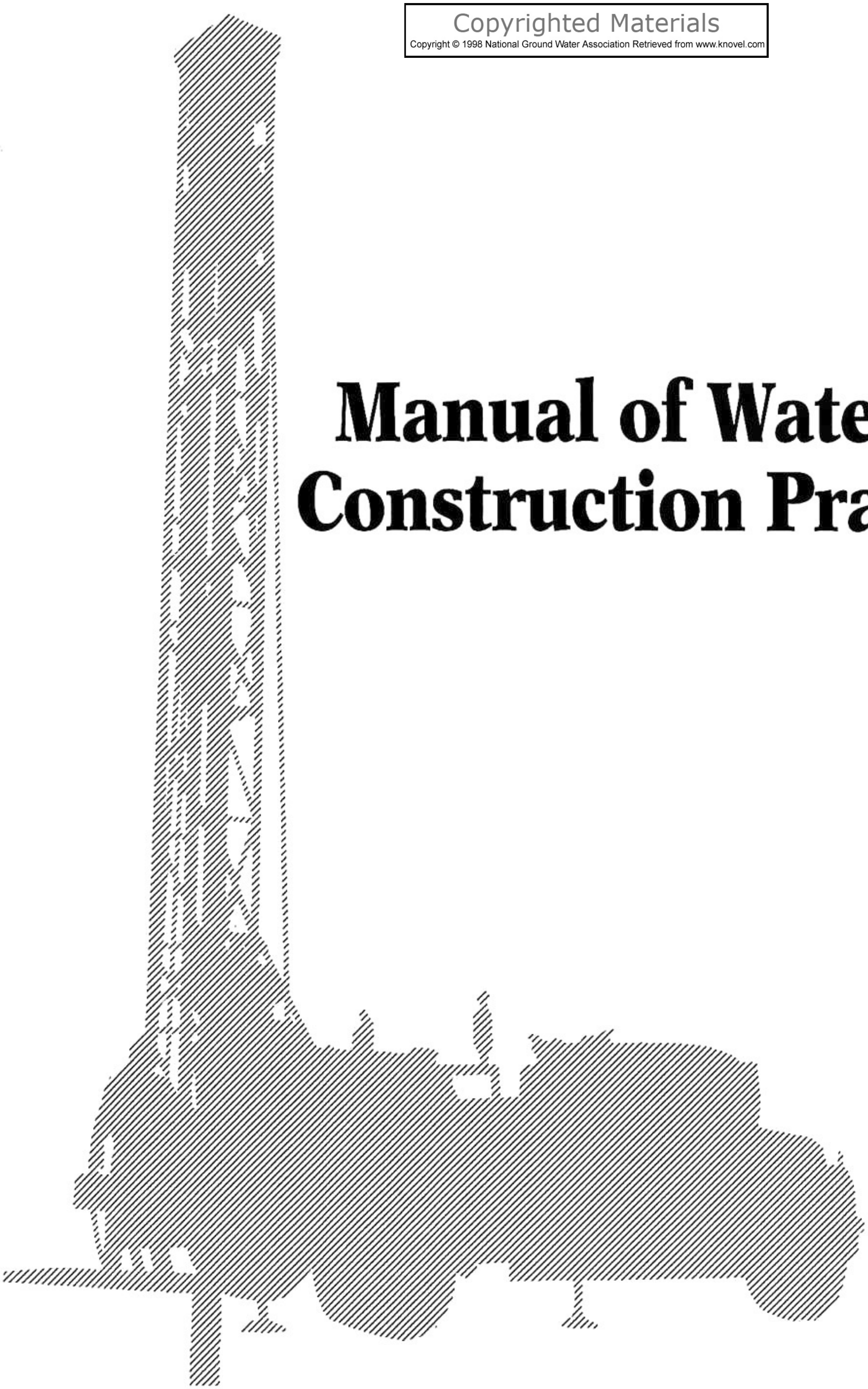


Manual of Water Well Construction Practices

2nd Edition

national ground water association
NGWA Press

601 Dempsey Road, Westerville, OH 43081, (800) 551-7379

MISSION STATEMENT

The purpose of this work is to provide background and an outline for plans and specifications that will lead to a water supply well that will fulfill its construction objective: Sufficient and safe water for human consumption without contaminating the aquifer. The manual is intended to outline well construction practices for drilled wells that are considered to be comprehensive and environmentally sound by the ground water and regulatory community in the United States for water supply wells. The intended result is maximum quality in well construction practices.

INTRODUCTION

Historically, ground water has been considered of good sanitary quality requiring little or no treatment before use as drinking water. 50 million Americans obtain their drinking water from individual home supply wells tapping this water resource. Data collected from at least the late 1960s to the present suggests that we may have been taking the high degree of microbiological purity of our ground water supplies for granted.

Aquifers are not sterile or always free from chemical contaminants. Recent regional studies from the U.S. Midwest conducted by the Centers for Disease Control and Prevention (CDC) in the Mid-west and by the U.S. Geological Survey National Water-Quality Assessment (NAWQA) studies show that many private (and also public) ground-water systems produce water containing coliform bacteria. However, the actual source of the coliform bacteria was not identified. Cross-contamination, backflows, and leaks in the system may be sources of bacterial contamination. However, there is no special reason why coliform bacteria could not persist in aquifers.

Concern about viruses in ground water drives the development of a Groundwater Disinfection Rule by the U.S. Environmental Protection Agency (EPA). In addition, work throughout the nation, especially since the passage of the landmark Comprehensive Emergency Response, Compensation and Liability Act (CERCLA or "Superfund") legislation, shows that chemical contamination of ground water is a serious concern in many places.

The CDC survey showed that the method used to construct wells, and the construction details themselves, affect the microbiological and toxicological quality, and potentially the safety, of a ground water supply. Proper well construction is the basis for well construction standards developed by U.S. states and jurisdictions in other countries. It is also the basis for consensus standards such as ANSI/AWWA A100 Standard for Water Wells. There is a consensus standard for irrigation wells produced by the American Society of Agricultural Engineers. Although statistical analysis of NAWQA studies conducted so far have been inconclusive on the point, the results of the Midwest

CDC analysis have finally provided large-scale positive correlations between bacteriological safety and better well construction practices.

Deficiencies in well construction in both individual and public supplies are not difficult to find and include: 1) insufficient and substandard well casing; 2) inadequate formation seal (grouting) between the well casing and the bore hole; 3) poor welding or joining of casing joints; 4) lack of sanitary seals; 5) poor well intake design, location, and construction; and 5) well terminus deficiencies such as using well pits to protect from freezing. Any one of these deficiencies may allow introduction of microbial or chemical contamination from the surface to the ground water and into the supply system, and therefore impairing the quality of product water.

The problems facing many people receiving drinking water from individual water supply systems were brought forth during testimony before the U.S. Congress on the original Safe Drinking Water Act in the early 1970s. Testimony at that time indicated that millions of Americans may be receiving drinking water that would not meet drinking standards mandated by the Act. Congress expressed concern and desire that adequate protection for persons relying on individual water systems for their drinking water be made available. This responsibility has remained with individual states and territories in the U.S.

Well deficiencies also have historically and currently resulted in poor water quality, production, and service life in public and other types of water supply wells. Most of the construction and protection issues are the same as for individual water supply wells.

Origins of this Manual

In the 1960's, the National Water Well Association (NWWA, now National Ground Water Association, NGWA) began to focus on how to improve well construction procedures to better protect the public health. Starting in 1971, the NWWA began to develop "a set of generally accepted specifications for well construction that could be widely distributed to consulting engineers, water well contractors, municipalities, industries, agriculturalists, and individual home owners. The document would serve to complement existing regulations, help educate the public, upgrade existing well construction techniques and thereby afford a greater protection to our ground water reserves." This process resulted in the *Manual of Water Well Construction Standards,* Environmental Protection Agency - 570/9-75-001, published by Environmental Protection Agency in 1975.

During preparation of the 1975 *Manual*, consideration was given to minimum standards already required by many states as well as pertinent suggested standards and specifications already available from other national and state associations. The *Manual* was designed recognizing that well construction techniques may vary with five major criteria: namely, (1) intended use of the water, (2) required capacity of the well, (3) nature of the producing zone, (4) intended drilling method, and (5) manner in which the well construction will be paid for. Using these criteria to describe construction of a well, alternate methods were established for the many facets of well construction such as test drilling, logging, casing, grouting, cementing, gravel packing, plumbness, alignment, development, testing, disinfection, sampling, and decommissioning (proper permanent abandonment or destruction).

The 1975 *Manual* served many years as a standard reference in water supply well construction and decommissioning. At the time of its publication as an EPA document, the well construction practices outlined in it were "supported by EPA as being complete and environmentally sound" but were furnished "for informational and educational purposes only." The NWWA/NGWA never developed a "well standard" in the sense of the American Water Works Association's Standard A100, but the *Manual* has stood the test of time as an outline in specification development and as a reference and training tool.

Since 1975, a revolution has occurred in the ground-water industry and its technology. The NWWA has become the NGWA, reflecting the fact that the industry is concerned with more than what are still our most important product: water wells. The "monitoring and remediation" sector became very large, and this sector was an engine driving innovation in well construction methods, materials, pumps and instrumentation. As a result, much more is known about the performance of materials used in water wells. Some methods described in the 1975 *Manual* have become outdated or are no longer favored due to potential health concerns (e.g., use of lead packers). New methods have appeared. Changes in grouting technology and materials have been profound.

Recognizing the effect of these changes, a NGWA Task Force was formed in 1994 to update the 1975 *Manual.* The purpose of the update was for the *Manual* to continue to:

(1) Serve as a reference document for professional well installation.

(2) Provide a training document for well inspectors (an NGWA-identified need).

(3) Provide a standard guide for well construction within the limitations of local, state, and federal law.

While it is beyond the scope of this document, the NGWA considers it important to recognize that there are many purposes for well construction beyond potable water supply, and to recognize that quality construction applicable for water wells is a benefit to other types of wells, including those for irrigation, long-term dewatering, monitoring, and ground water remediation.

One intention of publishing a manual on optimal well construction practice is to correct a common view reflected in the 1975 *Manual*, that nonpotable wells may be constructed to lesser standards than potable water supply wells. Constructing other wells (remediation, heat pump, etc.) to lesser standards, or by less qualified personnel, increases the risk of aquifer contamination due to poor construction practices or inadequate sanitation. Payment as a criterion is also de-emphasized, although discussed.

Audience for this manual

The intended audience for this manual are those people who are (1) learning about, (2) supervising and regulating, and (3) making specifications for the planning, construction, testing, maintenance, and final decommissioning of wells. Water well contractors and drillers performing these services will find it to be a quick reference to many useful methods and a standard of practice. The manual is intended to be compact and designed for quick reference, rather than being a comprehensive "bible" of well construction practice. For this, references to other sources are supplied.

It is possible to use the language provided in the specification portion of this manual directly as a basis for developing well specifications. However, the specific language should be adapted to specific situations (using professional judgment) in light of experience and factors such as state and/or local regulations.

What is a "well"?

Broadly speaking, a "well" can be any construction that permits access to the local ground water for extraction at the surface. A common popular image is of the brick or stone-lined dug well with winch and bucket. This indeed has been historically the most common well design, and still is constructed and used today in some parts of the world.

Most modern well construction consists of the drilled tubular well consisting of a borehole, tube casing, and sometimes a well screen designed to pass water, but retain the formation. A modern exception is the radial collector well, which resembles a dug well caisson, but is equipped with horizontal laterals driven into the water-producing formation to collect water. Most wells are vertical, but there are increasing applications for horizontally oriented and angled wells in the ground water field. This edition of this manual will generally address vertical, tubular wells. However, many aspects of vertical well construction apply to radial and horizontal or angled wells.

What is a good well?

A "good" well is one that meets the objectives of those who have commissioned its construction, and does not pose a threat to ground water. A water supply well produces a suitable yield of water of the desired quality. A monitoring well, produces water which is representative of the quality of water in the monitored zone. A plume control or remediation well may be designed specifically to intercept contaminated water, and to minimize the intake of uncontaminated water. Some wells, such as those for site or mine dewatering, may only have a production objective. Irrigation wells may not be concerned with bacteriological quality, but critically concerned with mineral quality. In general, however, "good" wells of all types shall have these characteristics:

(1) Proper construction to preclude sources of contamination or cross-contamination, and to assure structural integrity;

(2) Good design and material selection to provide structural integrity and adequate well service life;

(3) Proper development to make the most of the water-producing capabilities of the aquifer being used and/or to provide water representative of the aquifer;

(4) Provision for maintenance and testing to prolong well life, provide ease of service, and to permit a ready evaluation of well characteristics.

Where these conditions are met, the well will be expected to have acceptable performance and useful service life.

Difficulties of working in the ground

The underground and structures constructed in it are by nature less accessible than those on the surface. This situation makes for challenges in proper well siting, construction, and maintenance. A review of literature, or a conversation with ground water industry professionals reveals that ground water testing methods, drilling and well construction are often complex tasks that require more skill to do well than it may seem to on first glance. Mistakes can be expensive.

Deficiencies in well construction are not easy to detect, especially those outside the casing beyond the view of borehole cameras. If deficiencies do become apparent, they are difficult to correct. Deficiencies in well decommissioning sealing are, if anything, more damaging because they are more difficult to detect and correct.

Increasingly, wells are more difficult and expensive to site and construct, whatever their purpose. Poor-producing water wells are increasingly expensive failures. Construction and testing regulations for wells have extended to even the smallest public water supply systems and private well users.

How to make the right decisions

For these reasons, knowledge, experience, and professionalism are necessary in all phases of well planning, construction, and management. Well construction and decommissioning standards have long existed both as state or local statutes or regulations, or as consensus industry standards. More standard guides and practices are becoming available, particularly through the American Society for Testing and Materials Committee D18. In addition, states develop their own manuals of standard practice. These can serve as useful bases for planning, and sometimes become "quasi-legal" when cited in regulations. Anyone working in the industry should be aware of them.

Standard methods, guides, and regulations alone will not assure quality work in well planning, construction, testing, and decommissioning. They can in fact (if rigidly worded) become barriers to innovation by experienced ground water professionals or the installation of cost-effective wells.

What standards almost universally lack is any useful guidance to judge the qualifications of the people using them. It is this "human factor" that is the most important. All aspects of a ground water planning and construction program should be conducted by professionals experienced in the operations.

Some key people and possible indicators to their qualifications:

Key people	**Role in ground water projects**	**Qualification indicators**
Well contractors	Drilling, installing casing, pumps and other well equipment, service of wells, well decommissioning. On private well projects, they make plans and work without supervision.	State licensing (minimum: requirements vary by state). Certification (e.g., NGWA) Experience histories. Reputation.
Hydrogeologists or engineers	Planning ground water projects, designing wells and wellfields, writing specifications, testing wells, troubleshooting, working with contractors and regulators.	State licensing professional & registration (PE requirements vary by state: some states do not license geologists). Certification (e.g., NGWA): especially useful for assessing hydrogeologists. Experience histories: P.E.'s should have specific ground water experience. Academic degrees.

Well inspectors and regulators	Reviewing plans for ground water projects, site selection and approval, wells and wellfield designs, writing regulations, inspecting wells, troubleshooting, working with contractors, engineers and hydrogeologists.	State classifications (usually experience and qualification-based). Certification (e.g., NGWA): professional status. Experience and academic degrees.
Owners	Ultimately responsible for permits, adhering to regulations, providing safe water to users of the ground-water source, maintenance of wells, payment for services rendered.	Being well informed, interacting in a businesslike fashion with contractors, consultants, and regulators.

Professional judgment is used to make right decisions, such as deciding the cost and time to be invested in a project or well. Historically, cost and quality have had a linear relationship in well construction. This relationship has broken down with the advent of tough, corrosion-resistant plastics, and lower-cost, high-quality pumps, for example. Time and expense invested one place (geophysical studies) may save money elsewhere (cutting down on drilling costs). Maintenance, which has a cost in time and materials, is shown to reduce the cost of a well over its life span, and the cost of water or project operation by prolonging useful well and pump life.

Knowledge of these various aspects of planning helps to make the right decisions on ground water projects. This manual is presented as a modern and definitive tool in helping to make those decisions.

References

ANSI/AWWA A100-97. 1997. AWWA Standard for Water Wells. American Water Works Assn., Denver, CO.

Bickford, T.M., B.D. Lindsey, and M.R. Beaver, 1996. Bacteriological Quality of Ground Water Used for Household Supply, Lower Susquehanna River Basin, Pennsylvania and Maryland. Water Resources Iinvestigations Report 96-4212, U.S. Geological Survey, Reston, VA.

Gray, K. and A.Highsmith, 1996. What do the CDC studies on microbial contamination of private wells tell us? Presented at *Under the Microscope: Examining Microbes in Groundwater,* The Groundwater Foundation 12th Annual Fall Symposium, Boston, MA.

Great Lakes-Upper Mississippi River Board of State Public Health and Environmental Managers. 1987. *Recommended Standards for Water Works. Health Research Inc.*, Health Education Services Div., Albany, NY.

NWWA Committee on Water Well Standards. 1975. *Manual of Water Well Construction Standards,* EPA - 570/9-75-001. Office of Water Supply, Washington, DC.

Smith, S.A. 1997. Well construction, maintenance and abandonment: How they help in preventing contamination. *Under the Microscope: Examining Microbes in Groundwater,* Proc. of The Groundwater Foundation Fall Symposium. AWWA Research Foundation and American Water Works Assn., Denver, CO, pp. 115-126.

Yates, M. 1997. What are sources, movement and fate of microbial contamination? *Under the Microscope: Examining Microbes in Groundwater*, Proc. of The Groundwater Foundation Fall Symposium. AWWA Research Foundation and American Water Works Assn., Denver, CO, pp. 161-170.

CDC. 1998. Survey of Water Drawn from Domestic Wells in Nine Midwestern States.

TABLE OF CONTENTS

CHAPTER 4

CHAPTER 5

CHAPTER 6

CHAPTER 7

CHAPTER 8

CHAPTER 9

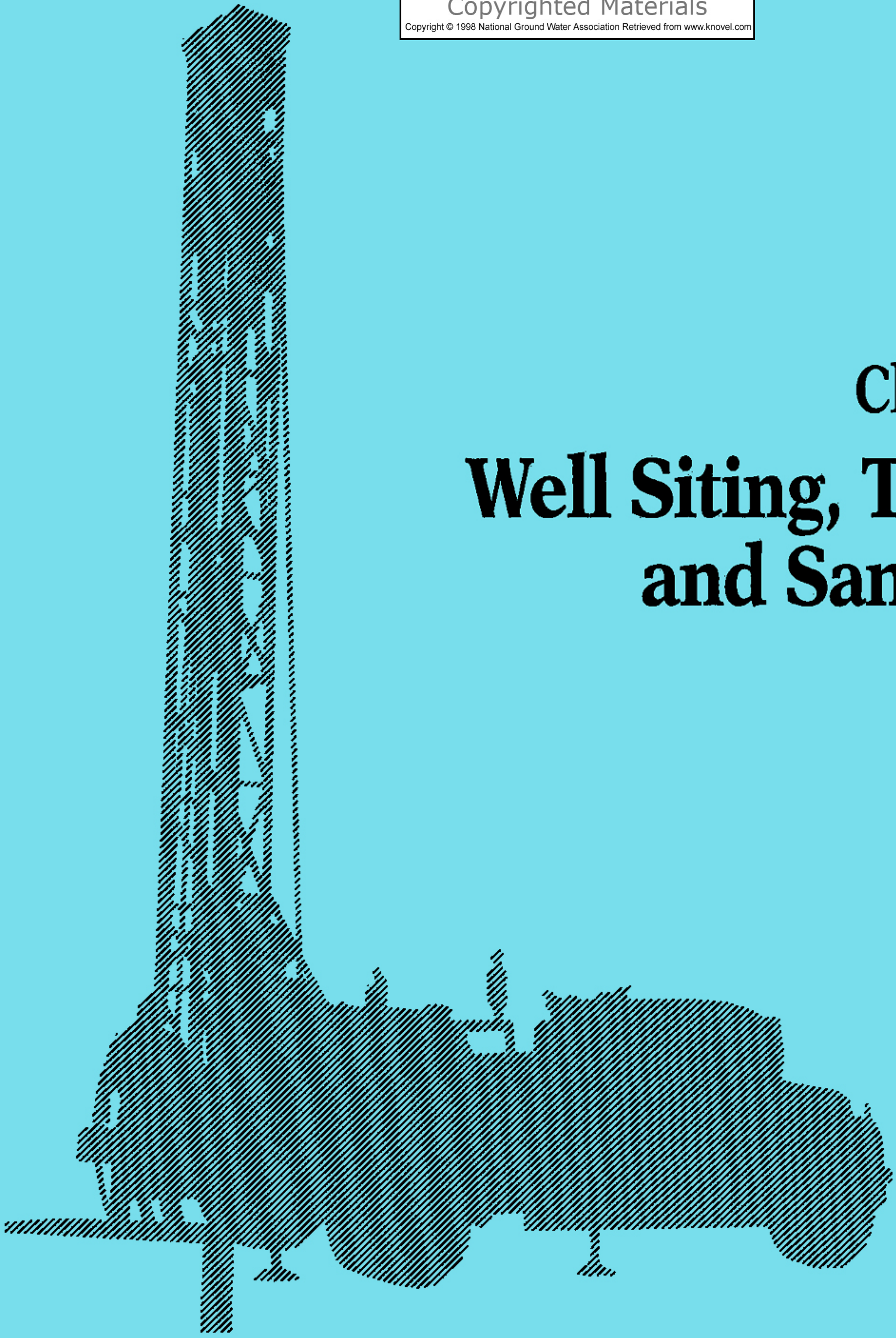
CHAPTER 10

CHAPTER 11

CHAPTER 12

CHAPTER 13

APPENDIX



Chapter 1
Well Siting, Testing and Sampling

1 Well Siting,Testing and Sampling

1.1 Issues in Planning Testing

1.1.1 Site Selection. Locating test bores and wells (and eventually water wells), if based on technical criteria rather than convenience alone, begins with a site selection process before drilling or testing is planned. The goal should be pre-selection of the best possible sites, and anticipation of both technical and other practical problems (e.g., neighboring wells). This decision-making process involves a combination of hydrogeological advisors, regulatory personnel, well drilling contractors, engineers, and the property owners involved. Tools include maps, aerial photographs, well logs and other relevant file information from the area, and site inspection. Issues include:

(1) Potential yield and water quality;

(2) Vulnerability to known or suspected contamination or natural risks such as flooding;

(3) Regulated distance from potential contaminant sources (e.g., septic tanks; oil wells);

(4) Potential for interference with other wells, surface water flows, or environmentally important water uses (e.g., wetlands or springs) or areas;

(5) Potential for interference with utilities.

Potential drilling sites being analyzed as potential water well sites should have some reasonable expectation of providing sufficient, potable water; meet regulatory requirements; and not pose unacceptable health or safety risks to workers or future water users. For public water supply wells, will the location allow for a defensible wellhead protection area that does not include multiple potential pollution sources.

In the U.S., water supply is for the most part regulated at the state and local level. Public water supply wells are regulated under state enforcement of the Safe Drinking Water Act. Private water supply wells fall under state and local control, with agencies and regulations varying greatly from state to state (see Appendix chart of state regulations).

Non-hydrogeological and non-regulatory factors are important as well. These include access for rigs and other equipment, access to power (either for testing or eventually for production wells), and distance from the water use.

1.1.2 Test Borehole and Well Drilling. The purpose of drilling a test hole is to obtain information on ground water quality and formation materials, and to help establish essential "ground truth" at a specified location, including:

(1) The depth and extent of the water-bearing formations, or zones within formations;

(2) Thickness, nature, and areal extent of confining layers;

(3) Existence of specific features of note (oily or sand seams)

(4) Water quality and actual yield and drawdown information.

Location of test holes should be based on the objectives of the drilling project, and should be selected based on available geologic information. For example, a test hole drilled to test a location for municipal water supply would be selected for maximum uncontaminated production. Test holes to confirm the location of a contaminant plume would be located based on existing knowledge of the plume and other field information such as geophysical survey results. A hole to characterize a water-bearing fracture zone would be located based on maps, and aerial and geophysical surveys.

Other factors involved include state and local regulations on well spacing and set-back distances from potential contamination sources. These are often preset distances set regardless of local conditions at a specific site. However, they have been established with the intention to provide criteria for reasonable protection of potable drinking water from potential contaminant sources (septic tanks and leachfields, sewer lines, fuel tanks, etc.). For most purposes, minimum requirements should be considered as minimums. Where there is credible information that would permit closer spacings than regulation require, some jurisdictions permit variances. However, such variance applications must be well supported with evidence.

The nature of the exploration program depends on the size and complexity of the project, the complexity of the hydrogeologic setting, and relative uncertainty of finding suitable quantities of good quality water. For water wells, cost-effectiveness is very important in the exploration planning. In many cases, the test hole will be enlarged and cased, becoming a finished well. For test boreholes constructed by the rotary method, the "pilot hole" is, in effect, a test hole.

When warranted, a test hole may be converted into a test well fully capable of being operated as a permanent production well. This is done by enlarging ("reaming out") the borehole as necessary to accommodate the final production casing, grout seal, and screen (where required).

Another factor in contamination studies (not necessarily water wells) is the need to minimize the volume of contaminated cuttings and fluid to handle. The drilling method in this case would be selected for maximum information recovery with a minimum sample production in spoils or cuttings.

Access is another consideration. Gaining access under buildings or from remote locations is the impetus behind the refinement of directional drilling in the ground-water field. Where possible, wells should be located for reasonable access by typically large drilling rigs, and for later well service.

It is recommended that samples be collected of all materials penetrated by the drilled borehole. As many samples should be taken as required and by such means as will assure collection of representative samples of a specific aquifer(s) or formation(s) that will be free of material from intervals above the aquifer or formation of interest. Care must be taken to accurately determine the depth interval from which each sample is taken.

1.2 Hole Location And Purpose

Test holes should be constructed at suitable locations to obtain information regarding the depth, thickness and water-yielding potential of the formations encountered. Geographic locations should be accurately stated by suitable descriptions relative to fixed reference points that can be reasonably expected to be available long into the future for relocating the hole. In general, project or site geologists would determine the test hole locations and mark them for drillers.

1.3 Drilling Methods

Descriptions of drilling methods may be found in Section 2.1, Methods of Well Construction. Methods, or details of practice, used for test hole construction may be different from those used for water well construction, and are usually defined by the project geologists. While methods used for geologic testing and water well construction may be similar, they have differing objectives. The first objective of test drilling is information. The first objective of well construction is a quality, productive well.

In geologic test drilling, fluid enhancements may be prohibited or tightly restricted due to interference with analytical methods. Tools are selected for maximum recovery of sample rather than hole making. Some methods, such as the hollow stem auger, dual-tube reverse circulation, casing-advancement, diamond core drilling, or rotary sonic methods (see Specifications section), not commonly used in water supply well construction, are more likely to be employed to provide high-quality samples.

1.4 Drilling Logs and Reports

Drilling logs and other records of the test hole are critically important for later evaluation in planning production wells. They may be the only site-specific geologic information available for a property or even the local area. Contractors and geologists must prepare and keep complete logs setting forth critical hydrogeological information, including:

(1) The reference point for all depth measurements;

(2) The depth at which each change of formation occurs;

(3) The depth at which the first water was encountered;

(4) The depth at which each stratum was encountered;

(5) The thickness of each stratum;

(6) The identification of the material of which each stratum is composed and its essential characteristics;

(7) Depths of major fractures or other features (e.g., oily seams);

(8) The depth interval from which each water and formation sample was taken;

(9) The depth at which hole diameters (bit sizes) change.

(10) The depth to the static water level (SWL) and changes in SWL with well depth.

If a test well is constructed, also report:

(11) Total depth of completed well;

(12) Any and all other pertinent information for a complete and accurate log, e.g., temperature, pH, appearance (color), or odor of any water samples taken;

(13) Depth or location of any lost drilling fluids, drilling materials or tools;

(14) The depth and material used for the surface seal, if applicable;

(15) The nominal hole diameter of the well bore above and below casing seal;

(16) The amount of cement (number of sacks) installed for the seal, if applicable;

(17) The depth and description of the well casing;

(18) The description (to include length, diameter, slot sizes, material, and manufacturer) and location of well screens, or number, size and location of perforations;

(19) The sealing off of water-bearing strata, if any, and the exact location thereof.

1.5 Geophysical/Mechanical Logs

1.5.1 Geophysical Logging In Exploration

Geophysical borehole logging includes all techniques of lowering sensing devices into a borehole and recording some physical parameter that may be interpreted in terms of the characteristics of the rocks, the fluids contained in the rocks, or the construction of the well. Geophysical logs supplement and help in the interpretation and correlation of lithologic, hydraulic, and water quality information obtained from the borehole.

The interval to be logged should be the total depth of the borehole subject to satisfactory borehole conditions or an appropriate intermediate interval of interest, within the limitations of the logging technique, and/or other directives from the owner or consultant.

1.5.2 Borehole Preparation.

When the hole has been drilled to a depth determined by contractual and/or geological conditions it must be prepared for geophysical logging. Borehole preparation should include, but not be limited to: (1) continuation of circulation until drill cuttings have been removed from the borehole and (2) circulation of the drilling mud in the borehole until it is uniform and the drill pipe has been removed from the borehole, or (3) removal of all drilling and/or formation fluids, as appropriate for the instruments to be used.

The drilling contractor must make all reasonable efforts to leave the borehole free from obstructions in preparation for geophysical logging. The log(s) must be made immediately following the completion of borehole preparation unless otherwise stated in the contract or as stipulated by the project geologist, or based on logging equipment manufacturer specifications.

1.5.3 Geophysical Log Interpretations

Geophysical log interpretation should consist of all processes of determining information from geophysical logs. All geophysical log interpretation must be done by a qualified log analyst. The log analyst must be able to demonstrate competence through background, training, certification, and experience when called upon.

1.5.4 Borehole Log Type Descriptions

Spontaneous Potential Log (Self-Potential). Records the natural potential developed between the borehole fluid and the surrounding rock materials. All spontaneous potential measurements are made in an uncased, fluid-filled borehole. Measurements are made in millivolts. Millivolts per horizontal chart width are shown on the log heading along with the polarity. The spontaneous potential log may be run in conjunction with resistivity logs. Collectively, this log suite is commonly called an "Electric log".

Resistance Logging. A resistance log measures the resistance (expressed in ohms) of the earth materials lying between an inhole electrode and a surface electrode, or between two inhole electrodes. All measurements are made in an uncased, fluid-filled borehole. A resistance log may consist of a single-point, point-resistance, or single-electrode systems. The number of ohms per horizontal chart width are indicated on the log heading.

Resistivity Logging. Resistivity logging includes all devices that measure the electrical resistivity of a known or assumed volume of earth material under direct application of an electric current or an induced electric current. Measurements are made in ohm-meters and/or ohm-feet. Multiple-electrode resistivity measurements include such logs as the short and long normal, lateral, focused, well resistivity, microfocused, and induction. Trade names applied to these logs can be substituted for the generic log types provided the generic type is referenced.

Natural Gamma Logging. Records of the amount of natural-gamma radiation emitted by earth materials are called natural-gamma logs. Natural gamma radiation measuring devices include thallium-activated sodium iodide crystals (scintillator) and Geiger-Mueller tubes. Measurements are made in counts per second or seconds per count and should be related to API gamma-ray units and to a field standard in which the response of the logging equipment is checked periodically. Gamma logs may be made in cased holes.

Acoustical Logging. An acoustic log (sonic log) is a record of the transit time of an acoustic pulse between transmitters and receivers in a probe. Measurements are recorded in microseconds per foot (or meter). Calibration points appear on the log preferably before and after the run, as an indication of the uphole system drift. Acoustic televiewer logging provides the acoustic information in the form of a visual representation of borehole structure.

Caliper Logging. A record of the average borehole diameter is called a caliper log. Measurements are made with a probe employing three or more arms or feelers hinged at the upper end and maintained against the hole wall by springs. Calibration to a known diameter is made before and after a run. Measurements are recorded in the inch-foot and/or metric system, and are so designated on the log heading.

Temperature Logging. The continuous record of the temperature of the environment immediately surrounding a sensor in a borehole is called temperature log. Where possible, a temperature log should be run simultaneously with a differential-temperature log. Sensors are calibrated with an accurate thermometer in a stabilized fluid bath. Measurements are recorded in degrees Centigrade or Fahrenheit. The run number and the direction of the probe during logging, up or down, appear on all logs.

Fluid-Movement (Borehole Flowmeter) Logging. Fluid-movement logging include all techniques for measuring natural and/or artificially induced flow within a single borehole. Devices used to measure the vertical and horizontal components of flow in a single borehole may include impeller flowmeters, thermal flowmeters, and various systems for injecting and detecting radioactive and chemical tracers. Measurements may be made in convenient inch-foot and/or metric systems per unit of time, or in graphic form showing percentage of flow past any given point. A caliper log should be made in conjunction with any fluid-movement log.

Photographic Logging. A photographic log records on photographic film or video recording method the environment in a cased, uncased, or screened borehole or any combination thereof. Borehole television logs of air-drilled boreholes is a highly cost-effective means of logging long rock intervals. Television is also an effective means of gathering geologic and well construction information where records have been lost, or in troubleshooting.

The photographic record is made and may be in color or black and white. Still photographs should be spaced covering a minimum five foot (2-m) interval of well or borehole and video continuous unless otherwise stipulated. All photographs and video records should be marked as to depth below ground surface. A written log of features of interest should be provided.

1.6 Formation Sampling Methods

In the exploration process, representative samples must be collected, identified and stored in accordance with geologic practice, and collected with sufficient frequency and at sufficient increments of depth to permit a thorough evaluation of the water-bearing properties and relevant physical-chemical characteristics of the formations encountered in drilling the test hole. Samples may be collected by numerous means. There is an extensive technical literature on sampling practice, including those referenced here. There is also a developing standard practice in soil, rock and ground-water sampling that should be consulted. Readers should refer to the most recent American Society for Testing and Materials (ASTM) *Annual Book of Standards* volume covering water, soil and rock, and U.S. Geological Survey, U.S.EPA, and state technical guidance manuals relevant to the project.

Return Flow Method (Continuous). A return flow sample is taken by removing a representative sample of the formation from the circulating drilling fluid. For the sample to have value, it is important to know the circulation time and probable depth of the formation from which the cuttings are derived.

Return Flow Method (Circulated). In this case, the penetration of the bit is stopped when the bottom of the sampling interval is reached for such time as is required for all the cuttings to move from the last drilled section of the hole and settle at the sampling point. The return ditch and sample catching device is cleaned of all cuttings after each sample is taken.

Auger Method. Formation samples obtained using the auger method are brought up by the auger flights. This process has to be performed with special care to assure that the cuttings are representative of the formation being penetrated.

Bailer' Method. In clay and consolidated formations the sample can be taken by bailing the hole clean then advancing the drill bit and collecting cuttings. In sand and gravel the sample can be taken by driving casing ahead of the drill bit then bailing with a flat bottom or suction bailer. In stable unconsolidated formations, samples should be taken at set feet (meter) intervals (usually 5 ft or 2 m).

Core Barrel Method. A core barrel is advanced, by being rotated, driven, or pushed its full length into the undisturbed formation. Once the core barrel has penetrated the desired interval, it is withdrawn and the core recovered and stored in a suitable core container. If driven or pushed, the force required (blows or pulldown pressure) should be recorded.

Piston Tube Method. A piston tube sampler is driven or pushed into the undisturbed material at the bottom of the drilled hole to take formation core samples. This method is used to prevent the material in the core from expanding and to assure that the full core be held securely as the sampler is removed from the test hole. Upon removal to the surface the sample is to be capped and sealed in its tube.

Split Spoon Method. A steel cylinder is driven vertically into the undisturbed formation at the bottom of the drilled hole for its full length or a specific predetermined number of hammer blows.

Side-Hole Core Method. Formation samples may be taken using a side-hole core sampler that penetrates the borehole wall to provide a core of a given size.

Direct-Push Sampling. This variation of the cone penetrometer is a convenient and relatively rapid method of obtaining hydrogeologic and formation fluid quality information from softer alluvial or lacustrine soil materials. Direct sensors can be used to record resistance to penetration, inclination, and pore pressure. Samples may be taken using retractable sampling ports attached to pumps to provide a relatively detailed profile of water quality in an interval.

1.7 Formation Sampling Interval

Formation samples are taken starting at starting depths of interest (specifying either the surface or some certain depth, static water level, bottom of clay, etc.), and at formation changes, continuing to an end point of interest. Special care must be taken in collecting samples from expected producing zones. Direct-push samples may be taken at very fine intervals. Some data, such as penetration rates, may be recorded continuously.

1.8 Water (Aquifer) Sampling

Water samples are taken for analysis from each aquifer interval of interest. Samples may be obtained by methods that assure representative samples from given formation intervals. The available methods are extensive and varied. Readers are referred to the extensive technical literature, including those referenced here. Water sampling can be further categorized into methods for the unsaturated and saturated zones. Saturated zone sampling most resembles water well sampling for analysis. Typically the scientists involved on a project will make the decisions about sampling and analytical methods.

In general, purging is considered to be a necessary part of the sampling process. It removes fouling material and "stale" water possibly affected by the well casing and exposed to oxidation. However, purging also changes the ground-water pressure around the well, which may change the solubility of some chemicals in the water, and drives volatile organics into the atmosphere. Just enough should be removed to eliminate sampling effects, but no more. Sampling in ground water monitoring must be chosen with the analysis in mind. For example, water being sampled for volatile organic compounds (VOC) must be sampled so that oxidation is minimized

Pumps are most commonly used for both purging and sampling. Some sensitive samples such as those for VOCs may be bailed if pumping is determined likely to strip them.

Among the pumps used are conventional submersible pumps, which are especially suitable for purging wells with yields above about 5 gpm (0.33 L/s). The same pumps can be throttled to less than 0.5 gpm (0.05 L/s). The pressure loss through an impeller at high flow, however, may strip volatile organics, but at low flow, pressure is high and stripping minimal.

Variable flow submersibles on the market now may be as small as 1.8-in. (45.7 mm) in diameter and still capable of good flow characteristics, and constructed of stainless steel and non-reactive plastics. Gas-driven bladder pumps are also used with success. They provide representative sampling under field conditions, more conveniently than bailers.

References

American Society for Testing and Materials, 1993. *Annual Book of Standards, Vol. 04.08, Soil and Rock, Dimension Stone, Geosynthetics.*

American Society for Testing and Materials, 1996. *Annual Book of Standards, Vol. 04.09, Soil and Rock (II): D4943 - latest; Geosynthetics. Note: Since 1994, new standards are printed in this way.*

Australian Drilling Industry Training Committee, 1997. *Drilling, The Manual of Methods, Application, and Management, Lewis Publishers, Boca Raton, FL.*

Boulding, J.R., 1995. *Practical Handbook of Soil, Vadose-Zone, and Ground-Water Contamination. Lewis Publishers, Boca Raton, FL.*

Chai, E.Y., 1996. A systematic approach to representative sampling in the environment, *Sampling Environmental Media, ASTM STP 1282, American Society for Testing and Materials, West Conshohocken, PA, pp. 33-44.*

Driscoll, F. 1986. *Groundwater and Wells, Johnson Division, St. Paul, MN.*

Farrar, J.A., 1996. Research and standardization needs for direct push technology applied to environmental site characterization, *Sampling Environmental Media, ASTM STP 1282, American Society for Testing and Materials, West Conshohocken, PA, pp. 93-107.*

Roscoe Moss Co., 1990. *Handbook of Ground Water Development. Wiley-Interscience, New York.*

Soloyanis, S.C., 1996. A common sense sampling strategy to expedite hazardous waste site cleanup, *Sampling Environmental Media, ASTM STP 1282, American Society for Testing and Materials, West Conshohocken, PA, pp. 21-32.*

Chapter 2

Methods of Well Construction

2 Methods of Well Construction

Using information gathered by available means, the type of well construction needed to meet the project objective, in this case, obtaining sufficient, potable water of good quality, can proceed. This knowledge of the character and depth of the producing zone and of the overlying formations will allow the choice of the construction method best suited to the type well required.

In determining the procedure to be followed in constructing a well, there are two factors that predominate and must be considered before detailed planning can continue. These factors are (1) the type well desired, and (2) the method of its construction. Following are the descriptions of types of wells and the methods to be used for their construction.

2.1 Well Construction Types

For the purpose of these standards the types of wells are defined as follows:

The Radial Collector Type Well. This type is a variant of the dug well, and usually consists of a concrete shaft or caisson (diameter three feet and larger) from which horizontal intake pipes (laterals) project radially (100-500 feet long). The length, number, and orientation of laterals is specific to the site conditions and water needs. Use of these wells when applicable, is acceptable and highly cost-effective where high-capacity (millions-gal/day or megaliter scale) ground water supplies need to be developed from shallow but areally extensive unconsolidated aquifers. In recent years, radial collector wells have come under scrutiny due to their potential for pumping ground water under the influence of surface water. Disinfection is highly recommended for potable water safety if not required. However, studies have shown them to be effective in providing high quality water free of surface-water elements when properly sited and constructed.

Radial collector wells are largely constructed by a small number of specialized contractors who work worldwide. Because of the specialized construction nature, these wells are not considered in this practice discussion. Readers are referred to the limited technical literature on the subject.

Unconsolidated Formation Natural Filter Well. This type of well is built to obtain water at various depths from unconsolidated formations which can be stabilized naturally by development following the installation of the casing and screen. A well of this type may be constructed by jetting, boring, driving, drilling or a combination of methods. It is not effective where thin zones of productive zones must be developed in long intervals containing abundant fine particles. To assure safety from surface infiltration, a surface seal to a suitable depth is necessary.

Unconsolidated Formation, Artificial Filter Pack Well. This type of well is built to obtain water at various depths from unconsolidated formations that cannot be stabilized by the use of a casing/screen combination and development only. Stabilization of the formation requires addition of a material that is coarser than the formation material in the screened interval. This added material acts as an additional filter to prevent the fine aquifer materials from entering the well. This type of well may be constructed by boring, driving, or drilling, or a combination of two or more of these methods. This type of construction is usually essential in some large-diameter wells drilled with bucket augers, reverse circulation rotary drilling, or temporary casing advancement methods. Surface seals completed to the screened interval are essential to prevent surface water infiltration.

Consolidated Formation Open Borehole Partially Cased Well. This type of well is built to obtain water at various depths from consolidated formations, either fractured or unfractured. It is not cased or screened in the producing zone for no formation stabilization or filtering is needed. The well may be cased through the formations above the producing zone, if they are unconsolidated or unstable, to prevent borehole collapse or to exclude water of undesirable quality. A minimum casing length with annular seal is recommended to prevent surface water infiltration (and is usually required). This type of well is constructed by drilling.

Unstable Consolidated Formation Partially Cased Well. This type of well is built to obtain water from unstable, potentially caving formations. It is usually screened through the producing zone and may, under some conditions, require the addition of coarse filter (formation stabilizer) material. With some exceptions, the well will usually be cased through all the formations above the producing zone and will have a surface seal. This type of well is constructed by drilling.

2.2 Methods of Construction

Construction methods are many and varied, ranging from simple digging with hand tools to high speed drilling with sophisticated equipment. In general, depth and diameter capabilities depend on the power of the drilling equipment in relation to the force, friction resistance, and fluid flow requirements of the method involved. Methods depending on hand or portable expedient power are usually very limited in depth and diameter. Methods with large-diameter hole-making tools are subject to higher friction forces that limit depth capabilities. Another factor is the casing and pipe handling capabilities of the equipment involved. The most commonly used methods are described below.

2.2.1 Well Construction Method Descriptions

Boring Method. In this method the hole is constructed by the use of a selected diameter hand or power auger, which is turned to bore the hole to the desired depth. Cuttings are removed by pulling and emptying the auger or bucket or by the screw action of the auger flight itself. Boring methods are usually used to construct relatively large diameter (24 inches) wells in silty sand deposits up to about 100 ft in depth. Casing is commonly advanced with the tools, lowered as the hole deepens.

Driving Method. In this method the hole is constructed by forcing a casing equipped with a drive point into the ground by a series of blows, either manually or machine-delivered, on the top of the casing. Driven wells (or "well points") should be installed only in soft formations that are relatively free of clays, silts, cobbles or boulders. They are feasible only where aquifers are shallow and the quantity of water desired is small. Well points can be installed by hand or machine. Depths are limited (usually < 50 ft).

Jetting and Hydraulicing Method. Driven or jetted wells are a rapid and effective method for constructing dewatering or plume control arrays in shallow, unconsolidated materials. They have also been commonly used in New England for water supply well arrays in small, linear glacial sands and gravel deposits.

The jet drill is basically a combination percussion unit and pressure pump. The drill pipe consists of a small diameter standard pipe with a bit or chisel attached to the bottom section. Water is forced down through the drill pipe by means of the pressure pump and out through holes in the bit. This water, being under pressure, carries the cuttings to the surface through the space between the casing and the drill pipe. This method is best suited for smaller holes of from 2 to 4 inch (50 to 100 mm) diameter.

A percussion machine is also used for drilling holes by the hydraulicing method. The difference between this and the jetting method is that with the hydraulicing method no pressure pump is needed. The hydraulicing unit utilizes a bit with an opening at the top and a valve seat and ball check valve above it. Water is directed into the hole by gravity in the space between the drill pipe and the casing.

NOTE: While expedient, wells constructed by jetting and hydraulicing methods are less likely to produce water of acceptable potable microbial quality, and have shorter service lives than deeper drilled wells. Minimal surface seal requirements in most jurisdictions are likely to make this well construction method unacceptable unless designs are modified to include seal installation. Many bored well designs are also quite vulnerable to microbial infiltration from shallow soil or the surface. Provision should be made for disinfection if these are the only feasible water source or construction methods available.

Cable Tool Method. The cable tool method is used to construct wells by alternately lifting and dropping a set of drilling tools suspended on a wire cable so that with each stroke the drill bit strikes the bottom of the hole. The repeated action of the percussion drill permits bit penetration of the underground formations. The loosened material and drill cuttings are mixed with drilling water by action of the bit and the resulting slurry must be removed from the drill hole by a bailer or sand pump. In drilling a dry hole, water must be added periodically to replace that removed with the drill cuttings. Tools for drilling and bailing are carried on separate lines or cables. Each cable is spooled on a separate drum.

In cable tool or percussion drilling there are basically three major operations:

(1) The drilling of the hole by chiseling or crushing the rock, clay, or other material by the impact of the drill bit;

(2) Removing the cuttings with a bailer as cuttings accumulate in the hole; and

(3) Driving or forcing the well casing down into the hole as the drilling proceeds.

Well casing used in most percussion type drilling operations usually ranges from four to 24 inches (100 to 610 mm) in diameter. This casing is used to keep the well bore from collapsing and to prevent surface or subsurface leakage of water or contaminants into the well bore. Cable tool equipment is capable of constructing wells to well over 2000 ft. Depth and casing sizes possible depend largely on the casing and tool-handling capabilities of the available rigs.

Conventional (Direct) Fluid Rotary Drilling Method. In the conventional mud-rotary method of drilling, drilling is accomplished by rotating a drill pipe and bit by means of a power drive. The drill bit cuts and breaks up the rock material as it penetrates the formation. Drilling fluid is pumped through the rotating drill pipe and holes in the bit. This fluid flushes the bit face, swirls in the bottom of the hole, picks up material broken by the bit, builds a filter cake and stabilizes the hole, then flows upward in the well bore, carrying the cuttings to the surface. The fluid also lubricates and cools the bit.

The drill pipe and bit move progressively downward, deepening the hole as the operation proceeds. At the land surface, the drilling fluid flows into a settling pit where the cuttings settle to the bottom. From the settling (mud) pit the fluid overflows into a second pit from which it is picked up through the suction hose of the mud pump and recirculated through the drill pipe. In the rotary drilling method, the well casing is not introduced into the hole until drilling operations are completed, the walls of the hole being supported by the pressure (weight) of the drilling fluid.

Rotary methods may be used to construct wells to multiple thousands of feet. Capabilities depend on the fluid-pumping capacity of the mud pumps (capacity to develop uphole velocity and bit and hole flushing volumes), and the rig's tool-handling capabilities and available rotational torque. Other factors in depth and hole quality are fluid-quality management, and control of the hole verticality and alignment.

Reverse Circulation Drilling Method. In reverse circulation drilling, instead of circulating the drilling fluid through the drill pipe and up the outside of the pipe, the process is reversed. Fluid is fed down through the space between the wall of the hole and the drill pipe and it is then pumped up, together with the cuttings, through the hollow part of the drill pipe and out a discharge pipe. With the addition of air (applied via a compressor through piping along the outside of the drill stem) drilling depths possible with this method range up to 2,000 feet (more under favorable circumstances), although 110-200 ft in alluvial aquifers is more common.

Of particular importance is the use of a light (very low solids) drilling fluid, compared to direct rotary drilling. Bringing cuttings up the drill pipe reduces the need for a viscous and heavy drilling mud to lift cuttings, which can seal-off water-bearing formations. In the reverse rotary method, the walls of the hole are held in place by the pressure of the fluid against the sides of the hole. The use of a relatively clear drilling fluid is possible because drilling is rapid; however, a substantial quantity of suitable water must be available or on hand during construction to maintain an open hole due to infiltration loss. Bentonite or other additives may be added to the drilling fluid to prevent fluid loss to the formations encountered.

This method is used for rapid drilling of large diameter holes in soft formations where small boulders are encountered. Boulders up to six inches (15 cm) in diameter can be brought up to the surface through the hollow drill pipe. Such performance is possible because of the extremely high velocity of the fluid as it is drawn up through the drill pipe. In the reverse circulation method, holes 16 inches to 72 inches (410 to 183 cm) in diameter have been drilled.

Air Rotary Drilling Method. In the air rotary method of drilling, air serves as the fluid and excavation is accomplished exactly as is done in the conventional mud rotary method. The bit cuts and breaks up the formation.

Air is forced down through the drilling pipe and out through holes at the bottom of the rotary bit. The air serves both to cool the drill bit and force cuttings up and out of the hole. A stream of water is often introduced into the air system to help cool the drill bit and control dust. This is sometimes augmented with other additives to form a mist. The cuttings move up in the annular space between the drill pipe and the wall of the hole and are collected at the top. Air is used principally in hard clay or rock formations, because once the air pressure is turned off, loose formations tend to cave in against the drill pipe. This method is not generally recommended for drilling in unconsolidated materials because the quality of the samples are usually poor. Foaming additives are occasionally used to increase the up-hole carrying capacity of the return air.

Down-the-Hole (Down Hole Hammer, Hammer Drilling) Method. The down-the-hole method involves a pneumatically operated bottom-hole drill that efficiently combines the percussion action of cable tool drilling with the turning action of rotary drilling. The pneumatic drill can be used on a standard rotary rig with an air compressor of sufficient capacity. It is used for fast and economical drilling of medium to extremely hard formations. Fast penetration results from the blows transmitted directly to the bit by the air piston. As in air rotary, air circulation flushes the bit and carries cuttings to the surface. Air also powers the hammer. The system both hammers and rotates the tungsten-carbide bits against the borehole face to dislodge cuttings. Continuous hole cleaning exposes new formation to the bit and practically no energy is wasted in redrilling old cuttings.

Down-the-hole drilling is generally the fastest method of penetration in hard rock. The bit is turned slowly (5 to 15 rpm) by the same method by which the drill bit in the fluid or air drilling operation is rotated. Foaming additives are occasionally used to increase the up-hole carrying capacity of the return air.

Air drilling methods may be used to drill multiple 100s of feet, depending on the formation and capabilities of equipment. Capabilities depend on the capacity of the air compressors used (capacity to develop uphole velocity, bit and hole flushing volumes, and capability to operate the downhole hammer against hydrostatic pressure), and the rig's tool-handling capabilities. As with mud rotary, available rotational torque is important in air rotary, but much less so with a downhole hammer. Other factors in depth and hole quality are fluid-quality management, and control of the hole verticality and alignment.

Casing Advancement Methods. A variety of casing advancement methods are available besides the Cable Tool Method. Each of these advance or install casing as part of the drilling process. This is done in rotary drilling when fluid pressure or borehole integrity alone cannot hold the borehole open, or where there is excessive loss of drilling fluid to lost circulation. Options include air percussion-driven top-drive casing hammers for air rotary rigs, and rotation-and-pulldown pushed casings with an eccentric under-reamer bit run with conventional rotary drill tools.

In wireline casing advancement methods, casing serves as the drill string, and tools are withdrawn upon completion. Dual rotary casing advancement is a form of drilling where the casing is advanced by rotating it (usually counter-clockwise) while simultaneously drilling with conventional rotary methods inside the casing. Other forms of casing advancement typically utilize under-reamer bits to "kerf" additional space within the formation that allows for the casing without getting stuck to the borehole walls. Eccentric under-reamer bits are typically withdrawn. Ring bits used in dual rotary casing advancement are sacrificed if the casing is left in place.

Drilling fluid control is particularly important for all drilling methods to minimize the potential for contamination, and to maximize the effectiveness of well development to provide maximum hydraulic contact with the producing formation. All water used should be essentially free of coliform bacteria and of a chemical quality compatible with the fluid additives such as bentonite. Where there is a question, the water should be tested and treated as needed. The use of unfiltered surface water should always be avoided.

In air drilling, oil is a component of the air stream from the compressor. The compressor and air system should be in good maintenance condition to minimize oil. Oil filters and air/oil separators must be used in drilling potable water wells. Water for mist in air drilling must be coliform and contaminant free.

References

Australian Drilling Industry Training Committee, 1997. *Drilling: The Manual of Methods, Applications and Management. Lewis Publishers, Boca Raton, FL.*

Bennett, T.W., 1970. On the design and construction of infiltration galleries, *Ground Water vol. 8: no. 3.*

Driscoll, F. 1986. *Groundwater and Wells, Johnson Division, St. Paul, MN.*

Gaber, M.S., and B.O. Fisher, 1988. *Michigan Water Well Grouting Manual. Michigan Dept. of Public Health, Lansing.*

Gollnitz, W.D., J.L. Clancy, S.C. Garner, 1994. Natural reduction of microscopic particulates in an alluvial aquifer, Proc. 2nd International Conference on Ground Water Ecology, American Water Resources Assn., Herndon, VA, pp. 127-136.

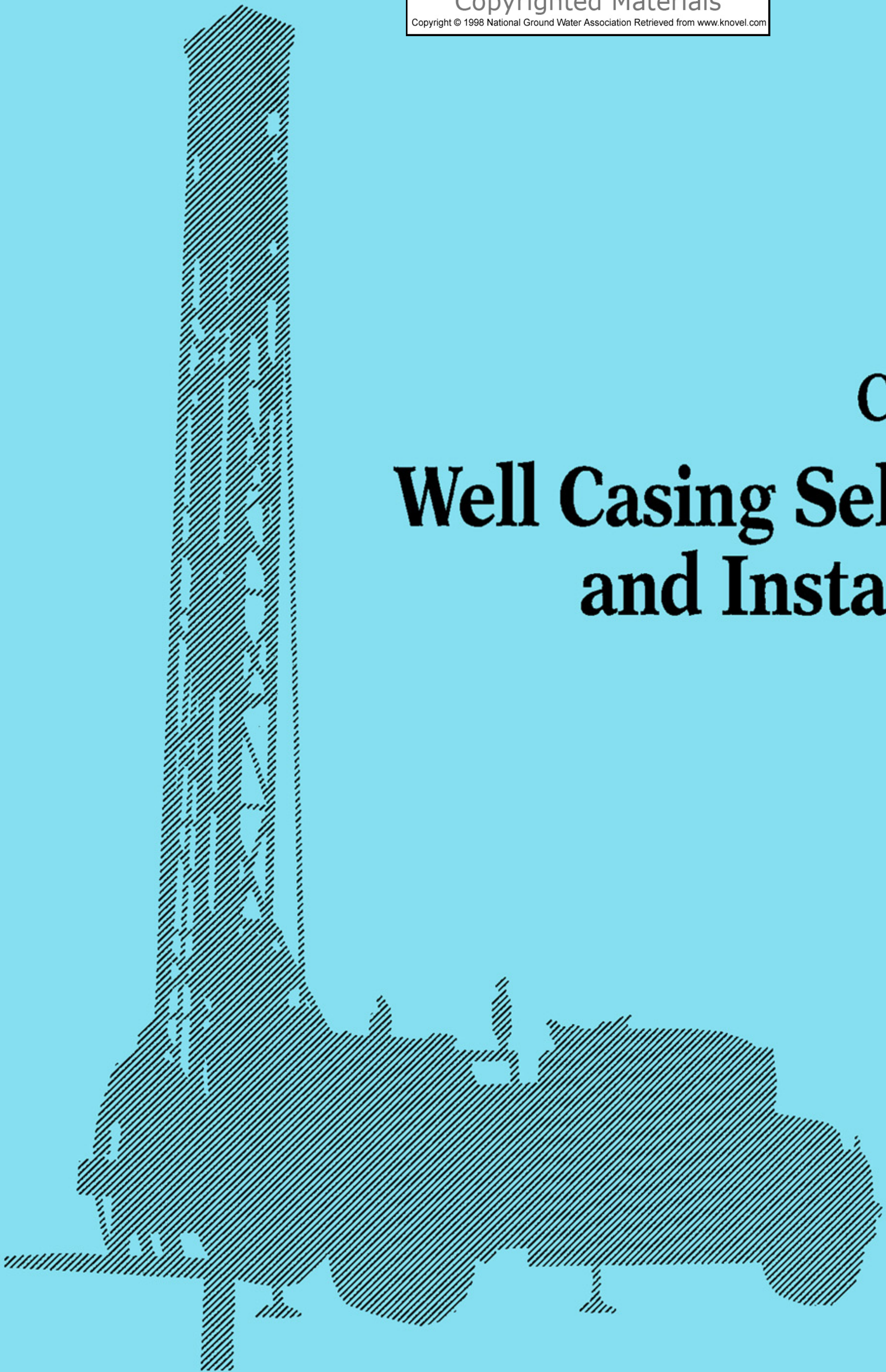
Gray, K. and A.Highsmith, 1996. What do the CDC studies on microbial contamination of private wells tell us? Presented at *Under the Microscope: Examining Microbes in Groundwater, The Groundwater Foundation Fall Symposium, Boston, MA.*

Great Lakes-Upper Mississippi River Board of State Public Health and Environmental Managers. 1987. *Recommended Standards for Water Works. Health Research Inc., Health Education Services Div., Albany, NY.*

Mikels, M.S., 1992. Characterizing the influence of surface water on water produced by collector wells, *Journal AWWA 84(9): pp. 77-84.*

NWWA Committee on Water Well Standards. 1975. *Manual of Water Well Construction Standards, EPA - 570/9-75-001. Office of Water Supply, Washington, DC.*

Roscoe Moss Co., 1990. *Handbook of Ground Water Development. Wiley-Interscience, New York.*



Chapter 3
Well Casing Selection and Installation

3 Well Casing Selection and Installation

Casing is installed to prevent the collapse of the walls of the borehole, to exclude pollutants from entering the water source at the well, and to provide a channel for conveying the water to the surface (or in the reverse direction, for injection). Casing also provides a housing for the pump mechanism.

Most common materials for well casing are carbon steel, plastic (most commonly, but not exclusively, PVC) and stainless steel. Unfortunately, the terms "casing" and "pipe" can be confused. There is, however, a distinguishing difference between pipe and casing. Steel "pipe" is manufactured in cylindrical form at the producing mill, whereas "casing" is made cylindrical by a fabricator from steel sheets or plates. Such steel casing is fabricated to resist external and vertical forces, rather than the internal burst forces that line pipe is designed to resist. Plastic casing products are extruded, much like seamless steel casing, but like steel casing, engineered (and selected during planning) to resist the pressures exerted by the surrounding materials, forces imposed on it during installation, and corrosion by soil and water environments.

Casing must be of the proper length to accomplish its purpose of providing secure access to the water source from the surface through unstable formations, and through zones of actual or potential contamination. Casing should extend above known levels of flooding, or be positively sealed against flooding flows. For wells screened in sand and gravel, casing should extend to at least five feet below the lowest estimated pumping level of a well to avoid excessive oxidation, clogging and corrosion at the screen. In consolidated formations, casing should be sealed securely into firm bedrock. An exception may be the case where water immediately on top of rock is the target. In this case, the well design should be such that the casing is solidly installed and sediment and unsanitary water excluded.

Care must be exercised when placing casing. In areas where subsidence or shifting forces are known or expected to occur, a self-sealing slip joint may be installed in the casing to allow for vertical movement and prevent collapse.

Both carbon alloy steel and plastic well casing are now commonly used successfully around the world. Plastic casing is increasingly used due to its light weight, ease of installation, durability, and corrosion resistance. Concrete, fiberglass and asbestos cement casing have also been used with varying degrees of success.

Less common metal casing materials such as stainless steel, cupro-nickel alloys, silicon bronze, aluminum, and other nonferrous metals, can be used for casing in special situations where the natural soil and water-quality conditions (primarily severe corrosion potential) dictate their employment, and plastic cannot be used for some reason.

3.1 Well Casing Standards

A number of technical and scientific organizations are active in promulgating pipe and casing specifications. Representative members of producers, consumers, and general interest groups develop specification details and tests which are then published by the organizations involved. Prominent and most active in connection with pipe and casing specifications are the American Society for Testing and Materials (ASTM), the American Petroleum Institute (API) and American Water Works Association (AWWA). Many AWWA standards also carry the designation of the American National Standards Institute (ANSI). ANSI/AWWA Standard A-100 for Water Wells references some relevant ANSI/AWWA, ASTM and API standards for casing materials and joints (**Figure 1**). The health and safety standards organization, National Sanitation Foundation (NSF) International, promulgates standards for piping and fittings used for providing potable water.

Such standards (Table 3.1 lists relevant casing pipe standards) serve three general functions. First, they stipulate factory testing standards and prescribe methods of measuring required mechanical, physical, and chemical properties. Second, they establish a common ground of understanding among casing specifiers, regulators, buyers and the producers. They eliminate most of the requirements for detailed information which would otherwise be necessary without a standard or specification number symbol. Third, they serve as a form of quality warranty. When the factories affix the standard designations on a length of materials and offer it for sale, they certify that it is made to meet all of the requirements of the specifications.

Table 3.1
Water Well Casing Material Standards

Material	Standard
Carbon steel	ANSI/AWWA C200
	ASTM A589-89a[1]
	ASTM A53-90b
	API Spec. 5L and 5LS
High-strength low-alloy	ASTM A714
Stainless steel	ASTM 312-86a
Plastic	ASTM F480

[1]ASTM standards cited may have year designations (e.g., 89 for 1989). The latest revisions apply.
Source: Modified from ANSI/AWWA A100.

As casing pipe cannot be practically handled in lengths to provide a jointless casing to total depth, some joining method is needed. Joints are potential weakness, corrosion and leak points. All joints should be made in a manner suitable to the material

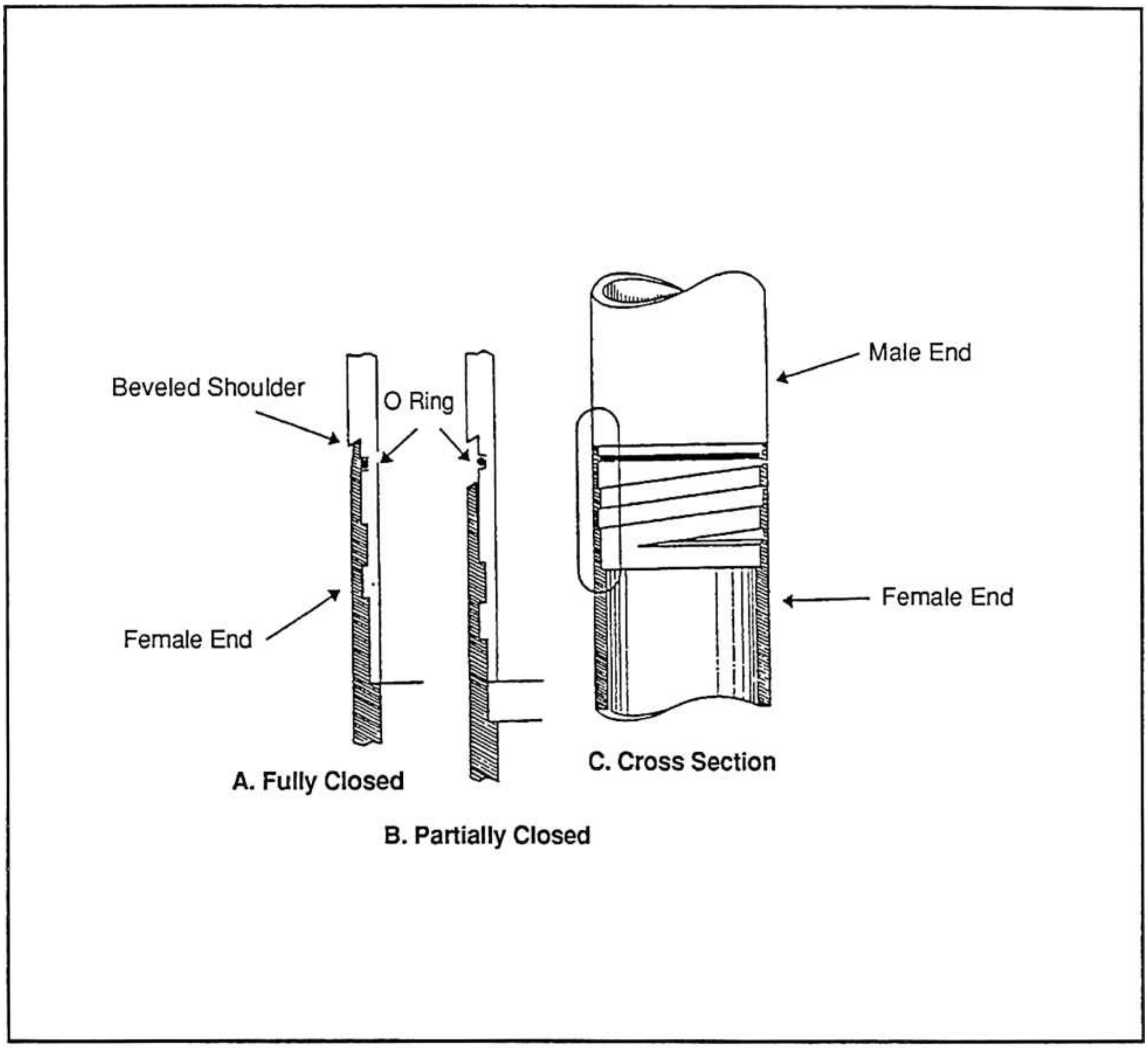


Figure 1. ASTM Flush Joint Thread.

Figure is from the *Australian Drilling Manual.*

to insure that they will be watertight. For example, solvent cementing of belled-end thermoplastic casings requires sufficient set times before the joint is complete.

Belled end thermoplastic casings should be joined with a solvent specific to the task of securely solvent welding heavy, vertically suspended casing pipe. An example would be a material that meets ASTM Standard D 2564. In general, more viscous cements should be used for larger pipe diameters. Screws or other penetrating fasteners should not be used.

Table 3.2 lists casing joint standards. If steel casing joints are welded, the standards of the American Welding Society should apply. Successful welding depends entirely on the skills of the welder. Most jurisdictions require that personnel performing casing welding be certified.

Table 3.2
Water Well Casing Joint Standards

Material	Type of Joint	Standard
Steel	Welded or threaded	AWWA C206
Plastic	Threaded or solvent-welded	ASTM F480
Two-ply steel	Welded	AWWA C206

Source: ANSI/AWWA A100. The latest revisions apply.

3.2 Selecting Casing Diameter

The diameter of well casings installed depend on many factors:

(1) Maximum flow capacity over the life of the well: Many times, the design of the well and casing size is determined by the need at the time the well is constructed without sufficient regard for future expansion or need.

(2) Flow rate and total dynamic head requirements: The pump housing casing (in the case of multiple casing-diameter sets) is determined by the bowl and motor diameters of the pumping equipment to be installed.

(3) Geology and aquifer considerations: Multiple casings may be necessary in some installations to case off unwanted zones. Smaller-diameter casings and screens may at times be set in deep wells below the pump. Further casings must fit and be properly sealed inside such conductor casings. If multiple casing sets are required, the casings must accommodate the total minimal annular space between liners and/or the borehole for installation of grout seals or sealing devices.

(4) Installation method: Casing diameters in multiple casing combinations may change depending on the method of installation.

(5) Plumbness and alignment: Where borehole plumbness and alignment may be a problem due to severe geologic drilling conditions, a larger casing diameter selection may be prudent to allow for deviation.

(6) Water quality: Where clogging and corrosion may be expected (and they can be commonly expected), too small a diameter casing may result in lodging of the pump later.

(7) Other devices: These may include water level transducers, airlines or chlorinators.

3.2.1 Pump Housing Casing Diameter Selection

The pump housing casing may be the only casing or one of a multiple-casing string in some deeper or more complicated installations. The pump housing well casing is best chosen as two nominal sizes larger than the bowl size of the pump that will be installed (6-inch I.D. casing for a 4-inch O.D. pump). For many domestic or agricultural applications, one nominal size difference is acceptable (5-inch I.D. casing for a 4-inch O.D. pump). However, current planners should take into consideration future well casing diameter needs, for example, installation of a bigger pump if hydrologically feasible, installation of liners if deepening the well, and incrustation that may lodge the pump in place over time.

Table 3.3 lists casing sizes recommended for wells of selected yield. These sizes were determined by taking the bowl sizes of 900 to 3500-rpm vertical (lineshaft) turbine pumps used to pump a given quantity of water and specifying two nominal sizes larger for the casing. The diameters specified are such that head losses due to vertical movement of water from the entrance portion of the well through the casing to the pump intake will be small.

If the casing size is selected according to the listing, there should be adequate clearance for the lineshaft turbine pump. The pump shaft will be plumb and binding will not occur even if the casing is slightly out of line and not exactly plumb.

Casing I.D. for submersible pumps should large enough to minimize the risk of binding during installation and retrieval and abrasion during operation (especially start-up torquing), but not too large so that there is adequate cooling water flow along the motor. Upflow along the motor should be about 0.5 ft/sec (0.15 m/sec), depending on motor size and manufacturer recommendation, but below 10 ft/sec (3 m/sec). Generally, to accommodate these requirements, the casing I.D. should be 2 in. larger than the largest O.D. of the pump and motor. For pump sets deeper than 400 ft, add an additional two inches to minimize the risk of pump binding during later retrieval and installation.

For smaller capacity (domestic) wells similar problems of relating casing size to pump size occur. Table 3.4 gives recommended casing sizes.

Table 3.3
Recommended Casing Diameters for Lineshaft Turbine Pumps*

Nominal Bowl Diameter (in.)	Pump Operating Speed (rpm)	Pump Yield	Recommended Casing Size
4	1800[1]	Less than 200 gpm[2]	6 in. I.D.
6	1800[1]	75 to 175 gpm	8 in. I.D.
8	1200 to 1800[1]	100 to 600 gpm	10 in. I.D.
10	1200 to 1800	200 to 700 gpm[3]	12 in. I.D.
14	1800	600 to 1300 gpm	16 in. O.D.
16	1200 to 1800	1200 to 1800 gpm	20 in. O.D.
20	1200 to 1800	1800 to 3000 gpm	24 in. O.D.
22	1200	3000 to 4500 gpm	28 in. O.D.
22	1800	3000 to 4500+ gpm	30 in. O.D.
22	1200	4500+ gpm	30 in. O.D

*For mm, multiply inches × 25.4.
[1]Some lineshaft models may have rotation speeds up to 3500 rpm in 8-in. and smaller bowl sizes, yielding 200–1200 gpm.
[2]Yield ratings are approximate. Check specific manufacturer ratings and dimensions.
[3]Some yield ratings may be much higher depending on pump design. Use bowl diameter as the casing sizing criterion.

Table 3.4
Casing Sizes—Low Capacity Pumps

Yield at 50-ft Drawdown	Recommended Minimum Casing Diameter	Deep Well Jet	Submersible Pump (3–4″ O.D.)
< 8 gpm to 16.5 gpm	2	X	
	3	X	
	4	X*	X*
	5	X	X
	6		X
> 16.5 gpm	4	X	X
	5	X	X
	6		X

*The casing diameter chosen should be at least 1 in. larger than the nominal outside diameter of the pump or jet assembly. For mm, multiply inches × 25.4.

3.2.2 Multiple Casing Settings

In cases of multiple casing settings, such as the need to incorporate a surface conductor casing, pump housing casing and screen-interval casing, the larger casings must be large enough to accommodate the O.D. of the subsequent casing strings, plus sufficient annular space for adequate (or code specified) grout seals, gravel pack, and other installations. Where a long screen interval will extend below the pump setting (e.g., when tapping deep, artesian aquifers) it is hydrologically and cost effective to install a smaller-diameter casing and screen than is needed for the pump. Pump conductor casing diameters (normally chosen for the pump diameter), may need to be made larger to permit the proper installation of a screen-casing seal and gravel pack.

3.3 Casing Material Selection

The method of installation is the first criterion in casing selection for water wells. There are two principal methods for installing casing. They are driving (of which jacking is a variation) and lowering (a variation of which is "floating", a method employed where the casing load is great, such as in large diameter deep wells, also is a variation).

Steel casing is the only practical material that can withstand the sharp impact of driving or the pressure imposed by jacking, such as employed in cable-tool or casing-driver well casing installation. Plastic, steel and other casing types such as fiberglass may be lowered or floated into position. Properly selected plastic casing can withstand some light vertical pushing pressure, but this is not recommended, and pushing joints past obstructions may result in cracking or separation.

Plastic casing has come into favor because of its light weight and strength, and relative economy as installed. Where casing corrosion is an identified problem (e.g., in hydrogen sulfide-containing ground water), plastic casing is preferred for its corrosion resistance.

Although it is possible to have pipe or casing made to any desired diameter or thickness, manufacturers and fabricators produce the products in common demand. Steel casing pipe diameters range from < 2 to 36 inches with thicknesses up to one inch.

Most steel pipe is made in a "standard (PE)" size. Standard size is the same as Schedule 40 up to 12 in. diameter. Casing pipe 12 in. and larger has a wall thickness of 0.375 in. Note: Casings 14 in. and larger are determined by the outside diameter of the casing, rather than the inside diameter.

The standard casing size is an industry standard that is made using either seamless, electric resistance welded (ERW), double-submerged arc welded (DSAW) or continuous weld (CW) manufacturing methods. Welded pipe may be fabricated with either a straight or spiral seam. Seamless pipe products are available, but more costly than welded-seam casing pipe, and have less-consistent wall thickness.

Thermoplastic well casing (including the most common type, polyvinyl chloride (PVC)) is available in a range of diameters, and covered by specifications of ASTM

(F480) and AWWA. A "SDR" or standard dimension ratio is commonly used to provide a minimum pressure-resistance requirement. The SDR provides a ratio of the pipe outside diameter and pipe wall thickness. For pipe of different size but the same SDR, the ratio of wall thickness to diameter remains constant. PVC mixtures used for well casing are selected for maximal tensile strength and modulus of elasticity, with minimal modifiers and compounding ingredients.

While PVC is currently the prevalent material in the marketplace, both acrylonitrile-butadiene-styrene (ABS) and fiberglass (plastic reinforced with glass fiber) are available as well casing. Styrene resin (SR) casing products have disappeared from the North American market, although they are available in southern South America.

ABS has a higher impact strength, improved rigidity at higher temperatures, and better resistance to well cleaning chemicals. It is heavier per unit and more costly than PVC, and offers slightly less hydraulic collapse resistance. Fiberglass products have not been received as favorably for potable water well construction due to perceived and actual problems with glass fiber sloughing. However, product quality and economic-regulatory conditions change so that well planners should be aware of alternative material characteristics. Casing sizing and wall thickness for ABS and fiberglass mirror that of PVC. PVC on the other hand, is controlled by ASTM slot/SDR requirements. There are some fundamental differences between fiberglass and PVC. Using major manufacturer's (BurgeSS) catalog: Fiberglass is I.D. controlled – PVC is O.D. controlled; Fiberglass is available in a few standard well thicknesses much like steel.

3.4 Selecting Casing Thickness

The thickness of material used for well casing should be selected in accordance with good design practice and experience as applied to conditions found at the well site. The ability of a specified casing to resist external forces can be calculated theoretically. However, the effect of forces imposed on it during installation are not known with certainty. Hydrostatic test pressures on pipe listed in manufacturers specification literature are internal pressures measured by the manufacturer and do not necessarily relate directly to working pressures. Accordingly, designers must introduce safety factors to insure that the casing will resist the forces expected to occur. A common safety factor is 2.0 (i.e., in practice doubling the calculated force expecting, or halving the rated capacity of the casing), applied to allow for uncertainty.

3.4.1 Steel Casing

The collapse strength of steel pipe for various diameters and thickness depends on how the pipe was manufactured. Several theoretical collapse pressure formula types are in use. One is Timoshenko's:

$$Pd^2 - \left(\frac{2Y_p}{d/t - 1} + \left[1 + 3\left[\frac{d}{t} - 1\right]e\right]P_{cr}\right)Pd + \frac{2Y_p P_{cr}}{(d/t - 1)} = 0 \qquad (1)$$

Where:
Pd = design collapse pressure_(psi)
Pcr = critical collapse pressure of a perfect cylinder (psi)
Yp = yield strength (e.g., 35,000 psi for ASTM A139 Grade B casing)

d = outside diameter of well casing pipe (in.)
t = wall thickness of the well casing pipe (in.)
e = eccentricity $= d_m/d_m - 1$(~0.01 to 0.015).

P_{cr} is calculated from:

$$P_{cr} = \frac{2E}{(1 - \mu^2)(d/t - 1)^3} \qquad (2)$$

Where:
Pcr = critical collapse pressure of a perfect cylinder (psi)
E = Young's modulus (3×10^7 psi) for steel
μ = Poisson's ratio (depends on the material, 0.28 for steel)

The American Petroleum Institute (API) elastic collapse formula is based on experimental collapse data. For

$\frac{d}{t} > \left(\frac{d}{t}\right)_{te}$ (a constant = 44.84), collapse pressure (P_c) is calculated from

$$P_c = \frac{46.95 \times 10^6}{(d/t)(d/t - 1)^2} \qquad (3)$$

Where the difference may be critical, it is best to compare the results of the two formulas and to choose the most conservative of the two.

Table 3.5 shows pressures at which it is estimated single casing will collapse if water is lowered on the inside of the casing, and the water on the outside remains static. When pumping grout behind a casing it must be kept in mind that the grout mixture weighs more than water, therefore the weight per cubic inch of grout must be calculated and the values in pounds used from the chart, rather than the "head in feet". Grout fluid weight can be converted to pressure in feet of depth:

Grout weight in lb/gal x 0.052 = psi/ft of length.

For example, 10 lb/gal. x 0.052 = 0.52psi/ft of length.

For casing diameters less than 8-inch, collapse pressure is less of a problem than resistance to impact driving as in cable tool drilling. Attention here should be focused on joint strength.

Collapse strength below 8-in. diameter casing is usually not critical, especially if Schedule 40 and above casing is used, or ANSI/AWWA A100 minimum standards adhered to.

The recommended minimum pipe thicknesses for various diameters of standard steel water well casing are shown in Table 3.6, which is based on both the need for strength in various kinds of construction, and the desirability of long-life resistance to corrosion.

Table 3.5
Calculated Collapse Strength of Steel Pipe in lb/in² and Feet of Water Head[1]

Nominal I.D. of Pipe (in.)	lb/in² (psi)[3] and Feet (of head)	3/16 in. (0.186)	1/4 in. (0.250)	5/16 in. (0.313)	3/8 in. (0.375)
8[2]	psi	646	1,532 (756*)	2,992	5,170
	feet	1,488	3,530	6,894	11,912
10	psi	331	784	1,532	2,647
	feet	763	1,806	3,530	6,099
12	psi	191	454	887	1,532
	feet	440	1,046	2,044	3,530
14	psi	121	286	558	965
	feet	279	659	1,286	2,223
16	psi	81	191	374	646
	feet	187	440	862	1,488
18	psi	57	134	263	454
	feet	131	309	606	1,046
20	psi	41	98 (95*)	192	331
	feet	94	226	442	763
24	psi	24	57	111	191
	feet	55	131	256	440
30	psi		29	57	98
	feet		67	131	226
32	psi		24	47	81
	feet		55	108	187
36	psi		17	33	57
	feet		39	76	131

[1]NOTE: The figures provided in this table are from published sources (NWWA 1975 and AWWA A100) and are approximations for information only. Actual collapse forces are site-specific and actual collapse resistance specific to products. Manufacturers should be consulted about the engineering characteristics of their particular pipe products.

[2]For mm, multiply inches × 25.4.

[3]1 lb/in² or psi = 2.31 ft of head at sea level. For expressions in bar (kg/cm²), multiply lb/in² × 6.9.

Table 3.6
Minimum Single-Wall Steel Well Casing Thickness for Selected Diameters (in.)[1]

Nominal Diameter (in inches)	6[2]	8	10	12	14	16	18	20	24	30
Depth in Feet										
<100	0.109	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.313	0.313
100–200	0.141	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.313	0.313
200–300	0.25	0.25	0.25	0.25	0.25	0.25	0.313	0.313	0.313	0.313
300–400	0.25	0.25	0.25	0.25	0.25	0.313	0.313	0.313	0.375	0.375
400–600	0.25	0.25	0.25	0.25	0.25	0.313	0.313	0.313	0.375	0.438
600–800	0.25	0.25	0.25	0.25	0.25	0.313	0.313	0.375	0.375	0.438
800–1000	0.25	0.25	0.25	0.25	0.313	0.313	0.313	0.375	0.438	0.5
1000–1500	0.25	0.25	0.313	0.313	0.313	0.375	0.375	0.375		
1500–2000	0.25	0.25	0.313	0.313	0.313	0.375	0.375	0.438		

[1]For mm, multiply inches × 25.4.
[2]For casing diameters less than 8 inch, a recommended minimum steel casing wall thickness standard is ASTM Schedule 40. For PVC, the casing sizes depend on the depth and grouting technique (see following). Some states may require a higher minimum pipe thickness for various diameters.
Source: Adapted from ANSI/AWWA A100 and Roscoe Moss Co. (1990).

Based on AWWA Standard ANSI/AWWA A100, the minimum wall thickness for steel casing, to provide adequate life under moderately corrosive conditions, should be 1/4 inch (0.250 in.) for 8-in. I.D. and larger casing. For very corrosive conditions, the thickness should be correspondingly greater.

3.4.2 Thermoplastic Casing

Acceptable thermoplastic casing wall thicknesses and diameters (including PVC and ABS) are governed by ASTM Standard F-480 and expressed as standard dimension ratios (SDR). SDR is the ratio of the outside pipe diameter to minimum wall thickness. Common SDR are 13.5, 17, 21, and 26. Plastic casing products may also be graded using iron pipe size and Schedule 40 and 80 classifications, which also define wall thickness.

Hydraulic collapse pressure resistance: For any given SDR, the pipe stiffness and collapse pressure resistance are independent of pipe size. For example, SDR 26 PVC well casing exhibits a constant resistance to hydraulic collapse pressure (RHCP) regardless of its actual diameter.

RHCP can be calculated if pipe properties are known, using the casing collapse formula published in ASTM F480:

$$(1)\quad P_c = \frac{2E}{1-\mu^2} \bullet \frac{1}{(d/t)(d/t-1)^2}, \text{ or } \quad (2)\quad P_c = \frac{2E}{1-\mu^2} \bullet \frac{1}{SDR(SDR-1)^2}$$

Where:

P_c	=	critical collapse pressure (psi)
E	=	modulus of elasticity (psi)
μ	=	Poisson's ratio (depends on the material, ~0.33 for plastic)
d	=	outside diameter of the well casing pipe (in.)
t	=	wall thickness of the well casing pipe (in.)
SDR	=	standard dimension ratio of casing pipe (in.)

A third was developed by Kurt (1979):

$$P_c = \frac{0.75(2E)}{(1-\mu^2)(d/t-1)^3}$$

Kurt's formula yields collapse pressures about 25%, (only-because a .75 quality correction factor is used NWWA *Manual* suggests 1.0), less than those calculated using F480 equation (1) above, and therefore can be considered more conservative. Actually, slightly less conservative when the recommended 1.0 factor is used.

It is commonly impractical for those specifying casing to be able to calculate RHCP exactly because particular properties of specific pipe products may be unknown or variable. For that reason, casing suppliers should be able to provide RHCP charts for their products in various casing diameters, SDR and Schedules. These should be consulted to determine whether or not they are adequate or inadequate for a proposed application. Table 3.7 is an example generic RHCP table for thermoplastic well casing. Table 3.8 lists minimal thermoplastic wall thicknesses.

Table 3.7

Approximate Hydraulic Collapse Pressure (lb/in^2) of Thermoplastic Well Casing[1]

Plastic Casing Material	SDR 13.5	SDR 17	SDR 21	SDR 26
PVC	470[2]	224	115	59
ABS	412	196	100	51
SR	376	180	92	47

[1]The figures provided in this table are approximations for information only. Actual collapse forces are site-specific and actual collapse resistance specific to products. Manufacturers should be consulted about the engineering characteristics of their particular pipe products.

[2]1 lb/in^2 or psi = 2.31 ft of head at sea level. For expression of pressure in bars (kg/cm^2), multiply lb/in^2 × 0.07. kPa = lb/in^2 × 6.9.

Source: Adapted from NWWA/PPI (1980). For listed prevalent resin types.

Table 3.8
Selected Minimum Wall Thickness (in.*) for Thermoplastic Casing[1]

By SDR Classification	SDR 13.5	SDR 17	SDR 21	SDR 26
Nom. Casing Diameter				
4	0.333	0.265	0.214	0.173
5	0.412	0.327	0.265	0.214
6	0.491	0.39	0.316	0.255
8		0.508	0.41	0.332
10	.796	0.632	0.511	0.413
12	.944	0.75	0.606	0.49
14		.824	0.667	0.539
16		.941	0.762	0.616

*mm = in. × 25.4.
[1]Manufacturer specifications and current ASTM standards should be consulted because products may be commercially available that are not included in this table.
Source: Adapted from NWWA/PPI (1980) and Driscoll (1986).

Temperature effects: Thermoplastic well casing rigidity is affected by temperature, with rigidity and collapse strength reduced at higher temperatures (>70°F or >21 C). This effect can become significant in deeper wells grouted with neat cement (see Chapter 4) where a marginal casing wall thickness is specified. This "RHCP derating" varies depending on the composition of casing pipe, but averages in the range of 0.2 to 0.5 psi/degree F for ABS casing and 0.3 to 0.6 psi/degree F for PVC casing (overall average 0.5 psi/degree F or 6.2 kPa/degree C).

As an example, consider a thermoplastic casing installed in 70°F (Florida) ground water and grouted in neat Type I cement (see Chap. 4). A temperature rise of 26°F (typical for cement in a 1.5-in. annulus) may be expected during cement curing. An RHCP derating of 13 psi would occur. It is very dangerous to express collapse pressure in anything other than psi units. "Ft. of head" is for water only (inside & out) . Many installations, of course, involve use of heaver mods and great slurries. If the casing were SDR 21 PVC installed to 250 ft (and the interior of the casing evacuated, for example, during development) collapse or ovalling may be possible.

3.5 Methods of Casing Installation

Casing may be installed by a variety of methods depending on the drilling method used, and the formation characteristics. Casing installation, grouting (Chapter 4), and development (Chapter 8) are the times when a casing is under most stress and may collapse or distort. In general, plastic casing should not be pushed, jacked, driven or forced into place. It should be lowered or floated into an obstruction-free borehole. Steel casing (with its much higher compressive strength) may be jacked, driven, or rotated into the hole.

Casing should be handled and stored carefully to avoid damage to the pipe prior to installation, especially to the ends or threads. During installation, care should be exercised to avoid bending or forcing casing into boreholes that are not straight except for directional wells, within the recommendations of casing and joint suppliers for these applications. Combined with normal tensile stresses, the increased axial stresses imposed on casing because of crooked holes may be significant.

Jacking. Jacking is used to install casing when drilling wells with cable tools, especially when mud scows are used. This method is also used to install horizontal laterals in radial collector wells.

A pulldown spread footing is installed around the well and the jacking force on the casing achieved by pulling down on the casing with the ram end of two to four hydraulic jacks. The cylinder end is secured to the spread footing so that force is applied firmly and exactly parallel to the axis of the borehole (plumb if vertical) (**Figure 2**).

The load pressure (which may approach 300 T) must not exceed the yield strength of the casing. Only steel casing can be employed if jacking is the installation method chosen. The penetrating edge of the casing should be protected by a standard drive shoe. The drill hole should be straight (and plumb in vertical wells) to minimize pipe and joint distortion.

Driving. Casing may be driven either by percussion from the cable tool string, or by a pneumatic tool designed to drive casing through unconsolidated formations. Only steel casing specified as drive casing can be used for driving (compressive stress of approximately 25,000 to 70,000 psi may be applied).

When permanent well casing is driven, a standard drive should be welded or threaded on the lower end of the string of casing. The shoe should have a beveled and tempered cutting edge of metal forged, cast or fabricated for this purpose. Welding quality is critical because of the risk of fatigue failure, especially near the bottom. The excavated drill hole should be straight and plumb to minimize pipe and joint distortion.

Lowering. The lowering method is used to install a jointed casing string in a predrilled hole. The casing may be lowered with the drilling machine, utilizing clamps, elevators or other mechanical devices to permit safe, controlled installation. The casing end is not closed and hydrostatic pressure inside and outside the casing can quickly

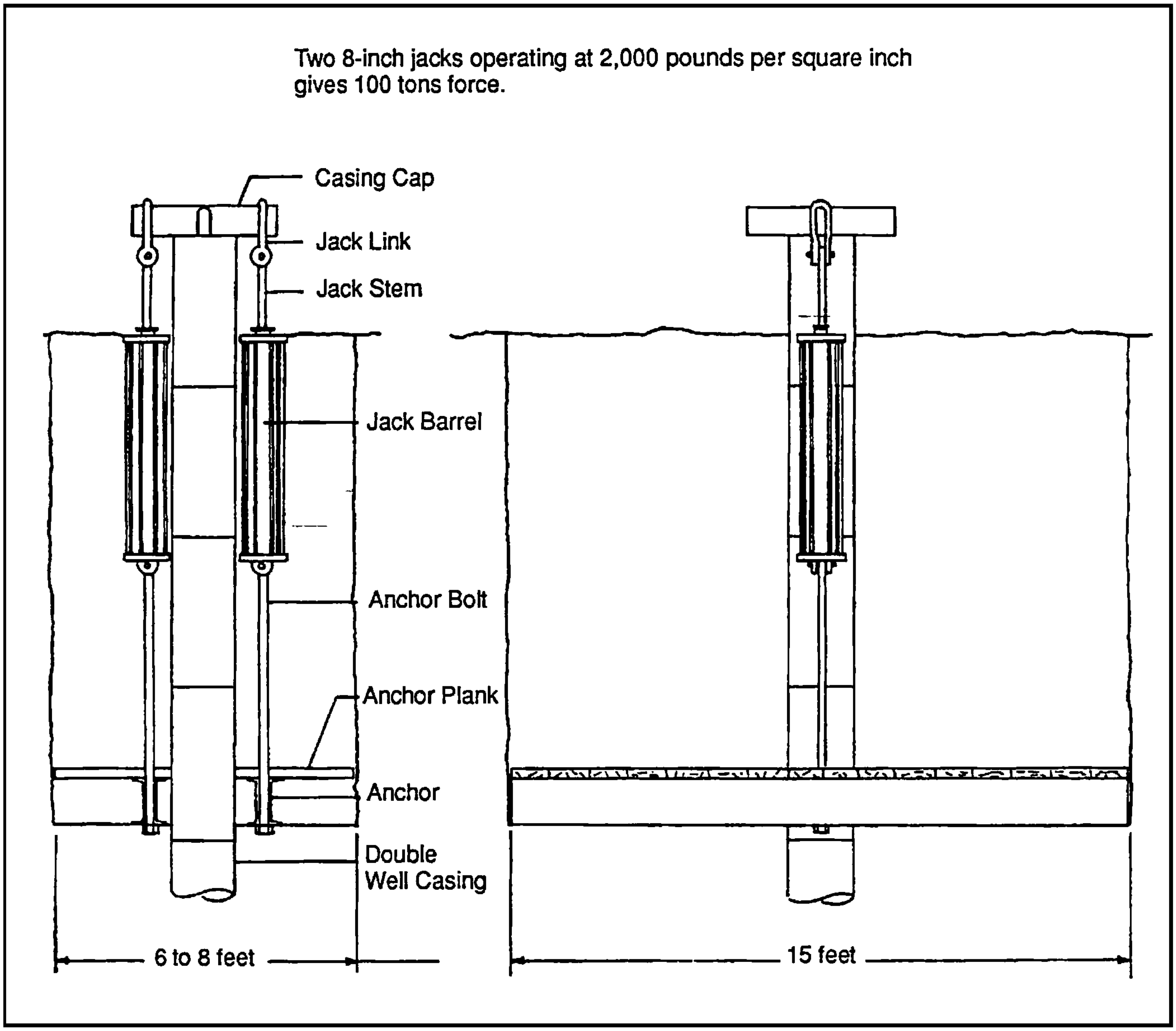


Figure 2. Typical jacks and anchors arrangement.

Figure is from the *Handbook of Ground Water Development*.

achieve equilibrium. The casing string should be kept suspended in tension to avoid distorting casing joints. Lowering may be used with all types of casing installations.

Floating. Where the casing load is extremely large it may be desirable to "float" the casing into place. This method is usually chosen when the total casing string weight approaches or exceeds the installation rig mast capacity, and is a much more critical procedure than lowering, where the casing inside and outside pressures are closer to equilibrium.

A float collar is installed on the casing at the appropriate place in the casing string or a (removable) float plug installed in the casing string near the bottom (**Figure 3**). The force of buoyant pressure on the collar or plug reduces load on the mast. Casing distortion problems occur when the load on the mast is held constant and the hydrostatic force difference between the outside and inside of the casing is large enough to induce collapse, buckling or ovalling.

The casing string should be kept suspended in tension to avoid distorting casing joints. Water or drilling mud should be loaded into the casing periodically to keep it in tension without exceeding about 2/3 of the mast loading limit. Floating may be used with all types of casing installations, but must be undertaken with great care.

3.6 Methods of Joining

As casing cannot normally be installed in single lengths, casing joints are needed. It is important that the resulting joint should have the same (or nearly the same) structural integrity as the casing itself, and must not leak.

Steel casing may be joined either by welding or threading-and-coupling. Welding should only be performed by personnel familiar with arc welding of curved pipe surfaces with deep joints. Beveling the casing pipe ends helps to assure deep, uniform seams. The welding rod used should be selected to match the steel alloy, and weld spatter and metal heat distortion beyond the joint minimized. If threaded and coupled joints are used, couplings should be API or equivalent, made up so that when tight all threads will be buried in the lip of the coupling.

Plastic or casing sections may be joined watertight by solvent welding and fiberglass by epoxy cementing with the directions of the manufacturer of the materials used. Developers of casing pipe materials recommend that solvent joints be permitted to set properly before they are lowered into place. Setting time is temperature and humidity dependent.

Threaded and coupled joints may be used for fiberglass, and in some cases with PVC or ABS, and are recommended for monitoring wells to avoid the introduction of

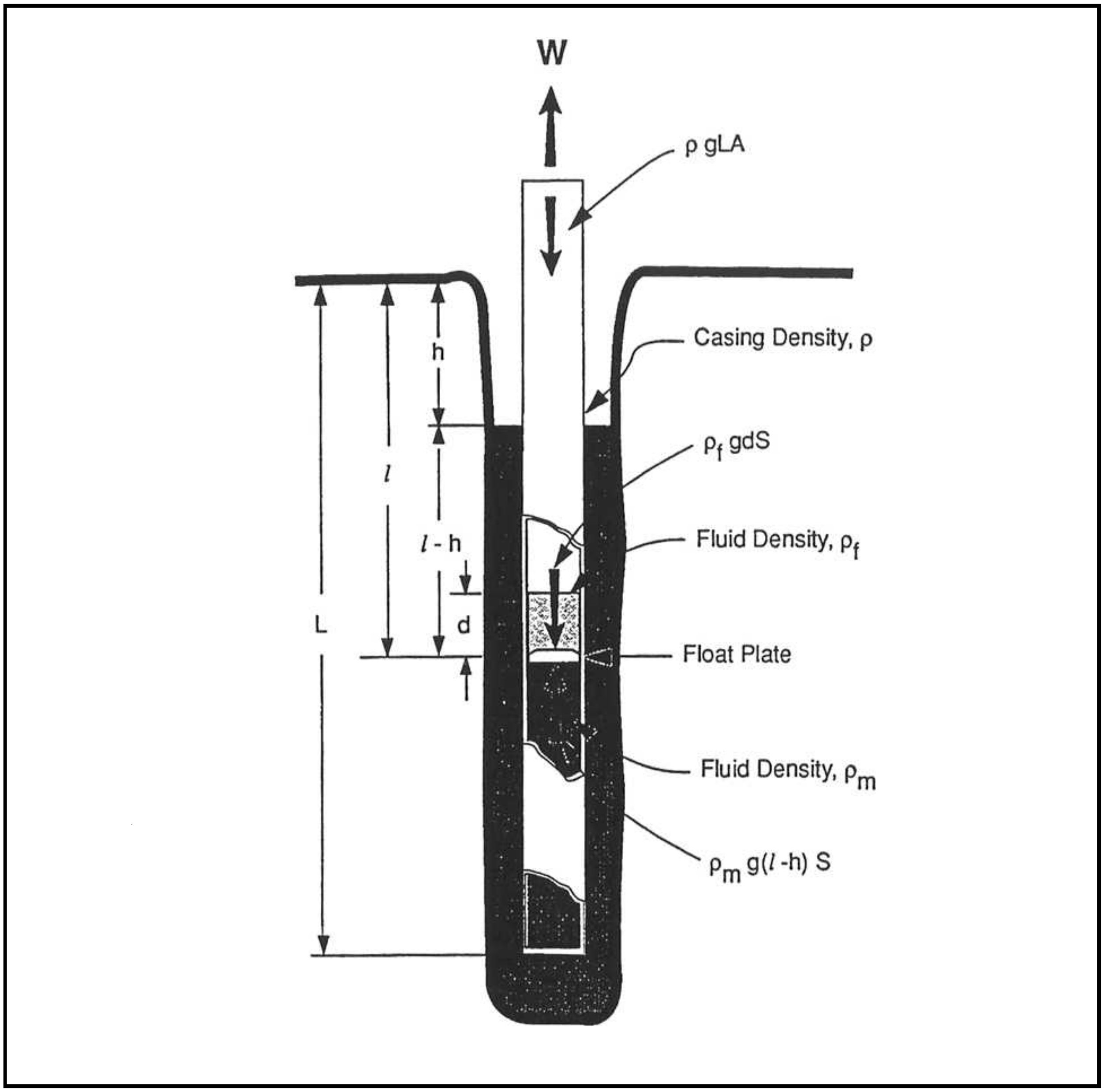


Figure 3. "Floating" casing into an open borehole.

Figure is from the *Handbook of Ground Water Development*.

materials which may interfere with water quality testing. However, pipe-thread type joints are easily distorted and damaged during casing installation.

A standard, very coarse thread joint standard (incorporated into ASTM F480) has been developed for flush-joint plastic casing joints. This type of joint permits a rapid, strong joint with a positive seal and a flush (smooth) casing exterior in smaller (2 to 4 -in.) casing diameters. The same joint is available for stainless steel casing and screen components.

A further type of casing joint, the spline-locking type, is in wide use with plastic casing. This joint type is acceptable in all well casing diameter classes (**Figure 4**). For safe and effective spline-lock joining, the installation should be carried out by personnel familiar with the installation method. When used as intended, the spline lock joint provides is a quick, strong, positive seal. The F480 threaded joints and spline-lock joints (which are manufactured and tested in accordance with ASTM F480) should be used in place of pipe-thread joints for casing.

Other materials: Casing made of other materials (concrete caisson, aluminum, etc.) should be joined in accordance with the manufacturer's instructions.

3.7 Casing Seating

Regardless of size, weight or length of the well casing, it is important that it be properly seated to insure a satisfactory well. When casing is to be seated (rather than suspended or "hung"), it should be firmly positioned so that it will not move vertically (settle) or go out of alignment.

In unconsolidated formations, the casing is firmly attached to the well screen either by direct joint connection or with a friction seal ("K" packer). The casing should be supported along its length by the grout seal (or compacted formation material in the case of driven casing). Aquifer material collapsed and compacted in the screen area during well development holds the screen in position. The completion of the sanitary surface seal will assist in supporting the casing.

In consolidated formations the casing should extend at least five feet into the rock formation to assure a proper seat and bottom seal. Where top-of-rock water is the target, the design should ensure a solid, sanitary seal in the formation. Where the casing is to be driven into position, the drive shoe should be driven to refusal (may be < 5 ft). Where the casing is to be lowered or floated into place (rather than driven), the borehole drilled into the rock should be large enough in diameter to accommodate an adequate grout seal to the end of the casing.

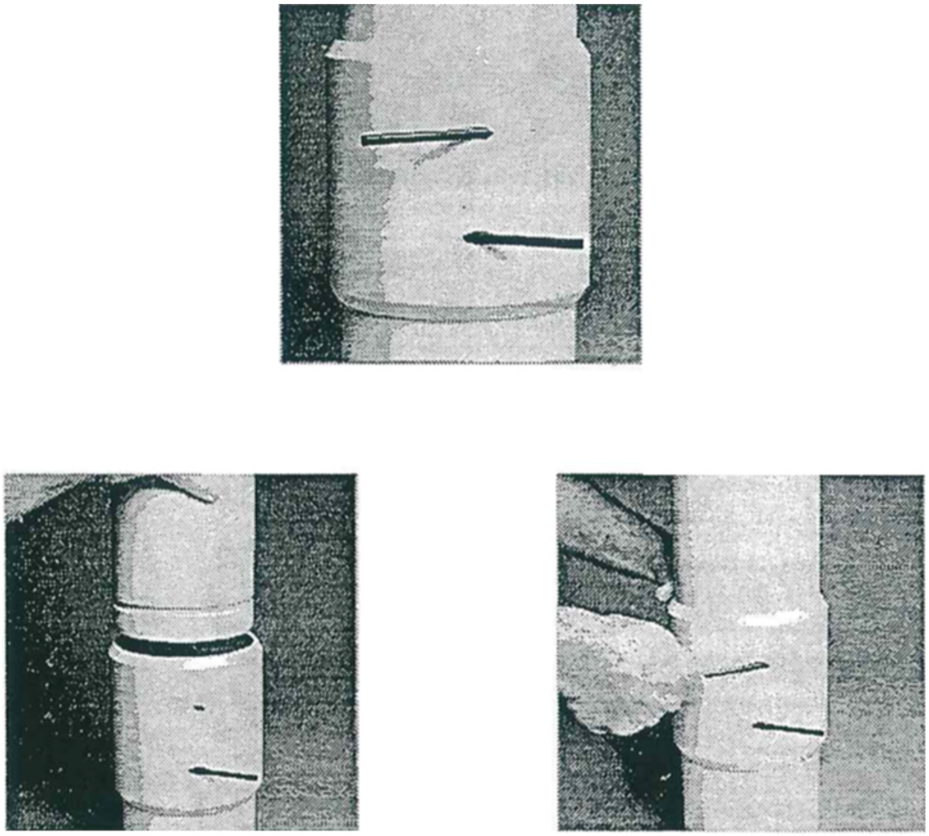


Figure 4. Spline Lock Joint.

Figure is from CertainTeed Corporation.

The lower or formation end of the casing should be fitted with a "shale trap" or grout boot to support the grout installed. It is important that the hole be fully round and in gage, or shale traps may allow grout to leak past.

Where casing has been driven, the success of achieving a seal can be checked by pressure testing. Maintaining a pressure of 7 to 10 psi within the well for one hour, without the addition of more air, is an indication of a positive seal. Grouting adds a level of security for both formation seat and joint seal integrity.

3.8 Sanitary Protection of Well

Well construction is not a sterile practice, but contamination from the surface can be minimized during construction. During the construction phase itself, it is important to protect the surface opening so that surface soil and foreign objects do not fall into the borehole.

Upon completion of the water supply well, the casing should extend not less than 12 inches (30 cm) above the pump house floor or final ground level elevation, and not less than 12 inches (30 cm) above the maximum anticipated flood level of record. Consult with local requirements which may be more stringent. A suitable threaded, flanged, or welded cap or compression seal must be installed until final surface workings are finished so as to prevent other surface contamination.

The ground, floor, or pad immediately surrounding the top of the well casing should slope away from the well. Any equipment which will permit direct open access to the well (e.g., vents in well seals) should also meet the above height requirements and sealed or screened so as to prevent the entrance of contaminants into the well from surface or near-surface sources.

There should be no openings in the casing wall below its top except for approved pitless well adapters or units, or measurement access ports and grout nipples installed in conformance with the relevant well construction standards (e.g., state or industry consensus). This includes drain holes for frost-free sampling spigots sometimes specified by state agencies, which should never drain into water well casings. Alternative frost-free sampling installations available should be used instead where needed.

The upper terminus (top) of the casing should be sealed to prevent casual entry of surface water, precipitation, animals or foreign objects. A top seal can take the form of (1) a sealed, vented or unvented well cap meeting Water Systems Council (WSC) standards if discharge from the well is below the surface (pitless adapter), (2) an approved well seal (WSC or state standards) if the discharge pipe extends out of the top of the well casing (e.g., in a well house), or (3) a secure lineshaft turbine base seal.

Pitless units must be attached to the casing by threading, welding, or compression connection in a manner which will make the joint sound and watertight.

Wells should be equipped with drawdown measurement ports or devices, but these should be sealed so that entry is not possible except during use.

References

American Society for Testing and Materials. *Annual Book of Standards, ASTM, West Conshohocken, PA.*

American Water Works Assn. *AWWA Standard for Water Wells, ANSI/AWWA A100, AWWA, Denver, CO.*

Australian Drilling Industry Training Committee, 1997. *Drilling: The Manual of Methods, Applications and Management. Lewis Publishers, Boca Raton, FL.*

Driscoll, F. 1986. *Groundwater and Wells, Johnson Division, St. Paul, MN.*

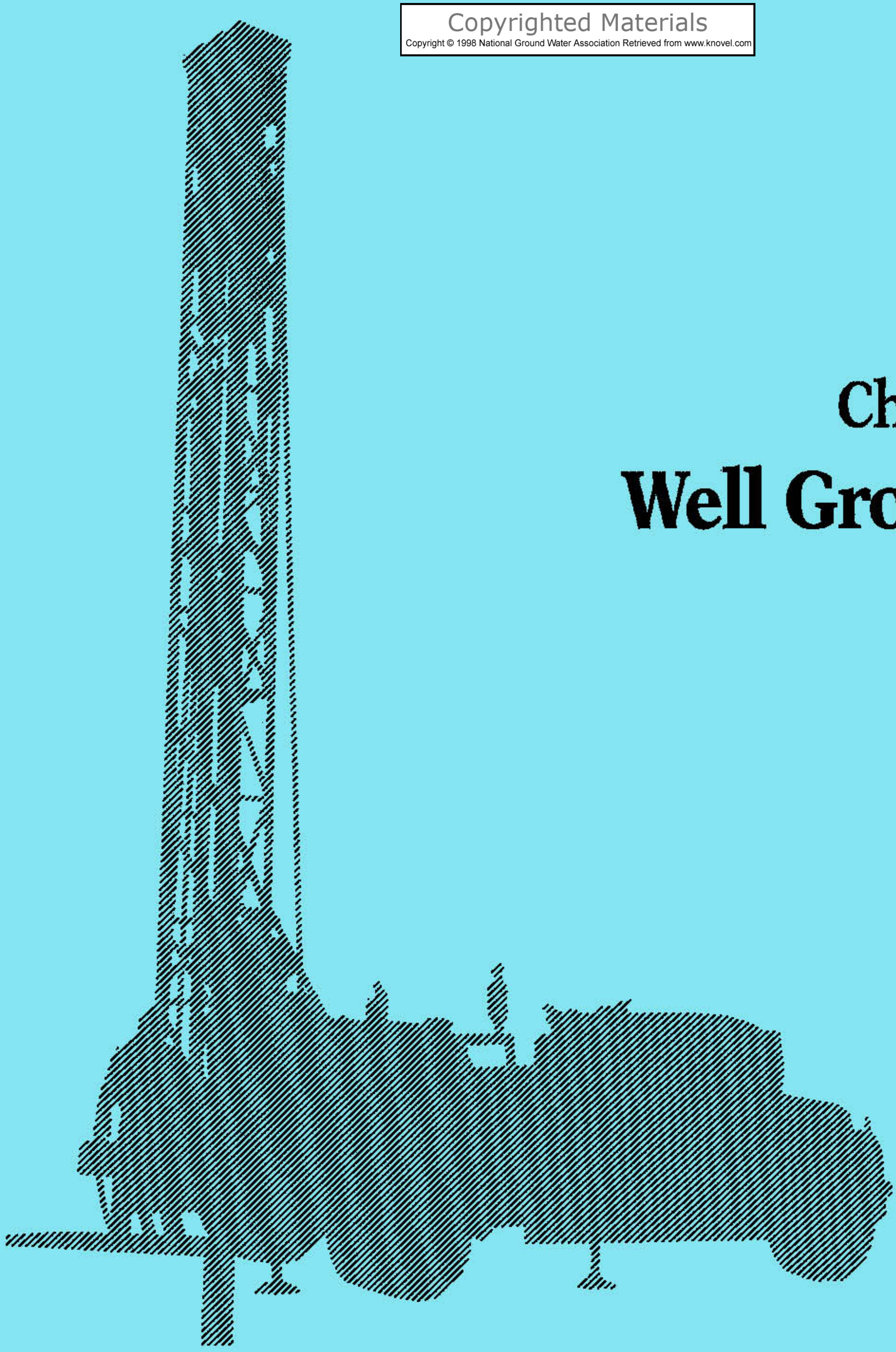
Great Lakes-Upper Mississippi River Board of State Public Health and Environmental Managers. 1987. *Recommended Standards for Water Works. Health Research Inc., Health Education Services Div., Albany, NY.*

C.E. Kurt, Johnson, R.C., and J.C. Warman. 1980. Engineering Performance of Thermoplastic Water Well Casings, WRRI Bulletin 44, Water Resources Research Institute, Auburn University, Auburn, AL.

NWWA Committee on Water Well Standards. 1975. *Manual of Water Well Construction Standards, EPA - 570/9-75-001. Office of Water Supply, Washington, DC.*

NWWA and Plastics Pipe Institute, 1980. *Manual on the Selection and Installation of Thermoplastic Water Well Casing, NWWA (NGWA), Westerville, OH.*

Roscoe Moss Co., 1990. *Handbook of Ground Water Development. Wiley-Interscience, New York.*



Chapter 4
Well Grouting

4 Well Grouting

<u>Renovation</u>

Filling the annular space with material equal to or better than the material removed in drilling. (You don't run into slurries in the sub-surface.)

4.1 Purposes of Well Grout

Well grouting consists of filling an annular space between a casing and the formation or outer casing with an impervious material. The reasons for grouting are:

(1) Protection of the aquifer, or aquifers (including the prevention of water movement between aquifers) to maintain water quality and preserve the hydraulic response of the producing zone(s), and

(2) Protection of the well against the entry of unwanted water from the surface or a subsurface zone.

(3) Protection of the casing. This may be necessary to guard against attack by corrosive waters, or where special assurance of structural integrity is desired. In this case, a satisfactory grouting program must result in complete envelopment of the casing.

Grouting and backfill have been demonstrated to significantly reduce the axial distortion of casing. They are also important in limiting or eliminating water circulation around casing pipe, which contributes to corrosion.

4.2 Grouting Requirements

In determining the specific grouting requirements of a well, consideration must be given to existing surface and subsurface conditions, including the geology, hydrology and location of sources of pollution. To protect against contamination or pollution by surface waters or shallow subsurface waters (such as effluent from septic tanks) the annular space must be sealed to whatever depth is necessary to protect the well, whether 10 feet or more than 1000 feet. In general, all casings lowered into the drilled borehole are fully grouted. Driven casings may be grouted, depending on subsurface and surface conditions.

Formations which yield polluted water or water of an undesirable quality (untreatable to meet standards by practical means) must be adequately sealed off to prevent pollution or contamination of the adjacent water-bearing zones. To accomplish this, the annular space of the well should be grouted from at least 10 feet above to 10 feet below the interval from which such polluted or mineralized water is being produced, if feasible.

Centralizers should be required to prevent the casing from contacting the wall of the bore hole, or to maintain a minimum annular space so that a complete seal can be obtained without void spaces.

Well grouting is required to one degree or another in most U.S. jurisdictions. Many have specific standards that must be met (e.g., minimum depth and grout formulation). If the owner of the well is not informed about well grouting (e.g., grouting is not included in the specifications), well contractors should explain the requirement and their obligations to the owner.

Except in the case of driven casings (process considered separately), the annular space should be flushed with drilling mud (not clear water) prior to grouting to assure that the space is open and ready to receive the sealing material. Once this is accomplished, grouting should be done in one continuous operation in which the annular space is filled to the desired depth. In very deep PVC installations, grouting in stages may be desirable to control collapsing pressures.

Grout containing cement should be entirely placed before the occurrence of the initial set (beginning of hardening) of the cement. Bentonite grout must be placed before hydration makes the material difficult to pump. Bentonite solids should (as much as possible) "yield" or hydrate in place in the borehole.

It is essential that ("in situ") the grout always be introduced at the bottom of the space being grouted. This is to avoid segregation or bridging of the grout materials and to push out foreign substances that may have inadvertently entered the hole. The grout seal should be inspected after setting of the grout to determine if more grout is needed to complete the seal.

Grouting casings in artesian flow situations requires special caution, skill and ingenuity. Grouts (both bentonite and cement based) must be still for an initial set to take place. Flows must be halted so that setting can occur. Casing grouting in artesian wells should be conducted by drillers experienced with the practice.

Caution is also required in deep seals. Where grouted intervals exceed 100 feet, the collapse strength of the casing should be checked prior to grouting (see charts, Chapter 3). A further caution involves cement grouting of wells with thermoplastic casings. PVC casing may lose some collapse resistance when exposed to heat produced by the hydration of some grout mixtures. This possibility should be planned for prior to grouting in order to install the preferred casing wall thickness and grout mixture. For example, the casing supplier should be consulted to obtain reliable "derating" recommendations for casing pipe due to increased temperature.

Grout should be emplaced in the shortest possible time. Pumping until the same grout appears at surface as the grout quality being pumped in the hole. Grout being pumped out drilling fluid in annulus should be approximately the same density.

4.3 Location Of Grout

The annular space to be grouted should be not less than a nominal 2 inches in radius. The length of the grout seal (including any surface seals) should be whatever is necessary to prevent the entrance of surface water or undesirable subsurface water into the well. In any circumstance, the length of seal must not be less than the minimum specified in the state or locally applicable construction code.

Except under specific local circumstances, the grout should be placed as a continuous seal from:

(1) The bottom of the permanent casing or,

(2) Where a filter pack has been installed, from the top of the pack (following development) or,

(3) Where a well screen only has been installed, from a point 5 feet (1.5 m) above the screen to the land surface, unless:

(4) When a pitless adapter or unit is to be installed, the grout should terminate within one foot of the field connection of the adapter or unit.

The entire space to be grouted must be open and available to receive the grout at the time the grouting operation is performed. If a section of larger pipe (conductor pipe) is installed to keep the entire annular space to be grouted open (e.g., in unstable, caving formation materials), this larger pipe must be removed from the zone where the seal is required as the grout is installed.

4.3.1. Surface Formation Seals

The effective length of grout seal for sanitary purposes is that distance measured from the deepest limit of the seal up to the depth of frost penetration (where applicable) or the top of the grout. If a pitless adapter or unit is to be installed, the upper limit of the seal is one foot below the field connection of the adapter or unit.

4.3.2 Bottom and Intermediate Seal Grouting

Grout should be placed in the annular space surrounding the bottom of the casing by the method specified (**Figure 5**). Where multiple-zone completions are acceptable and desirable, selected intervals may be grouted, interspersed with producing zones. All zones containing water of unsuitable quality should be grouted from a point at least 10 feet (1.5 m) below, to a point at least 10 feet (1.5 m) above the unsuitable zone, unless experience shows that a lesser length (e.g., 5 ft below to 5 ft above) is sufficient. The annular space surrounding the casing between grouted zones may be filled with sand and bentonite (in non-producing zones) or sand (for formation stabilizer and filtration).

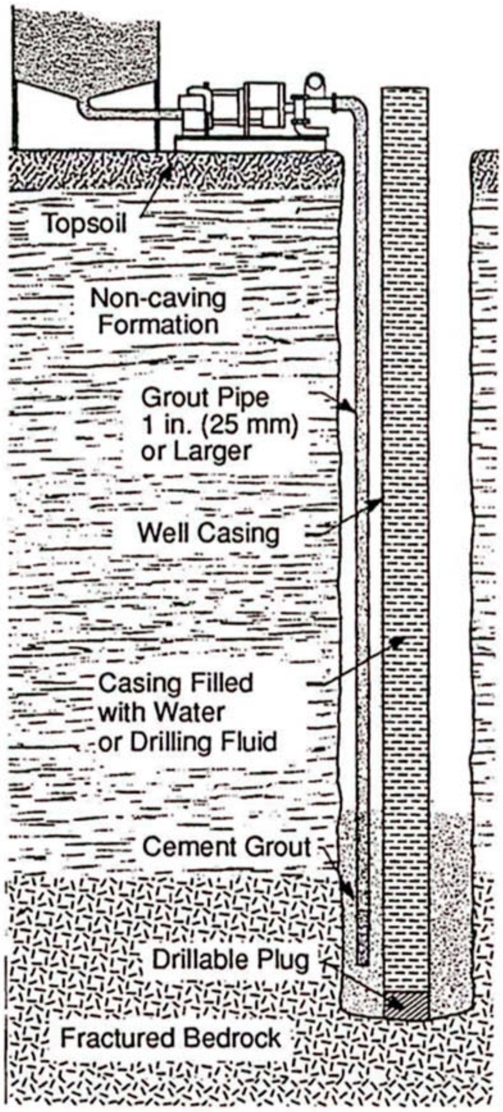


Figure 5. Placement of Grout.

Figure is from *Groundwater and Wells*.

4.4 Grouting Materials to be Used

Grout essentially serves to replace original formation material displaced or removed from the borehole. Materials to be used for sealing the annular space around a well casing should have the following characteristics:

(1) Low permeability upon emplacement to resist fluid flow through them.

(2) Capable of bonding to both the casing and the formation surface.

(3) Capable of developing sufficient strength to permit completion of the well without excessive delay.

(4) Chemically inert or nonreactive with the formation materials and ground water in contact with the grout seal.

(5) Easily handled. i.e., mixable, and capable of placement in the space to be grouted by available technical means and skilled personnel; easily cleaned from mixing and pumping equipment; and is safe for personnel to handle when used properly.

(6) Minimal penetration into surrounding formation materials.

(7) Readily available at reasonable cost.

Cuttings as fill: Cuttings are unsuitable as grout seals in potable aquifer zones, but may be a useful fill below an engineered grout seal set below the aquifer zone in very deep wells. Re-emplacing cuttings in such a situation provides a semi-solid base for the engineered grout seal, heavier but more buoyant than borehole fluids without additives. Cuttings reintroduced in this situation cannot be relied upon to provide a borehole seal and should be well isolated from potable aquifers by an engineered grout seal.

Engineered seal mixtures. Currently, materials that meet the above seven criteria to one degree or another are mixtures of cement and bentonite clay. No mixture exhibits all the ideal characteristics. There are advantages and disadvantages to both cement and bentonite clay, and to the various mixtures that attempt to take advantage of the better characteristics of each. Table 4.1 is a summary of cement and bentonite mixture characteristics.

Table 4.1
Grout Mixture Properties

	Advantages	Disadvantages
Cement-based grouts	Suitably low permeability under good conditions	Shrinkage and settling may result in unacceptably high permeability
	Easily mixed and pumped	Equipment cleanup is essential, and time consuming
	Hard, rigid seal, contains fluids under pressure (artesian flows)	High density results in loss of material to formation
	Supports casing rigidly	Casing cannot be moved after grout seal sets
	Suitable for most formations	May affect water quality
	Extensive field experience	May not adhere well to PVC casing
	Properties can be altered with additives	Long curing time (unless artificially treated)
	Readily available at reasonable cost almost everywhere	Heat of hydration requires operating of PVC collapse strength
Bentonite-based grouts	Suitably low in permeability with high-solids mixtures	Premature swelling and high viscosity may result in difficult pumping. Too small a pump result of excess mixing and wasted time.
	Expands, self-healing, resilient to cracking, non-shrinking in low-saline water	High viscosity requires specific mixing and pumping techniques
	No heat of hydration	Subject to washout in fractured rock with high fluid flow velocity or formation under pressure (severity depending on condition and percent solids emplaced)
	Low density, less differential pressure on casing during installation	Subject to failure in certain contaminated waters (saline, oil)
	Minimal curing time	Equipment cleanup shouldn't be difficult
	Casing movable after grouting (depending on condition and percent solids emplaced)	Casing movable after grouting (not a rigid seal)
	Readily available but can be more expensive than cement (cost-effectiveness should be a consideration)	Can be channeled during pressurizing in well cleaning

Source: Modified from Gaber and Fisher (1988).

Bentonite is usually not suitable as a sealant under the following conditions:

(1) When sealants will be in direct contact with aquifers (this should not occur with casing seals).

(2) Wherever structural strength or stability of the sealant is the overriding priority (although high-solids bentonite seals have dimensional stability).

(3) Wherever the sealant might dry out completely or be altered by saline ground water.

(4) Wherever flowing or moving water can generate enough force to break down the sealant.

4.4.1 Cement-Based Grout Mixtures

Cement grouts set up as structurally stiff, permanent seals that can contain high pressures or gassy fluids. They are preferred where a hard rock-like seal is desired to hold the casing firmly in position or to contain artesian or gaseous water. Cement mixtures are widely available, and readily mixed and pumped. A disadvantage with cement-based mixtures is the possibility of shrinkage and cracking of the seal, resulting in the development of a micro-annulus around the casing and introduction of high-pH water into the aquifer. Thus there is the potential for undesirable water migration around and through the grout seal. Hydraulic conductivities of neat cement borehole seals (around 10^{-5} cm/sec, compared to laboratory test conductivities on the order of 10^{-10} cm/sec) are most likely due to shrinkage. Table 4.2 provides some soil and grout permeability figures.

Table 4.2
Permeability of Selected Soil and Grout Materials

Material	Permeability (k) in cm/sec
Silty sand	10^{-1} to 10^{-5}
Glacial till	10^{-1} to 10^{-7}
Compacted soil	10^{-4} to 10^{-9}
Neat cement (6 sack)	10^{-5} to 10^{-7}
Bentonite grout (20% W/W slurry, chips, pellets)	10^{-6} to 10^{-9}
Cement and bentonite	10^{-5} to 10^{-11}

Source: After Gaber and Fisher, 1988, Lutenegger and DeGroot, 1993.

Cement types. Choice of cement types (Table 4.3), mixtures, and means of emplacement are important in determining how the seal will set and perform in the subsurface. Several types of Portland cement are suitable for use in well-grouting mixtures. ASTM standard C150 defines Portland cement characteristics:

Table 4.3
ASTM Cement Designations

Type I	General purpose Portland cement. Has low heat of hydration and longest curing time (48 hours before resuming drilling).
Type II	Moderate sulfate resistance: recommended for use where sulfate in ground water is between 150 and 1500 mg/L. Lower heat of hydration than Type I.
Type III	"High-early strength" providing faster curing rate (12 hours).
Type IV	Low heat of hydration cement designed for use where this is important. Develops strength slower than Type I.
Type V	High sulfate-resistant cement (for ground water with >1500 mg/L sulfate).

Source: Gaber and Fisher, 1988.

Effects on setting time and seal quality. The setting of cement is affected by a variety of factors, including water quality, temperature, pressure on the seal mixture, and water loss from the cement into the formation. One phenomenon is "flash setting" that occurs when uncontrolled infiltration of neat cement into granular formations occurs upon introduction. The result is a porous matrix with a high hydraulic conductivity.

Faster set-up times may occur in the following situations: (1) warmer temperatures, (2) deeper in the hole, where cement will tend to set faster as hydrostatic pressure squeezes water out, or (3) where water is lost into permeable zones.

The amount of water used per sack of cement is very important. If the cement slurry is too thin, a flash-setting mixture with low integrity and high potential for shrinking and cracking is very likely, especially at more shallow depths. A mixture of Portland cement (ASTM C150) and not more than seven (7) gallons of clean water per bag (one cubic foot or 94 pounds) of cement, should be used. The Society of Petroleum Engineers (SPE) recommends 46 % water for common cement (5.2 gal/94 lb cement bag).

Water quality is critical. Water for mixing should be of essentially drinking-water quality with less than 500 mg/L total dissolved solids to produce the best set. High chloride content may cause a flash set, resulting in a weak, porous cement. Sulfates in geological formation or mix water tend to replace cement anions, interfering with proper setting. The water should be free of foreign objects.

Special cements and mixtures, including bentonite, may be used to reduce shrinkage, reduce permeability, increase fluidity, reduce slurry weight, and/or control the setting time. These mixtures should be carefully designed prior to performing the grouting task. Accelerators may be added if reducing set time is important. Calcium chloride can be added at a rate of 2 to 4 lb (1 to 2 kg) per 94-lb bag of cement. These should be measured and mixed carefully. Table 4.4 summarizes the settings times of several common mixtures.

Table 4.4
Cement Curing Time Before Resuming Drilling or Well Development

Grout Type	Curing Time
Neat cement Type I	48 hours
Neat cement Type I with 2% bentonite	48 hours
Concrete grout Type I	48 hours
Neat cement with 2% $CaCl_2$	24 hours
High-early cement Type III	12 hours
High-early cement Type III w/2% bentonite	12 hours
Concrete grout Type III	12 hours

Source: Gaber and Fisher (1988).

Example Cement Grout Mixtures:

Sand-cement grout. A mixture of Portland cement (ASTM C150), sand and water in the proportion of not more than two parts by weight of sand to one part of cement with not more than seven (7) gallons of clean water per bag of cement (one cubic foot or 94 pounds). The sand is added to reduce shrinkage and produce a tighter bond with the casing.

Bentonite-cement grout. Bentonite as an additive has several notable effects on cement mixtures:

(1) Lowering hydraulic conductivity

(2) Increasing cement resilience to cracking

(3) Reduces heat of hydration – due to increase in water content

(4) Reduces compressive strength.

Contrary to some past recommendations, using bentonite as an additive to neat cement does not significantly reduce or eliminate shrinkage. Much of the sodium associated with bentonite mixed into a cement slurry is replaced by calcium due to ion exchange. Calcium bentonite has much less expansive capacity than sodium bentonite clays.

However, the capacity to make the cement more resilient, preventing the development of long internal cracks in cement with a bentonite content of 4 to 5 % (**Figure 6**) is probably the feature of bentonite that may make it valuable in cement borehole sealing if the detrimental features (e.g., reduced strength) are not critical.

Bentonite in the cement mixture requires additional water in the mix. ASTM D 5299 states that bentonite may increase shrinkage as it ties up water that would be incorporated into the cement. SPE recommendations call for the addition of 0.6 gal. of water per sack per 1 % increase in bentonite mixture. With the addition of adequate water to compensate for that taken up by the bentonite, such cement-bentonite seals may serve the intended purpose of providing a rigid seal, while helping to compensate for the drawbacks of cement seals.

4.4.2 Bentonite-Based Mixtures

Bentonite grout mixtures have a number of favorable characteristics:

(1) Bentonite, unlike cement-based mixtures, remains plastic when installed as a grout as long as it does not dry out, and can be rehydrated if it does dry. High-active-solids bentonite seals do not crack or separate from surfaces. Low solids (or low active solids) slurries will crack and separate in the vadose zone. Water is sucked out of slurry-due to vapor pressure differences (soils suction-slurry/plug drops to a pezometric level-SWL-or-first aquifer.

(2) Plastic, hydrated bentonite expands to fill voids, displacing air or water and other fluids.

(3) When properly prepared and emplaced, bentonite grout seals have hydraulic conductivities of 10^{-6} cm/sec or less, reportedly as low as 10-12 cm/sec. This very wide range is a result of such variables as placement methond (and skill), bentonite type used, contitions of the solids in the mixture, and the environment into which the seal is placed.

(4) Bentonite does not generate the heat of hydration experienced with cement, especially with larger annular radii (>2 in.).

Drilling bentonite vs. grouting bentonite: There has been a tendency in the past to employ drilling bentonite slurry also for grouting. It is important to note that materials called "bentonite" encompass a wide variety of natural clays consisting mostly of sodium montmorillonite (API standards, 85 % or more). With regards to grouting, not all bentonite mixtures are suitable as grouts. However, bentonite slurry mixtures for drilling and bentonite sealing mixtures actually have somewhat contradictory features (Table 4.5):

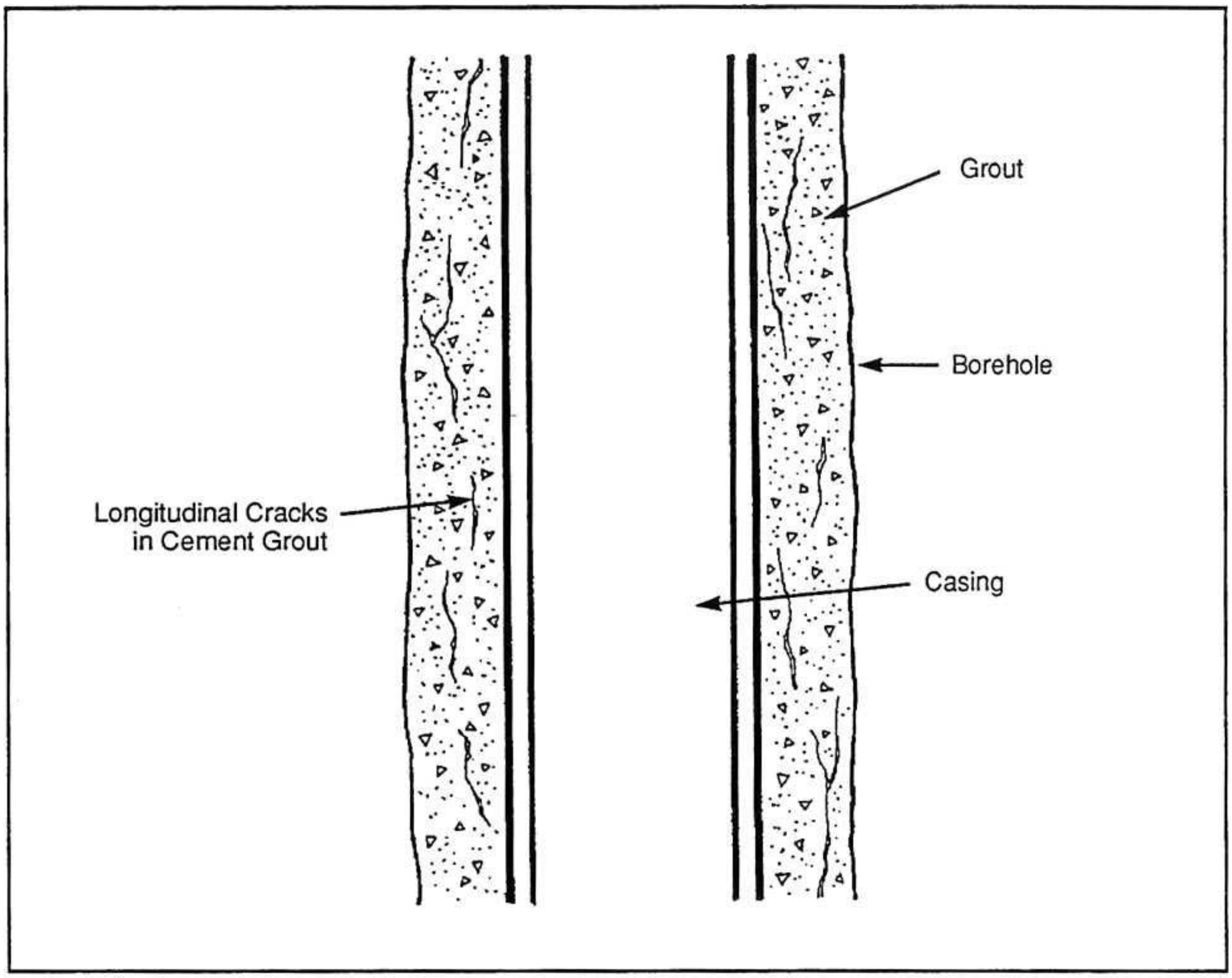


Figure 6. Longitudinal Cracks in Cement.

Table 4.5
Desirable Properties of Drilling Mud vs. Grout Bentonite

Drilling Mud Slurries	Grout Slurries
Controlled viscosities, modest specific-gravity ("low weight"), and low-to-medium gel strength.	Increased viscosity, high reactive solids* content and high gel strengths.
Typically finely ground (200 mesh).	Granular or pelletized, with a lower surface-area-to-mass ratio.

*"Reactive" solids are clays that expand and contribute to grout properties, as opposed to mineral impurities.

Solids content and type: The amount of shrinkage is controlled by the bentonite grout's solids content, with bentonites that have high reactive solids content shrinking far less than low-solids types used in drilling fluid mixtures. Granular high-solids grades also have more dimensional stability than virtually liquid **low-solids** slurries (similar in some respects to the difference between neat cement and concrete). For these reasons, **high-solids** bentonites should be used instead of drilling mud bentonite for borehole sealing applications. There is a need to define "high" solids. It presently appears to be based on what can be pumped with present equipment.

Some solids are more desirable than others. Unlike concrete, the preferable solids in bentonite are clays that provide the bulk and dimensional stability (keeping the seal shape and size) in the bentonite gel matrix without increasing the permeability.

Rock cuttings and sand have higher specific gravities than bentonite and tend to separate and sink in the hole (**Figure 7**). However, sand-dry bentonite mixtures (50:50) provide good stiff seals if emplaced so that separation is minimized (i.e., mixed in after the pump discharge and rapidly emplaced) and solids permitted to hydrate downhole.

High-solids bentonite grout types:

Powdered: Powdered bentonite clay products contain mixtures of sodium and calcium bentonite with other clays with a resulting slurry of 15 to 20 %-plus total suspended solids by weight. Their best feature is extended workability due to slower set-up and economy in large-hole jobs. The disadvantage is the relative poor dimensional stability and higher permeability of the seal. The quality of the clay mixture (degree of reactivity to hydration) is the main consideration. These products are more useful as annular sealing agents and may be less useful in some well and borehole sealing tasks.

Granular: Granular bentonites (e.g., Benseal, Enviroplug Grout) are also manufactured from high-solids, high-yield bentonites. The particles are coarse granular

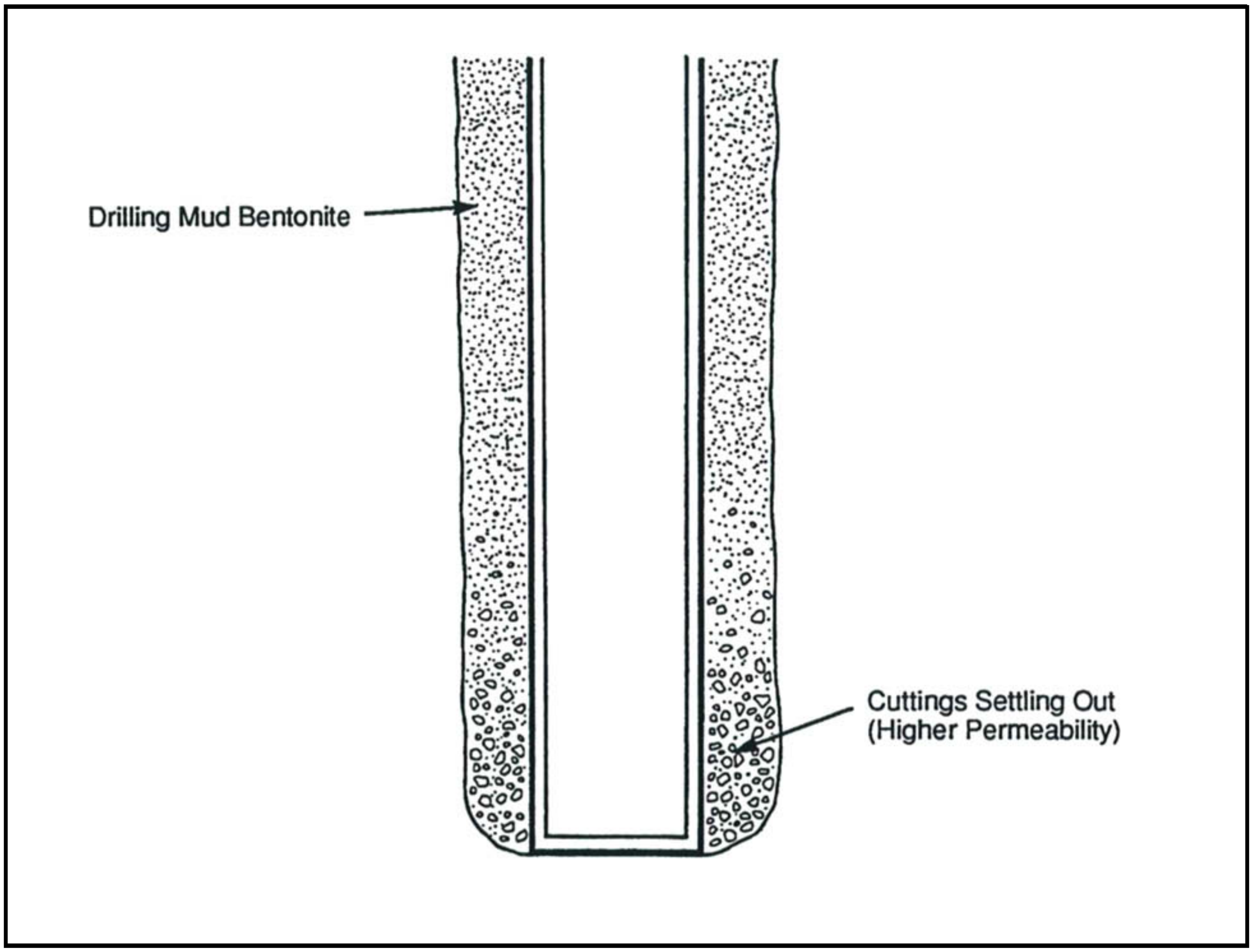


Figure 7. Segregation of Heavier Drill Cuttings Solids from Slurry in Drilling Mud Installed as Grout.

(nominal 8 mesh is usual) and finer than chips used in borehole abandonment sealing. These products provide better dimensional stability and lower hydraulic conductivity.

Environment (including water quality): Bentonite grouts may shrink if moisture is lost. The presence of saline ground water, strong acids or bases in contaminated ground water, or some organic compounds, may also cause desiccation and shrinkage.

Property-altering bentonite additives: At times, a more stiff "set" is preferred than can be provided by bentonite alone, which is plastic and somewhat compressible. Cement is sometimes recommended to be added to a primarily bentonite mixture to provide this stiffer finished product. However, cement constituents serve to destroy the sealing properties of sodium bentonites.

The trade-off for stiffness is generally in the form of a more brittle, more permeable seal. Calcium ions in the cement replace sodium ions by ion exchange, resulting in the clay particles settling closer together. Upon contact, the calcium ions link the platelets, causing flocculation. These changes are permanent once they are made.

In practice, major problems with cement addition to bentonite seals are the formation of cracks and failure to establish a seal with casing surfaces (**Figure 8**). This accounts for the generally higher permeability and may cause long paths of migration. For a stiffer, solid set, it is preferable to mix and place a very high-solids bentonite or bentonite-and-sand mixture, instead of adding cement.

Mixing water quality: Water should be fresh (not saline) and approximately of drinking water quality in total dissolved solids and calcium ion content. The water should be sanitary and free of foreign objects.

4.5 Methods of Installation of Grout

For both cement and bentonite mixtures, it is important that the grout is mixed and pumped rapidly in one continuous operation. All volumes and amounts must be measured or calculated and not a guess or eyeball estimate. There should be sufficient material and labor on hand, and equipment ready in working order. Grout, water, and additive quantities must be calculated (with some reserve) prior to beginning. If there is a possibility of encountering large voids (such as fracture zones), provision should be made for additional fill, concrete or neat cement to halt excessive grout loss to the void.

4.5.1 Preparation

Cement mixtures: Neat cement (cement and water), sand-cement, and concrete (cement, sand and coarse aggregate) are readily available already mixed or they can be easily mixed at the site. Neat cement and sand cement grouts are effective and permanent sealing materials and are preferred since their solids do not segregate out if mixed and installed properly. "Ready-mix" operations personnel may not be as familiar with

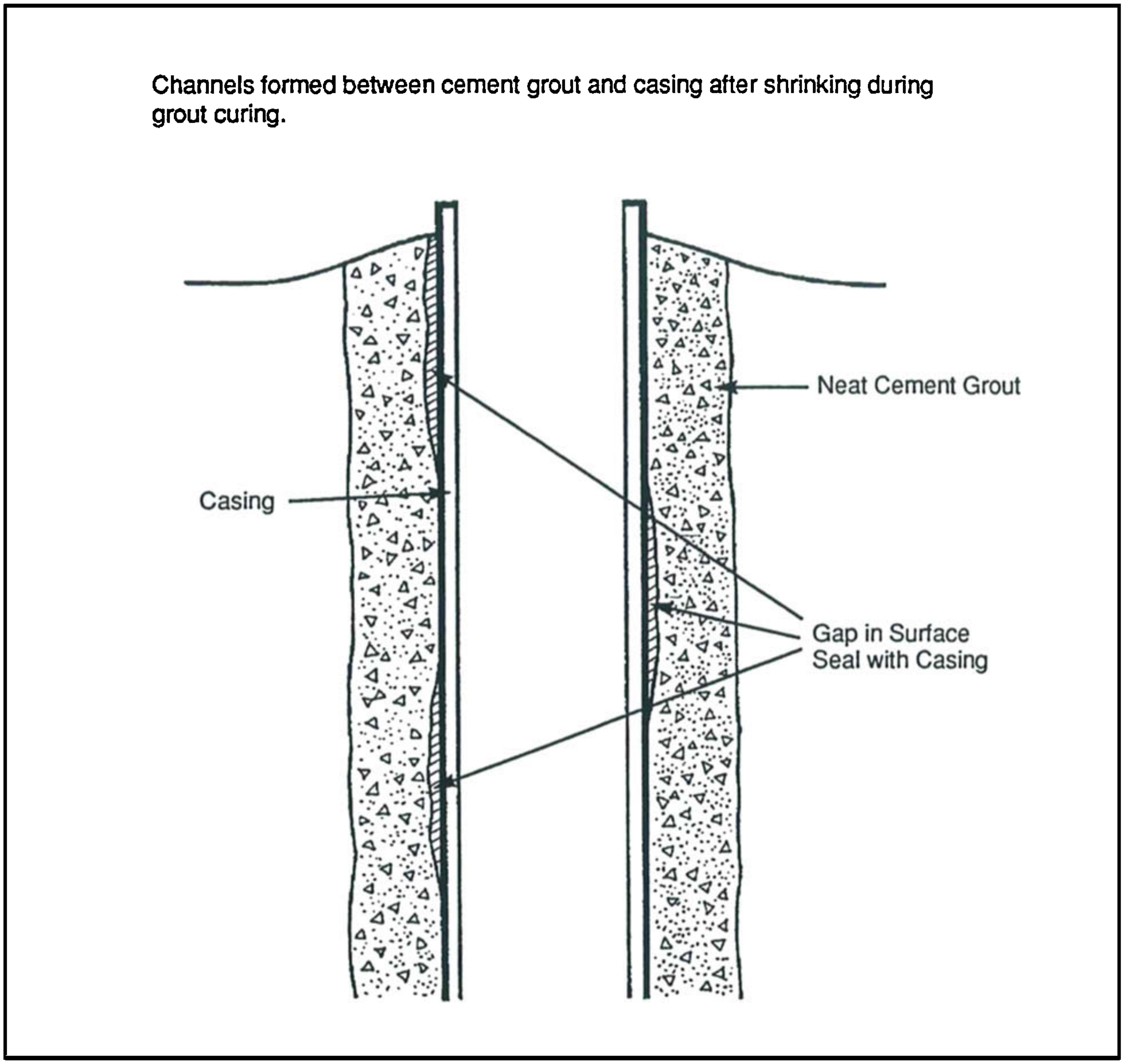


Figure 8. Failure to Establish a Seal with a Casing Surface.

handling neat cement grouting mixtures and should be briefed on the required mix and deliver instructions.

Bentonite mixtures: Emplacement of bentonite grout formulated from powdered or granular bentonite requires mixing on site using a grout mixer pump to facilitate blending and pumping with minimum disturbance of the solids. Tremie pipes should relatively large diameter so that pumping can proceed as rapidly as possible. Recirculation of the mix (as with a mud pump) should be minimized to limit damage to clay particles. Contrary to drilling fluid applications, a venturi mixer is not recommended for bentonite grout mixing, since it shears the clay particles and entrains air in the mix. "Blending" do not shearing is recommended. For that reason, centrifugal pumps are undesirable. A paddle mixer may be used to make up batches prior to pumping. Following manufacturer mixing instructions is important for good results in bentonite grouting.

One major advantage of course ground, high quality sodum sent bentonite is slower water absorption, and therefore delayed swelling, if there are enough unyielded (unreacted) solids in place and you do not exceed the liquid limit of the bentonite. If mixing and pumping are done quickly (within approximately 15 minutes, depending on the mixing equipment) a high-solids grout can be emplaced in a low-viscosity state. Swelling and setting then occurs downhole. This is the preferred place for swelling to occur, instead of at the surface.

One problem occurs when mixing and pumping into the hole cannot proceed fast enough, and the mix has been prepared with fresh water. The grout can then become very difficult to pump. There are three principle ways to prevent this possibility from becoming reality:

(1) The best way to avoid problems is planning so that solids "yield" or swell downhole as much as possible in the first place. The adding high-solids grout bentonite or bentonite-and-sand to a preblended slurry (see following) after the pump discharge (taking care not to disturb the clay particles any more than necessary) and down pumping a tremie large enough to take the mixture at the necessary rate.

(2) Mix of the bentonite in a previously prepared 1:400 solution of polymer-water (e.g., E-Z MUD, Wyo-Vis), with bentonite at 1.5 to 2 lb. per gal. This slows the yield in the slurry at the surface.

A variation is to mix granular bentonite in a premixed inorganic blend dispersion (e.g., AQUAGROUT) to provide a grout slurry with a higher solids content (24 %) and longer working time. However, the dispersant will reduce the amount of reactive solids and thus reduces the quality of the seal.

(3) Another approach is the Wisconsin-named "Ohio mix" (developed by Ohio well drillers), which involves starting with a slurry of 30 lb/100 gal. natural (untreated) API 200-mesh bentonite (e.g., Natural Gel, Gold Seal), into which 125 lb. of granular grout bentonite is mixed. The clay in the slurry eases the mixture of the grout bentonite and water and also delays hydration without the use of polymer or other blending agents.

Planning for installation requires an understanding of the volume and density of the mixture to be employed, and how much will be needed for the job. Table 4.6 lists some relevant grout properties and Table 4.7 lists annular fluid volumes for common casing and borehole diameters.

Table 4.6

Approximate Densities and Volumes of Some Grout Slurry Mixtures

Product	Mixture	Density lb/gal	Volume ft^3/sack[a]
Neat cement	6.0 gal/sack of cement	15	1.28
Neat cement + 2% bentonite	6.5 gal/sack of cement	14.7	1.36
Neat cement + 5% bentonite	8.5 gal/sack of cement	13.8	1.64
Neat cement + $CaCl_2$	6.0 gal/sack of cement, $CaCl_2$— 2 to 4 lb/sack	15	1.28
Concrete grout	6.0 gal + 1 sack each of cement and sand	17.5	2
Bentonite (granular) + polymer hydration retardant	Benseal[b] — 1.5 lb/gal. Water: water solution of 1 qt. polymer per 100 gal of water[b]	9.25	4.75
Bentonite (granular) + drilling bentonite ("Ohio mix")	Benseal[b] — 1.5 lb/gal. Water: water solution of 0.2–0.3 lb fine bentonite per gal of water[b]	9.25	5

[a]1 ft^3 = 7.48 gal. (0.028 m^3 or 28.3 L).

[b]Brands quoted for illustration only. Mixtures vary by products used. Follow manufacturer recommendations. For SI proportions, consult manufacturer instructions.

Table 4.7
Volume Between Casing and Borehole for Selected Casing Diameters

Casing O.D. (in.)	Hole diam. (in.)	Gal[a] per linear ft.of Annulus
4.5	6	0.643
	7	1.17
5.5	7	0.765
	8	1.377
6.625	9	1.51
	10	2.289
8.625[b]	11	1.9
	12	2.84
10.75	13	2.18
	14	3.28
13	15	2.284
	16	3.55
16	18	2.774
	20	5.875
20	22	3.427
	24	7.181

[a]1 gal. = 0.1337 ft^3, 3.785 L. 1 ft = 0.3 m.
[b]Make adjustments based on actual casing O.D.
Source: Anderson (1979).

Where exact volume calculations are critical, it is valuable to run a caliper log so that the exact annular volume can be determined. Variations in the hole cause deviation from calculations assuming the annular space occurs between two perfect cylinders (borehole wall and casing).

4.5.2 Emplacement in the Annulus

Setting a permanent conductor casing by displacement. This may be accomplished by setting a surface or conductor casing above the water table to keep an annulus from caving prior to well completion. The conductor casing should be at least two inches (51 mm) in diameter larger than the permanent casing, and the borehole sufficiently greater in diameter than the conductor casing (at least 1.5 to 2 in.) to permit an adequate seal of the conductor casing.

The required amount of cement is poured into the hole and immediately after, the casing with drillable plug is lowered into the mixture. Concrete may be used for this purpose above the water table.

Annular grouting of an installed lowered casing. Whether using bentonite or cement, grout is preferably forced into the annular space by suitable pumps or by air or water pressure. The casing should be suspended in tension so that it is not compressed or distorted.

When pumped, the grout is pumped in through a rigid tremie pipe. Preferred pumps are positive-displacement rotary, piston or air-diaphragm types better designed to pump high-solids, high-viscosity fluids. Air or water pressure may be used to accomplish displacement out of the casing up into the annulus to be grouted.

Tremie method. Where a tremie pipe is used there should be a minimum annular opening of two inches (51 mm) and preferably three inches (7.6 mm) between the outer surface of the inside casing and the inside surface of the external casing or borehole. The minimum size tremie pipe should be 1.5 in. and preferably 2 in. (I.D.) (38 to 51 mm). Where concrete grout is used the minimum size tremie pipe used should be 3 in. (76 mm) I.D. However, larger annular radii result in dramatically higher temperature rises during curing if cement is used, and this should be taken into consideration.

Grout material is placed by tremie pumping (after drilling fluid has been circulated in the annular space sufficiently to clear obstructions). When making a tremie emplacement, the tremie pipe must be lowered to the bottom of the zone being grouted, and raised slowly as the grout material is introduced. The tremie pipe should be kept full continuously from start to finish of the grouting procedure, with the discharge end of the tremie pipe being continuously submerged just below the surface of the grout until the zone to be grouted is completely filled. Keeping the tremie submerged at the bottom risks (1) loss of the pipe and (2) unnecessary force on the casing. Pump until certain that you are discharging true grout (as tested) from the annulus and not just colored water.

Positive placement-exterior method. Grout material may be placed by a positive displacement method such as pumping or forced injection by air pressure (after water or other drilling fluid has been circulated in the annular space sufficient to clear obstructions). Grout is injected in the annular space between the inner casing and either the outer casing or the borehole. The annular space must be a minimum of 1.5 inches (38 mm) for sand-and-cement or neat cement or bentonite grout, but may be not much more than that without compromising the seal.

The grout pipe must initially extend from the surface to the bottom of the zone to be grouted. The grout pipe should have a minimum inside diameter of one inch (25 mm) for sand-cement or neat cement grout. It should have a minimum diameter of 1.5 inches (38 mm) for bentonite or concrete grout. Grout must be placed, from bottom to top, in one continuous operation. The grout pipe may be slowly raised as the grout is placed but the discharge end of the grout pipe must be submerged in the emplaced grout at all times until grouting is completed.

The grout pipe must be maintained full, to the surface, at all times until the completion of the grouting of the entire specified zone. In the event of interruption in the grouting operations, the bottom of the pipe should be raised above the grout level and should not be resubmerged until all air and water have been displaced from the grout pipe and the pipe flushed clean with clear water.

Positive placement: Interior method with two plugs. Circulate water or other drilling fluid in the annular space sufficient to clear obstructions. In the two-plug cementing method, the first spacer plug, which is drillable (e.g., plaster), is inserted and the casing capped. A measured volume sufficient to grout the casing in place is pumped in. The casing is then uncapped, the second plug inserted, and the casing recapped. A measured volume of water slightly less than the volume of the casing is then pumped into the casing until the second plug is pushed to the bottom of the casing, expelling the grout from the casing up and into the annular space. The water in the casing is maintained constant to prevent backflow until the grout has set. Pressure is then maintained for a minimum of 24 hours or until such time as a sample of the grout indicates a satisfactory set. Cement grout is used for this procedure with a minimum annular space thickness of 1.5 inches (38 mm) completely surrounding the casing.

Positive placement: Interior method with upper plug. After water or other drilling fluid has been circulated in the annular space sufficient to clear obstructions, grout may be placed by the upper plug casing method. In this method, a measured quantity of grout, sufficient to grout the casing in place, is pumped into the capped casing.

Because this grout is in direct contact with the drilling fluid in the cased borehole, there will be a narrow zone of weak grout between the drilling fluid and the good grout. The casing is uncapped, and a drillable plug, constructed of plastic or other suitable material, is inserted on top of the grout and the casing recapped. A measured volume of water, equal to the volume of the casing, is pumped into the casing, forcing the plug to the bottom of the casing and expelling the grout into the annular space surrounding the casing, and possibly diluted grout out at the surface.

Utilizing this method, the weak grout zone at the interface of grout and drilling fluid will not be located at the critical position at the bottom of the casing. The water in the casing is maintained under pressure to prevent back flow until the grout has set. Pressure is maintained for a minimum of 24 hours or until such time as a sample of the grout indicates a satisfactory set. Bentonite, neat cement or sand-cement grout can be used for this procedure, with a minimum annular space opening of 1.5 inches (38 mm) completely surrounding the casing.

Positive placement: Interior method with capped casing. In this methods, grout is placed by pumping or air pressure injection through the grout pipe installed inside the casing from the casing head to a point 5 feet (1.5 m) above the bottom of the casing (after water or other drilling fluid has been circulated in the annular space sufficient to clear obstructions). The grout pipe extends (airtight) through a sealed cap on the casing head of the well casing. The casing head is equipped with a relief valve and the drop pipe is equipped at the top with a valve permitting injection. The lower end of the drop pipe and the casing remain open.

Clean water is injected down the grout pipe until it returns through the casing head relief valve. The relief valve is then closed and injection of water is continued until it flows from the bore hole outside of the casing to be grouted in place.

This circulation of water is intended to clean the hole and condition it to better take the grout. Without significant interruption, grout is substituted for water and (in a continuous manner) injected down the grout pipe until it returns to the surface outside of the casing. A small amount of water, not to exceed 17 gallons per hundred linear feet (30 m) of 2-inch (51-mm) drop pipe may be used to flush the grout pipe, but pressure maintained constant on the inside of the grout pipe and the inside of the casing until the grout has set.

Pressure is maintained for at least 24 hours, or until such time as a sample of the grout indicates a satisfactory set. Bentonite, neat cement or sand cement grout may be used for this procedure with a minimum annular space of 1.5 inches (38 mm) completely surrounding the casing.

Continuous injection method. Grout may be placed by the float shoe continuous injection method (after water or other drilling fluid has been circulated in the annular space sufficient to clear obstructions). The bottom of the casing is fitted with a suitable drillable float shoe. Tubing or pipe is run to the float shoe and connected to it by a bayonet fitting, left-hand thread coupling, or similar release mechanism. Water or other drilling fluid is circulated through the tubing and up through the annular space outside the casing. When the annular space is clean and open, grout is pumped down the pipe or tubing and forced by continual pumping out into the annular space surrounding the casing. Pumping continues until the entire zone to be grouted is filled. The grout pipe is then detached from the float shoe and raised to the surface for flushing.

After the grout has set, the float shoe, back pressure valve, and any concrete plug remaining in the bottom of the casing is drilled out. Bentonite, neat cement or sand cement grout may be used for this procedure with a minimum annular space of 1.5 inches completely surrounding the casing.

Grout displacement method. The hole is filled with the estimated volume of grout required for the purpose intended. The casing fitted at the bottom with a drillable back pressure valve, metal plate, or similar seal, is lowered through the grout to the bottom of the hole. If necessary to maintain the bottom of the casing at the bottom of the hole, the casing is filled with water or drilling fluid, and in some cases by applying a load on the bottom with drill pipe. The load is maintained until the grout has set, after which the bottom plug is drilled out and the well deepened. Use of this method is limited to wells not more than 100 feet in depth.

Grouting with a temporary conductor casing. A temporary casing may be pushed or driven into place with drilling proceeding inside. The temporary casing should be four inches (100 mm) in diameter larger than the permanent casing. The permanent casing may be installed inside the temporary casing. A surface grout seal may be poured in the resulting annulus. Poured concrete may be used above the water table (largest aggregate <1/2 in.).

Dry grouting methods with driven casings. This method has been developed as a means of providing a more positive seal around driven casings. Dry granular bentonite, which swells upon contact with soil moisture, must be used. Field experiments by the Michigan Department of Health indicate that this method can provide an annular seal with a permeability on the order of 10^{-7} cm/sec around a driven steel casing with threaded couplings to a depth of at least 30 ft, however this may not be possible with a high water table, where the grout tends to lodge. Couplings have to be present as bentonite will not travel past the water table surface with smooth-bore welded casing.

In the single-driven pipe procedure, the bentonite is poured dry in a mound around the casing and replenished as grout is pulled along with the casing pipe as it is driven into the ground. Approximately 2.5 lb of bentonite per foot is used for a 4-inch diameter casing. More grout will be needed for larger casing diameters, with the amount needed being highly site-specific.

An alternative procedure involves feeding the dry granular bentonite inside a 10 to 15 ft (3-5 m) conductor casing. The level of the solid bentonite being fed in is kept below the level where casing joints are broken. This provides a larger-diameter surface grout seal, which optionally can be completed with concrete. The conductor casing is removed before grout is set.

Cement curing times before construction may be resumed: See Table 4.3 for average or minimum set times. Some authorities recommend an additional magin of safety, by allowing Portland Cement Type I mixtures to set 72 hours and Type III mixtures 36 hours.

Cement temperature management: Cement heat of hydration is a potential source of problems for plastic casing (see Chapter 3). The critical time is about 6 to 12 hr after grout emplacement when temperatures peak. Temperatures rise much higher in air-filled as opposed to water-filled casings due to the difference in heat-exchange capacities of air and water. Where feasible, filling the plastic casing with water and circulating it slowly with a pump helps to reduce the heat peak that reduces the hydraulic collapse resistance of the casing.

4.6 Centralizers

Centralizers are used to maintain a lowered or floated casing in the center of a drilled hole to assure an even annular space around the casing for a more complete grout seal. Centralizers must be made from plastic or stainless steel that will not corrode in contact with the grout, and sturdy enough to stand up to handling during insertion. Connection bands on the casing must hold the centralizer in place without slipping. The profile of the centralizer should permit movement in both vertical directions and allow for some rotation. Some centralizer options include (**Figure 9**):

(1) Centralizer at bottom of hole only.

(2) Centralizer at bottom of hole and other critical points. Centralizers are attached to the bottom of the casing at other critical grouting points such as zones of unsuitable water quality.

(3) Centralizers at 25-foot intervals. Centralizers are spaced at intervals not greater than 25 feet (7.5 m).

4.7 Grout Integrity Testing

There are presently no fool-proof field tests that can be performed to determine if a proper grout seal has been achieved. There are five most commonly used field tests:

(1) Static water level -- Measuring change in introduced water level in the casing vs. time.

(2) Water temperature -- More cement behind the casing will cause a larger temperature anomaly on a temperature log, if run within 24 hr (cement grout only).

(3) Water chemical composition -- Determining if cement is affecting ground water physical-chemical quality.

(4) Pressure -- Degree of pressure loss in sealed casing over time.

(5) Cement bond log test -- Acoustic log signal amplitude is dampened and signal time delayed.

Each of these has imperfections. However, under controlled conditions, the latter two tests may indicate in a general way the nature of the grout seal and its probable effectiveness. The proper choice of any field method depends solely on a clear

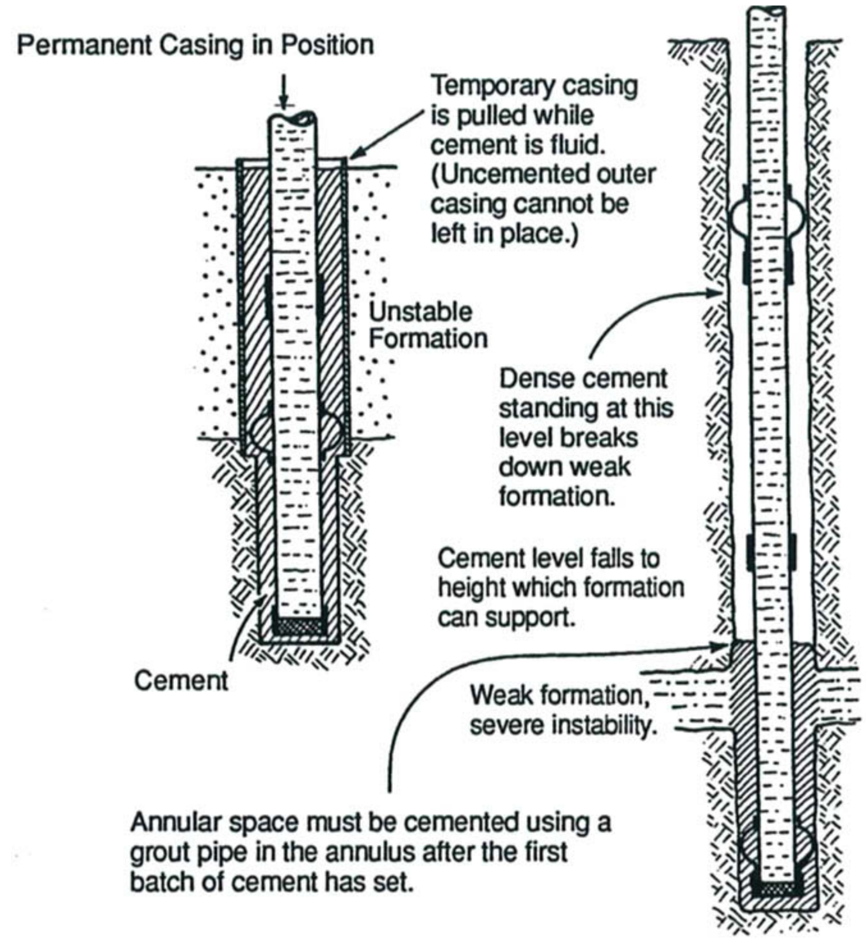


Figure 9. Use of Centralizers.

Figure is from the *Australian Drilling Manual*.

understanding of the specific hydrogeologic conditions and the construction techniques and materials employed in the grouting operation.

It should be noted that in situations where the effectiveness of the grouting procedure is of extreme importance, it is recommended that the grouted zone either be pressure tested or an appropriate cement bond log run if cement is used as grout. The interpretation of the data from such tests must be made by a log analyst with considerable experience with such data.

4.7.1 Acoustic Sonic Cement Bond Log For Cement Bond

This procedure is suitable for cement grout seals only although research is being conducted on bentonite seals. It is conducted upon completion of the cure of the grout (normally 72 hours but varying with materials and additives used). An acoustic sonic cement bond log is run in the borehole from the top to bottom to determine the quality of grout emplacements. The interpretation of the log should be made by a log analyst experienced with the interpretation of such data.

4.7.2 Pressure Testing Of Grouting Seal

Pressure testing of the grout seal may be employed following the appropriate time for curing of the grout, and may be used for either cement or bentonite grout seals. A pressure of 7 to 10 psi (48 to 69 kPa) of air is to be maintained within the well, without the addition of more air, for a period of not less than one hour. Any loss of air should be construed as indicating a defective seal, which would need to be corrected by resealing, followed by a pressure test at 15 psi (103 kPa or ~1 bar) for one hour.

References

American Society for Testing and Materials. *Annual Book of Standards, ASTM, West Conshohocken, PA.*

Anderson, K.E., 1979. Water Well Handbook, Missouri Water Well & Pump Contractors Assn., Belle, MO.

Australian Drilling Industry Training Committee, 1997. *Drilling: The Manual of Methods, Applications and Management. Lewis Publishers, Boca Raton, FL.*

Campbell, M.D. and J.H. Lehr, 1973. *Water Well Technology. McGraw-Hill, New York.*

Driscoll, F. 1986. *Groundwater and Wells, Johnson Division, St. Paul, MN.*

Gaber, M.S., and B.O. Fisher, 1988. *Michigan Water Well Grouting Manual. Michigan Dept. of Public Health, Lansing.*

Halliburton Services. undated. Recommended cementing practices (displacement mechanics). Houston, TX.

Harth, G. 1994. Bore cementing, part B. Drillers Seminar Handbook, 1994, Dalby 2 & 3 March 1994, Queensland Department of Natural Resources, Toowoomba, pp. 7.16-7.30.

Kurt, C.E., Johnson, R.C., and J.C. Warman. 1980. Engineering Performance of Thermoplastic Water Well Casings, WRRI Bulletin 44, Water Resources Research Institute, Auburn University, Auburn, AL.

Lutenegger, A.J. and D.J. DeGroot. 1993. Hydrologic properties of contaminant transport barriers as borehole sealants. *Hydraulic Conductivity and Waste Contaminant Transport in Soils, ASTM STP 1142, D.E. Daniel and S.J. Trautwein, eds., ASTM, Philadelphia, PA.*

NWWA Committee on Water Well Standards. 1975. *Manual of Water Well Construction Standards, EPA - 570/9-75-001. Office of Water Supply, Washington, DC.*

Roscoe Moss Co., 1990. *Handbook of Ground Water Development. Wiley-Interscience, New York.*

Smith, S.A., 1994. *Well and Borehole Sealing: Importance, Materials, Methods and Recommendations for Decommissioning, Ground Water Publishing Co., Westerville, OH.*

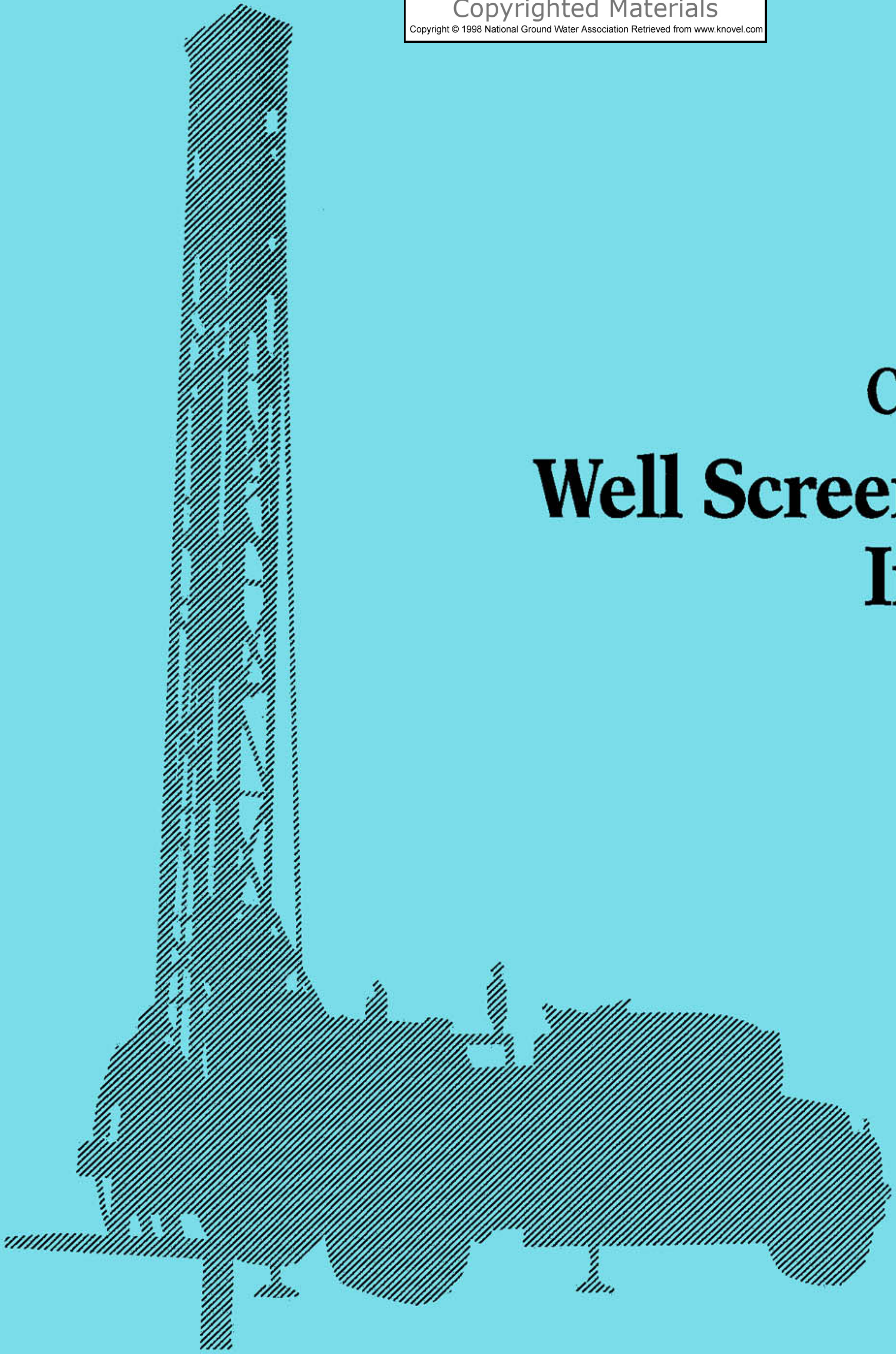
Smith, S. and C. Mason. 1985. Bentonite grouting. *Water Well Journal vol. 39 no. 2, pp. 35-37 (February).*

Stichman, R.W. 1990a. Shrinkage in cement-bentonite grouts. *National Drillers Buyers Guide. February 1990.*

Stichman, R.W. 1990b. Cement-bentonite grouts revisited. *National Drillers Buyers Guide. April 1990.*

Stichman, R.W. 1990c. Cement-bentonite grouts revisited. *National Drillers Buyers Guide. November 1990, p. 97.*

Ogden & Ruff, "Axial Strength of Bentonite Seals." *Department of Civil Engineering, Colorado State University, 1989.*



Chapter 5
Well Screens and Intakes

5 Well Screens and Intakes

To fulfill their function of providing water from aquifers, wells must allow access for water to the well casing. In wells developed in competent, non-sloughing rock formations, this intake is most often an open borehole of sufficient length and diameter to provide the optimal amount of water. In unconsolidated materials, and under certain conditions in consolidated materials, there must be openings opposite the water-bearing material to allow the water to flow into the well (**Figure 10**).

Long practice has permitted the development of expedient perforations in casings or open-bottom completions. However, for the purpose of permanent water supply, these methods do not adequately protect against the entrance of fine material during pumping. For this reason (along with initial hydraulic efficiency and long-term resistance to performance degradation), wells in unconsolidated and poorly consolidated materials should be completed with an engineered well screen. For water wells expected to have long service lives, a screen should be specifically engineered for the formation characteristics and water quality of the well.

5.1 Purpose, Types and Design of Screened Wells

Well screens are engineered intake structures that provide known slot openings to permit the entry of water while excluding formation particles. Screens are not designed to exclude the finest material. They are designed to hold out the coarser (more hydraulically transmissive) particle sizes, while relying on these particles to assist in excluding finer materials. This is done by developing the well in such a way that the natural and, in some cases, artificially introduced, coarse-grained materials, retain finer-grained materials while enabling the water to enter without excessive head loss. A certain percentage of finer materials will be removed through the casing during development.

5.1.1 "Natural" and "Artificial" Screen Packs

There are two basic types of wells in unconsolidated formations: (1) naturally developed wells and (2) those with an artificially introduced filter media.

Naturally developed wells are favorable in formations where the materials surrounding the screen are (1) highly uniform in grain size (homogeneous) but graded in such a way that the fine grains will not clog the screen, or (2) non-uniform so that the developed graded materials can form a naturally high-transmissive zone around the screen, called a "natural pack". In either case, during the process of development, the finer materials from the aquifer(s) are removed so that only the coarser materials are in contact with the screen.

In formations which lack coarse grained materials and grading is uniform, or stratified units that have zones of fine material, an engineered filter pack of selected

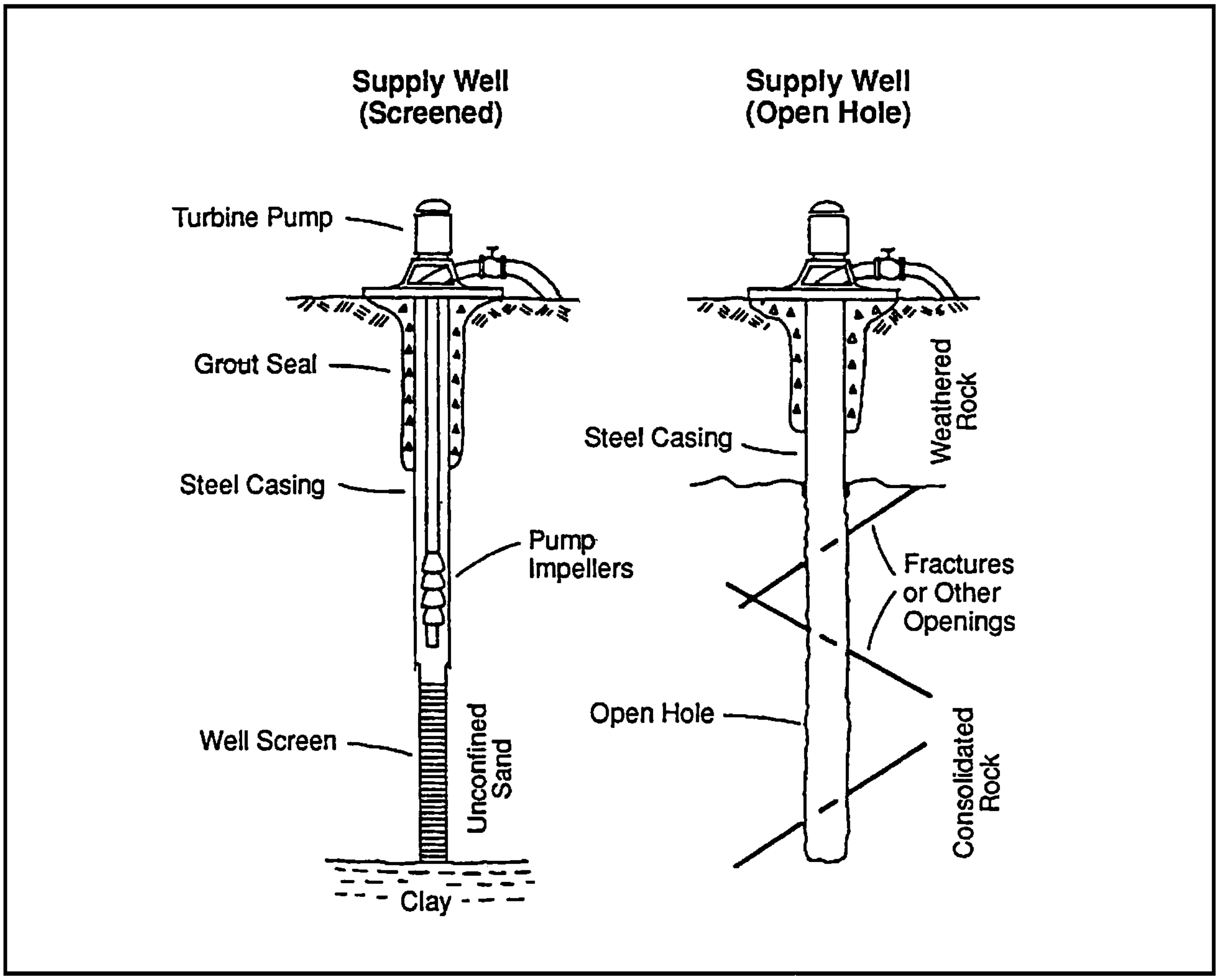


Figure 10. Screened and Open Borehole Wells.

Figure is from *Basic Ground-Water Hydrology* material having a grain size coarser than the natural formation is placed around the screen to accomplish this purpose. Such a well is called an artificially packed well or, in many areas, a gravel-packed well (because fine gravels are often used for packing). Such filters are described in Chapter 6.

Artificially packed wells are usually justified when the aquifer is (1) not homogeneous, (2) has uniformity coefficient less than 3.0, and (3) an effective grain size less than 0.01 inch, and a screen for a naturally developed well would not transmit the desired yield at an acceptable inlet velocity. They are also recommended in stratified aquifer situations in cases where more than 5 feet (1.5 m) of screen is required (and regardless of the homogeneity or uniformity coefficient of the aquifer formation). If aquifers in an interval are less than 5 feet (1.5 m) thick and separated vertically by less than 5 feet (1.5 m), the artificial filter should be used.

Artificial packs are sometimes needed to (1) stabilize well-graded aquifers having a large percentage of fine materials in order to avoid excessive settlement of materials above the screen, (2) where the overlying formations consist of thin beds of fine sand, clay and gravel, or (3) to permit the use of larger screen slots. In addition, in poorly consolidated rock that tends to disintegrate and cave at the time of pumping, an artificial pack may be needed.

5.1.2 Screen Inlet Area and Entrance Velocity Issues

Screen inlet area (see following) is an important and somewhat consideration in screen design. The well screen aperture openings, screen length and diameter (that together constitute inlet area) should be selected so as to have sufficient open area to transmit the desired yield without excessive head loss and flow velocity across the screen entrance.

There is an active debate on how high this velocity should be, which most likely depends on regional differences in formation material composition, water quality, and other factors such as potential for clogging biofouling. Recommendations (all based on empirical testing results) range all the way from <0.1 ft/sec to >4 ft/sec. Select an aperture (slot) entrance velocity equal to or less than 1.5 ft/sec to meet the standards of ANSI/AWWA A100. However, wire-wound screen doctrine recommends <0.1 ft/sec. It is good practice for screen design to be based on the recommendation of a local, experienced hydrogeologist or geological engineer using good drilling sample data, rather than adhering rigidly to a standard.

Gross open area of a screen is important to know in calculating the entrance velocity at a design pumping rate. Manufacturers can supply the figure for their screen design, however, part of the slot openings is blocked by the sand and gravel of the formation or pack. How high the percentage blockage is depends on the particle size of the aquifer and pack, as well as the slot opening geometry.

5.2 Screen Type, Aperture Size, and Material Selection

Screens for naturally developed wells are designed and selected based on a sieve analysis of the particle sizes of the formation material and its water quality. Filter-packed screens are selected to retain a filter pack selected to retain the formation (Chapter 6). Screens designs should provide an open area at least equal to the open area (porosity) of the surrounding formation, and provide design pumping volumes at an acceptable entrance velocity for the service life of the well. Screens design also must consider the mechanical loading that the screen will experience under installed conditions (tensile, collapse, shear forces) (**Figure 11**).

5.2.1 Screen Type Selection

Punched (with material removed) and slotted pipe. An economical screen can be manufactured from pipe that has been mechanically punched (with the material removed) or slotted by saw or mill. The slots should have as uniform spacing and size as practical. Slots or holes should taper outward (widen toward the interior). Due to corrosion concerns with metal pipe, slotted or punched construction should be limited to thermoplastic pipe material with sufficient strength to withstand the forces of installation and pumping when formed into screen. However, slotted or punched screens should not be relied upon for strength in deep or unstable settings. Slotted or punched screens generally should be completed with artificial filter pack (Chapter 6), with slot sizes selected for the filter pack.

Louvered-slot pipe. The screen consists of casing pipe that has punched openings in it where material has not been removed, but opens outward to form louvers. Louver design screens may be selected where strength is a primary criterion for selection. The openings need to be uniform and their total area such that the entrance velocity at the design condition must not exceed 4 feet per second per manufacturer recommendations (or 1.5 ft/sec per ANSI/AWWA A100). Louver screen pipe should be steel or stainless steel (an alloy selected to have sufficient corrosion resistance in the design aquifer environment when slotted). Louver screens should be completed with artificial filter pack, with the slots selected for the filter pack.

Continuous slot wire wound screen. The screen is constructed of wound wire, reinforced with longitudinal bars, the wire having a cross section that will form an opening between each adjacent coil of wire that is shaped in such a manner as to increase in size inward (tapers outward). The wire is firmly attached to the bars which are, in turn, attached to a coupling adapter. Wire-wound screens may be constructed of any weldable

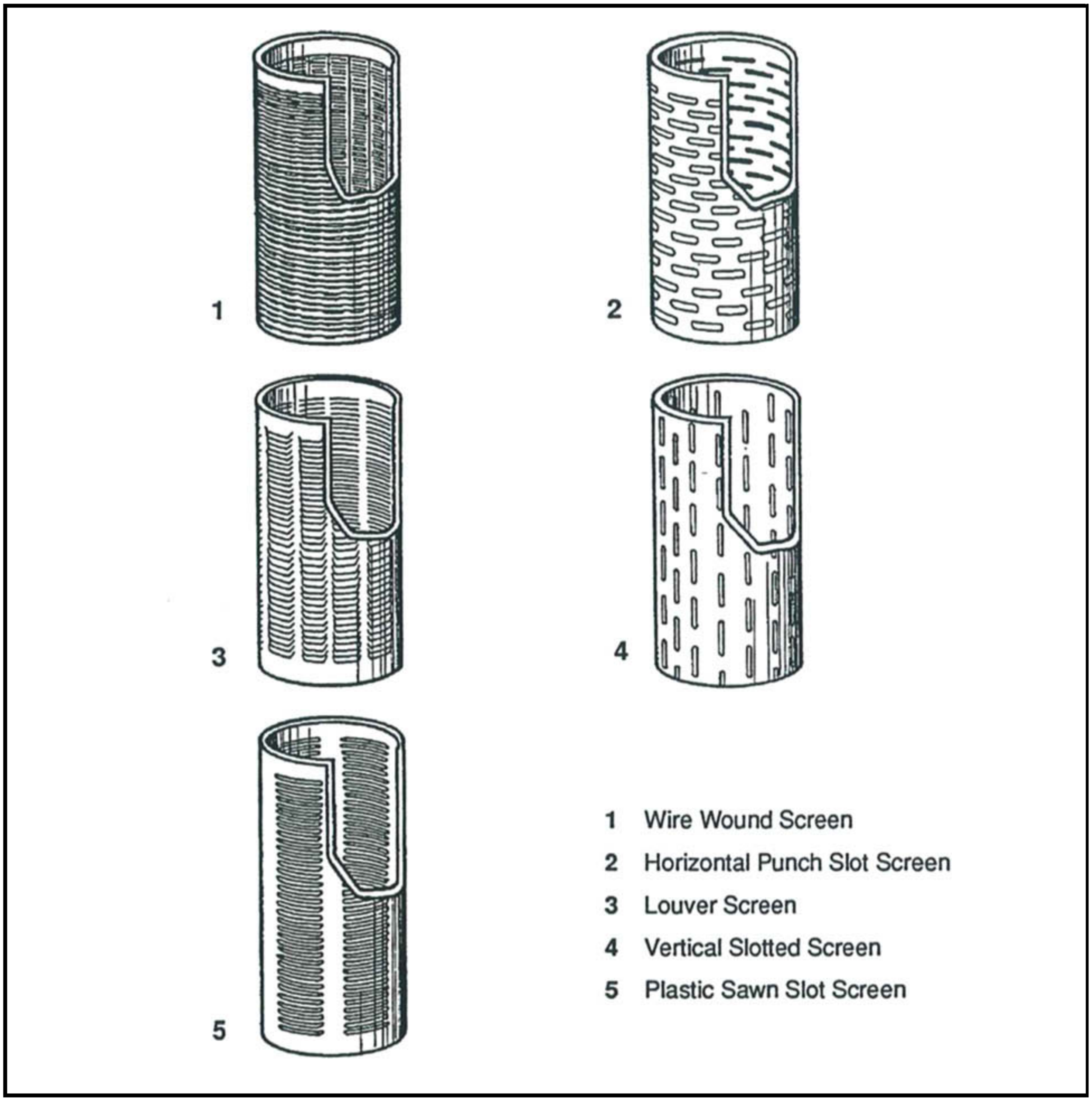


Figure 11. Screen Types.

metal (typically stainless steel) wire, reinforcing rods, and attachments. Mild steel construction is not recommended for water wells due to typically rapid corrosion (although mild steel screens have had acceptable service lives in selected circumstances with favorable environments). Alternatively, "wire-wrap" design screens may be formed or molded from thermoplastic or fiberglass-reinforced plastic. Wire-wound screens may be completed either naturally or artificially packed. Per manufacturer recommendations, the total open area should be such that the entrance velocity at the design condition should not exceed 6 feet per minute (0.1 foot per second).

Stacked-ring V-slot screens. A modification of the continuous slot design involves stacking of thermoplastic slot elements on vertical reinforcing bars. The slot segments are designed so that the slot openings widen toward the center (taper outward). This design combines relatively high hydraulic efficiency, variability in slot dimension, and strength.

Reinforced wire wrapped punched pipe. Another hybrid screen type designed for strength in natural developed well completions consists of perforated pipe reinforced with longitudinal bars and wrapped with wire. The wire should have a cross section forming an opening between wires that increases in size as the slot extends inward. The wire will be firmly attached to the bars which are attached to the pipe. The total open area should be such that the design entrance velocity does not exceed 6 feet per minute (0.1 foot per second). Wire, pipe, and bars should be constructed of a single type of stainless steel or plastic to minimize or prevent corrosion.

Artificial filter screen (precast). The screen is constructed by placing graded silica particles between an inner a slotted or wire-wound screen, and an outer screen to contain the filter sand. The sand may be bonded or just packed in place. The total open area should be such that the entrance velocity of water at the design condition should not exceed six (6) feet per minute (0.1 foot per second).

5.2.2 Screen Aperture Size

Aperture size selection for naturally packed well completions is based on the following criteria:

(1) Where the uniformity coefficient of the aquifer is greater than 6 and the aquifer is overlain by an essentially non-caving formation, the aperture size should be that which retains 30 percent of the aquifer sample.

(2) Where the uniformity coefficient of the aquifer is greater than 6 and the aquifer is overlain by a readily (finer textured) caving formation, the aperture size should be that which retains 50 percent of the aquifer sample, and the top of the screen should be two or more feet (~ 1 m) below the finer formation.

(3) Where the uniformity coefficient of the aquifer is 3 or lower and the aquifer is overlain by an essentially non-caving formation, the aperture size should be that which retains 40 to 50 % of the aquifer sample.

(4) Where the uniformity coefficient of the aquifer is 3 or lower and the aquifer is overlain by a caving, finer textured formation, the aperture size should be that which retains 60 percent of the aquifer sample, and the top of the screen should be two or more feet (~ 1 m) below the finer formation.

(5) For conditions between the extremes listed, interpolate between the extremes to obtain the proper screen aperture size, or follow manufacturer recommendations.

(6) Where a formation to be screened has layers of differing grain sizes and gradations, use the following rule: If the 50 percent size of the coarsest layer is less than 4 times the 50 percent size of the finest layer, the aperture size is selected on the basis of the finest layer, or for each specific layer as indicated in 1, 2, 3, 4, or 5 (above). Alternatively, consider an artificially filter packed completion.

(7) If the water is corrosive or the accuracy of the chemical analysis is in doubt, select an aperture size that will retain 10 percent more than is indicated in the above paragraphs.

(8) Where fine sand overlies coarse sand, use the fine sand size aperture for the top two feet (61 cm) of the underlying coarse sand. The coarse size aperture should not be larger than twice the fine sand size.

Where an artificial filter is to be used the aperture size selection criteria are provided in Section 6.

5.2.3 Screen Material Selection

To reduce the possibility of corrosion, the well screen and its end fittings should be fabricated of the same material (Type 304 or Type 316 stainless steel, plastic, reinforced fiberglass, etc.). For all materials corrodible in water (metals), corrosion of a screen will be greater than for a similar mass of casing pipe due to (1) larger surface area, (2) metal alteration during manufacture, and (3) stress points from installation.

The material choice should be based on analyses of the physico-chemical and biological quality of the water and prior knowledge of the local water quality. A prudent choice would be to select materials to withstand the most corrosive water produced by nearby wells to account for changes in well water quality due to biochemical "maturing" over time. Blank sections used in combination with screens may or may not be of the same material as the screens. However, potential corrosion damage should be considered in such installations, and noncorrodible materials used whenever feasible. Installations with short blank sections of carbon steel placed between long screens of stainless steel are more at risk of corrosion damage, usually occurring at the contact point of the two material types. Passivation of the carbon steel usually inhibits corrosion before damage occurs, unless microbial corrosion is an active mechanism in the formation.

5.3 Screen Location, Length, and Diameter

The well screen(s) should be set at an elevation (or elevations in multiple zones where permittable) that approximate the best producing zone or zones. The screen setting should be based on results of an analysis of the formations penetrated as recorded in the driller's log, stratigraphic or boring log, and geophysical logs (if available) .

5.3.1 Screen length

Screen length should be selected by the following criteria to obtain the optimal yield from the water supply well:

A. Formation being screened is homogeneous and the ground water under artesian pressure:

(1) If less than 25 feet thick, use a length equal to 70 percent of the formation thickness.

(2) If between 25 feet and 50 feet thick, use a length equal to 75 percent of the formation thickness.

(3) If more than 50 feet thick, use a length equal to 80 percent of the formation thickness.

The screen may be centered in the unit, or slot zones placed opposite preferred zones.

B. Formation being screened is not homogeneous and ground water under artesian pressure:

Select the more permeable sections from:

(1) Sieve analyses.

(2) Geophysical logs.

(3) Driller's logs (estimates of fluid loss).

(4) Laboratory tests of permeability, if representative samples are available.

(5) Visual inspection of samples of the formation, or borehole television or photographic coverage of entire interval (where available -- usually stable consolidated formations).

C. Formation being screened is homogeneous and the ground water unconfined (water table conditions): Screen the lower one third of the formation.

D. Formation being screened is not homogeneous (highly stratified) and under unconfined conditions: Common practice is to select the screen length as one third the aquifer thickness. The screen is usually set in the lowest, most permeable sand.

Hydrological well tests should be made to establish the location of the most productive zone (Chapters 1 and 9).

5.3.2 Screen Diameter

The diameter of a screen is usually not a critical factor for specific capacity but is an issue in designing to compensate for expected screen encrustation or corrosion. Doubling the diameter of a screen generally only increases the specific capacity by 7 to 10 %. The primary advantage to increasing diameter is to increase the total intake open area and to decrease the velocity of flow up the screen (velocity should be 5 ft/sec or less).

Secondary effects of these design criteria are (1) optimal hydraulic efficiency and (2) longer time until natural well performance deterioration becomes apparent. If a lesser yield is specified, such as for a domestic well, the well screen may be situated for optimal performance, water quality and acceptable screen entrance velocity.

5.4 Method of Screen Installation

Suspended from surface method. The screen (with closed bottom) is attached by an approved manner to the casing and lowered into the fluid-filled open borehole to the design depth. In no instance should it be driven or forced. The casing and screen unit is suspended from the surface until the formation has collapsed against it or until a filter material or formation stabilizer has been added, and the screened area developed. This is the most practical method for artificial filter pack installations (**Figure 12**).

Washing method. The screen is fitted with a self-closing valve on the bottom and attached to the well casing. A smaller pipe is placed in the screen and fitted to the self-closing valve. The screen with its casing is then "washed" into place by pumping clear water or the lowest possible weight drilling fluid through the inner pipe until the screen is in position (**Figure 13**).

Pull back method. The well casing is driven or lowered through the formation to be screened and cleaned out to the level where the bottom of the screen is to be placed. The screen is fitted with a friction or "K" packer, designed to seal against the casing, but to permit the screen to be lowered to the bottom of the casing (the interior of the casing should be smooth and straight). The screen and packer are then be lowered to the completion level by means of a removable cable or drill stem apparatus firmly hooked or threaded to the screen. The screen is placed by gravity under conditions that limit the rate of descent. After the screen is in its proper location, a heavy steel bar, pipe, or drill stem may be set on the screen bottom to hold it down and the casing raised until the screen is exposed to the aquifer with the packer or seal lapped 12 inches (300 mm) into the casing, forming a watertight seal (**Figure 14**).

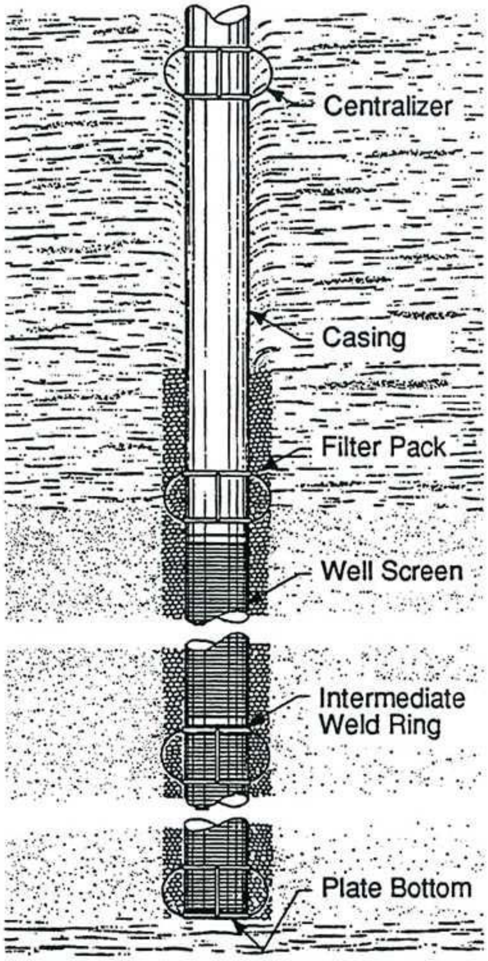


Figure 12. Artificially Filter-Packed Well.

Figure is from *Groundwater and Wells.*

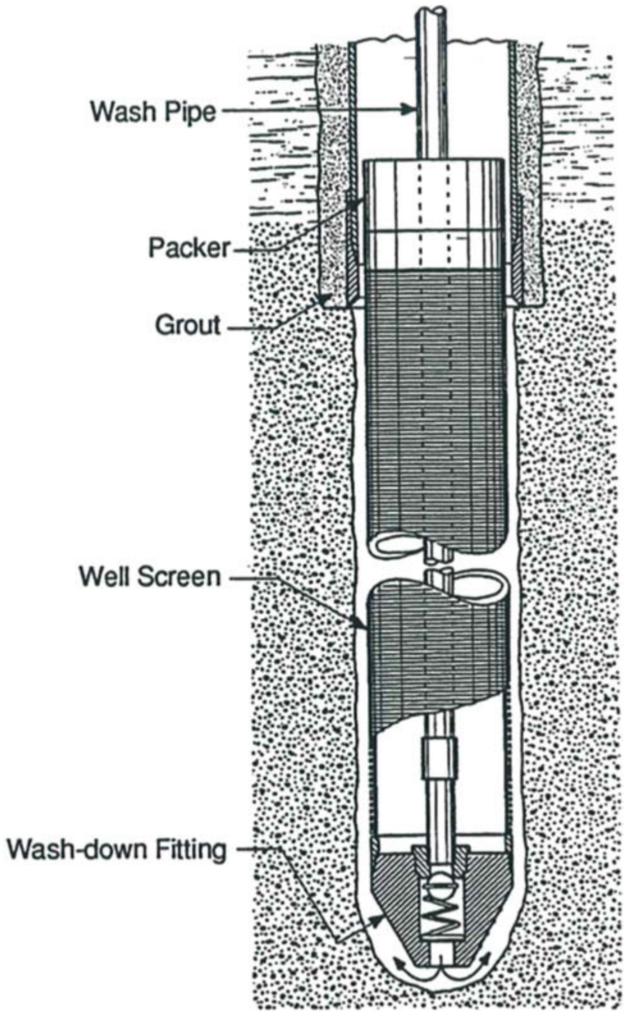


Figure 13. Wash-down Method.

Figure is from *Groundwater and Wells*.

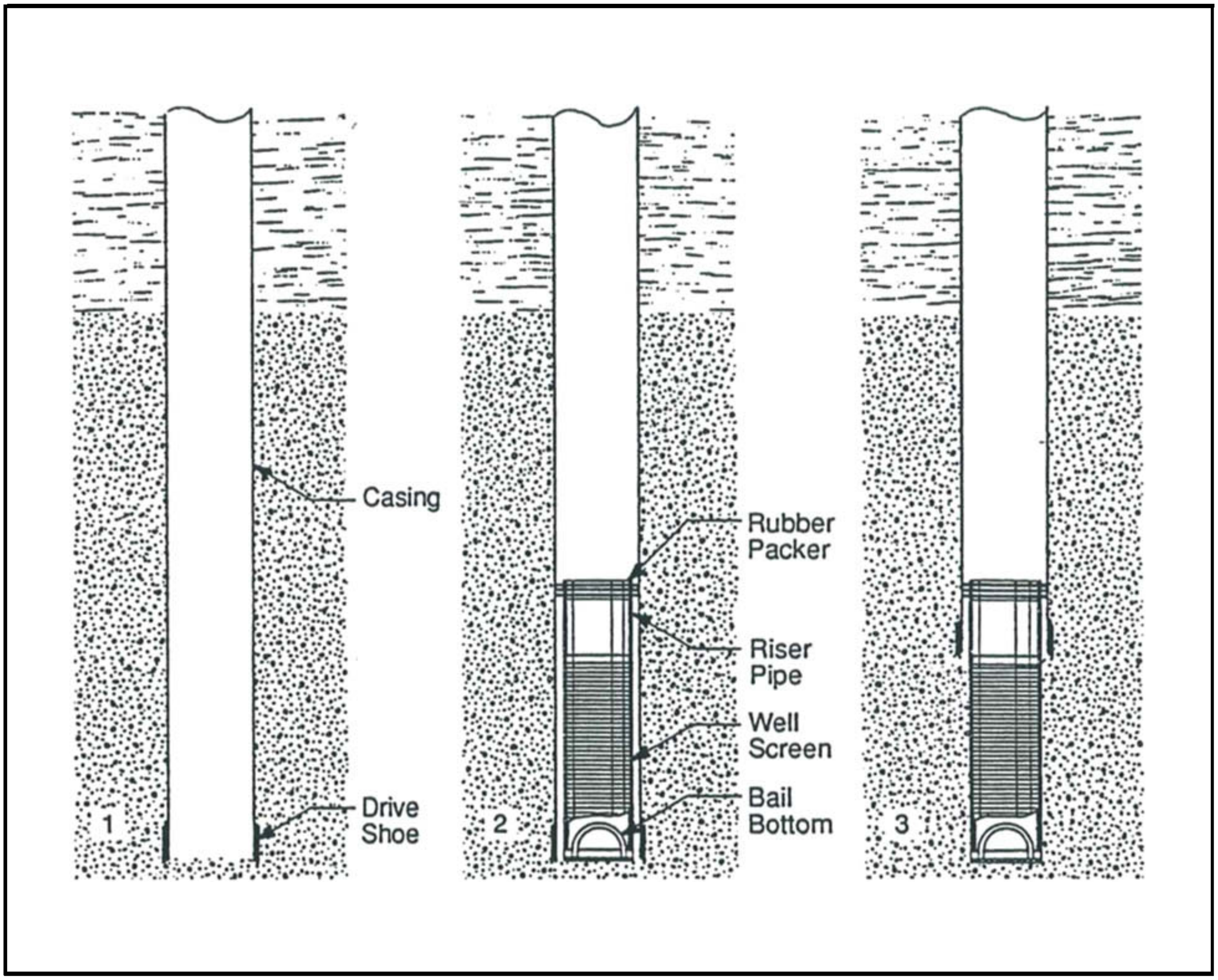


Figure 14. Pull-back or Telescoping Method.

Figure is from *Groundwater and Wells*.

Driven-through casing method. The casing is set at a level immediately above the top of the formation or portion of the formation to be screened. A well point screen fitted with a friction or "K" packer (**Figure 15**) is lowered through the casing to the top of the formation using the drill stem or lowering hook. The screen is then seated in the formation by driving it to the desired depth and sealing it to the casing (Section 5.6). Driving force and screen strength should be such that screen entrance slots are not distorted.

Bailed-through casing method. The casing is placed at a level immediately above the top of the formation or portion of the formation to be screened. A piece of plain tubing of the same material as the screen and several feet long is attached to the bottom of the screen. A similar piece, long enough to lap 3 feet (1 m) into the casing, and a packer are attached to the top of the screen. The screen and attachments are then be lowered through the casing to the top of the formation by cable and hook or an attached string of pipe. The screen is then be put into place by-bailing the aquifer material out from under it and allowing it to settle into the design position. After the screen is in place, it is sealed to the casing and the bottom tubing plugged with nondegradable material.

Bailed or air jetted through casing method. The casing is placed at a level immediately above the top of the formation or portion of the formation to be screened. A bail-down shoe is attached to the screen and a line of bail-down pipe attached to the shoe by a right and left-hand coupling, or similar release device. The screen is then be lowered by the bail-down pipe to the top of the aquifer and then bailed into place or seated by blowing air through the bail-down pipe. When the screen has reached the desired depth, the bail-down shoe is plugged at the bottom by an approved method, and the screen sealed to the casing.

Washed-through casing method. The casing is placed at a level immediately above the top of the formation to be screened. The screen is fitted with a self-closing valve at the bottom and a small inner pipe attached to the valve. The screen is then lowered through the casing by any means deemed appropriate. The screen is washed into place by pumping clear water or lowest-weight practical drilling fluid through the inner pipe (**Figure 16**). When in place, the screen is then sealed to the casing.

In all instances, fluids used should be appropriate for a potable water installation, and any additives used should not promote biofouling or corrosion, and be completely removable by conventional development methods. All screen installations are finished by appropriate well development until optimal performance is achieved (see Section 8).

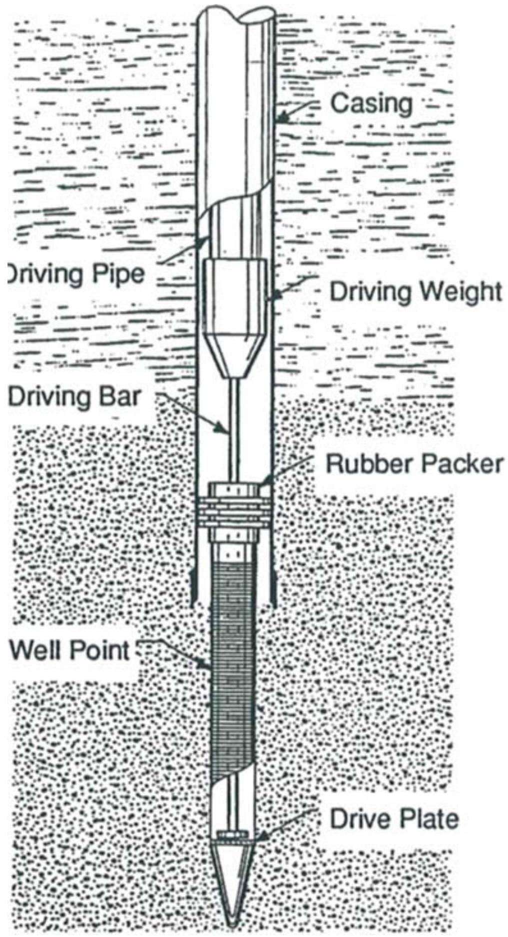


Figure 15. Drive-Through Method.

Figure is from ***Groundwater and Wells***.

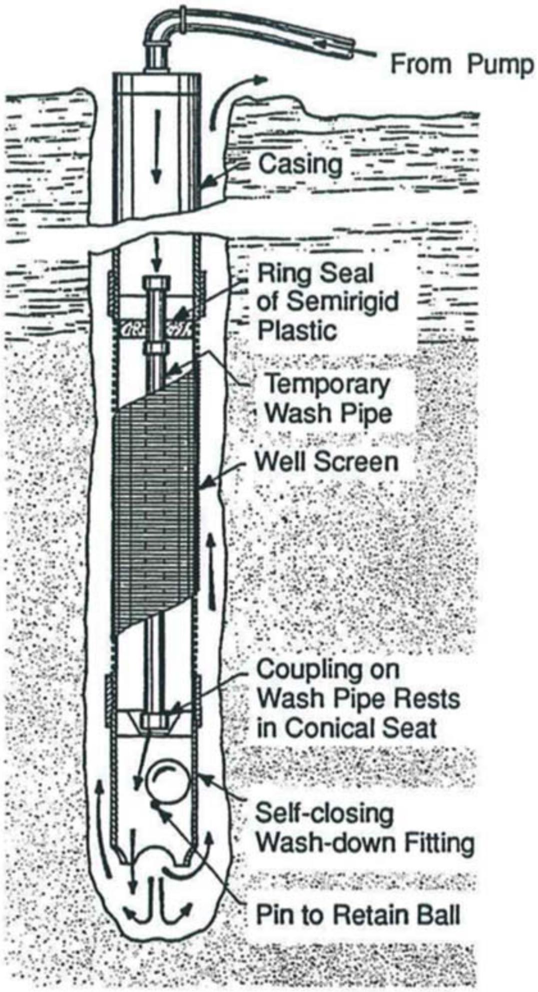


Figure 16. Bail-Through Casing Method.

Figure is from *Groundwater and Wells*.

5.5 Method of Joining Screen Sections

Screen sections for a single interval may be joined by threaded and coupled or spline-lock joints, socket-type fittings and solvent welding, or electric arc or acetylene welding. Welding rods, solvents (where used) and methods recommended by the screen manufacturer shall be employed. Resulting joint(s) must be straight, sand tight and retain 100 percent of the screen strength.

If joints are to be welded, the welding rod must be made of material suitable for joining corrosion resistant materials in a manner so as not to reduce that resistance. Heat distortion of the welded metal and weld spatter should be kept to a minimum to reduce corrosion attack. Where dissimilar metals are joined a dielectric coupling may be indicated where there is a history of corrosion problems.

Blank spacers for multiple-interval screens usually should be of the same material as the screen or a material noncorrodible in water (e.g., plastic or fiberglass). Blanks should be joined to the screen by the threaded and coupled or spline-lock joints, socket-type fittings and solvent welding, or electric arc or acetylene welding using materials and procedures described in Chapter 3 for casing. The resulting joints must be straight, sand tight and retain 100 percent of the screen strength (**Figure** 17).

5.6 Method of Connecting Screen to Casing

Screens must be attached to the casing so that a positive and permanent sand-tight seal results which excludes grout, or any undesirable leakage from the outside. The joint should be mechanically strong to withstand long-term use and future well redevelopment.

Mechanical or welded joint. The casing and screen are joined by threaded and coupled or spine-lock joints, socket fitting and solvent welding, or electric arc or acetylene welding using materials and procedures specified for casing in Section 3. The resulting joints must be straight, sand tight, and retain 100 percent of the screen strength.

Neoprene or rubber seal. A neoprene or rubber friction seal or "K" packer especially made for this purpose (designed to be self-sealing (sand-tight) in the well casing) is attached to the top of the screen.

Cement fill in annulus. The casing is joined to a pipe extending above and attached to the screen by filling the space between them with neat cement for a vertical distance of at least 3 feet (1 m) and at least 1 inch (2.5 cm) thick through the cement seal.

5.7 Methods of Sealing Screen Bottom

The bottom of a screen should be closed to force water through the engineered screen. If it is to bear the load of the casing and screen, it should be mechanically strong enough to withstand distortion. All bottom closing materials should be permanent and resist deterioration or dislodgment under working conditions.

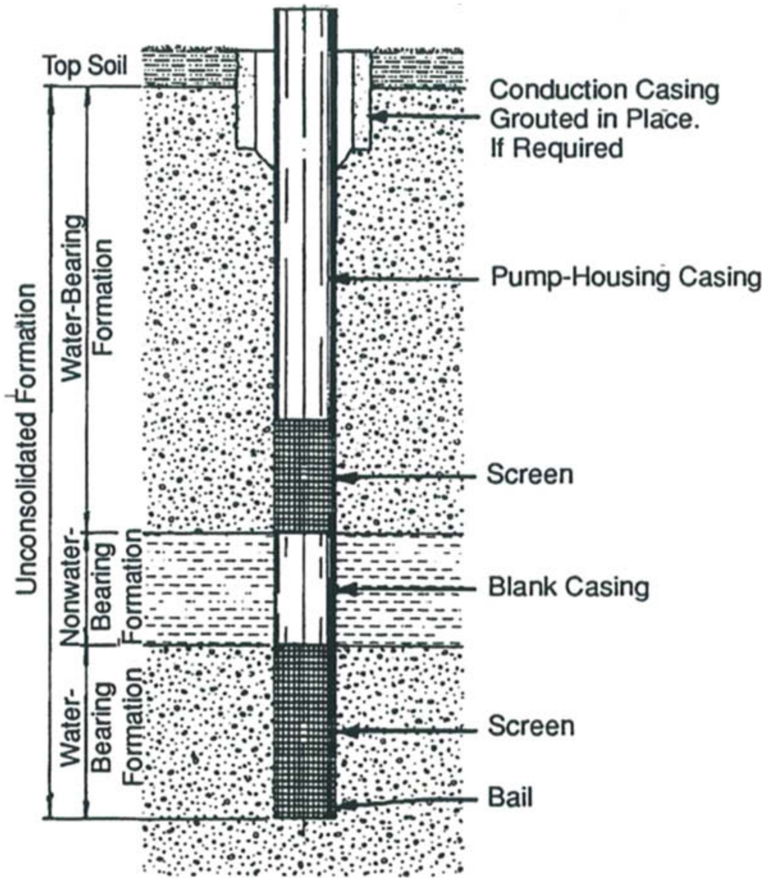


Figure 17. Casing and screen placed in open hole without forcing. Blank casing in nonwater-bearing formation optional.

Figure is from the *AWWA Standard for Water Wells (ANSI/AWWA A100-84)*

Fabricated plug method. The bottom of the deepest screen section is sealed with a threaded or welded plate, plug or point made of the same material as the screen body.

Self-closing valve method. The bottom of the deepest screen section is sealed by means of a self-closing valve on the bottom of the screen.

Bag cement method. A pipe extension at least 4 nominal screen diameters in length is attached to the bottom of the screen (the drill hole having been deepened below the aquifer interval to accommodate the extension). The bottom is then sealed by lowering into the extension pipe sufficient dry cement in small cloth bags to fill it to a depth of at least 3 nominal diameters, packing it firmly into place.

5.8 Open Borehole Completions

While not as complicated as screen completions, open borehole completions also have design considerations. Open boreholes are preferred in competent rock aquifers that do not slough sand, silt or clay particles. Where a screen is not needed for well integrity, the well operator does not have to contend with the initial cost and head loss, and screen clogging or corrosion over time.

The open borehole segment of the completed well should provide enough length and diameter to produce sufficient water from available fracture zones. The casing and casing grout seal should extend below upper poor quality zones and also below the pumping water level to minimize cascading during drawdown. Where a deeper zone will supply sufficient water, upper zones should be cased off to avoid cascading, biofouling and water quality degradation. If not necessary for production, deeper poor water quality zones encountered during drilling should be cemented off.

Open borehole zones should be developed, just as screened completions are developed. Refer to Section 8.

References

American Society for Testing and Materials. *Annual Book of Standards, ASTM, West Conshohocken, PA. Specifically:* D 5092 Standard practice for design and installation of ground-water monitoring wells in granular aquifers.

American Water Works Assn. *AWWA Standard for Water Wells, ANSI/AWWA A100, AWWA, Denver, CO.*

Australian Drilling Industry Training Committee, 1997. *Drilling: The Manual of Methods, Applications and Management. Lewis Publishers, Boca Raton, FL.*

Borch, M.A., S.A. Smith, and L.N. Noble. 1993. *Evaluation, Maintenance, and Restoration of Water Supply Wells. American Water Works Association Research Foundation, Denver, CO.*

Driscoll, F. 1986. *Groundwater and Wells, Johnson Division, St. Paul, MN.*

Helweg, O.J., V.H. Scott, and J.C. Scalmanini, 1984. *Improving Well and Pump Efficiency, American Water Works Assn., Denver, CO.*

NWWA Committee on Water Well Standards. 1975. *Manual of Water Well Construction Standards, EPA - 570/9-75-001. Office of Water Supply, Washington, DC.*

Roscoe Moss Co., 1990. *Handbook of Ground Water Development. Wiley-Interscience, New York.*

Williams, D.E., 1985. Modern techniques in well design, *Journal AWWA, 77(9): 68-74.*

Chapter 6
Well Filter Construction

6 Well Filter Construction

An artificial filter pack (often referred to as a gravel pack) consists of a clean sand or gravel of selected grain size and gradation which is installed in the annular space between the screen and the wall of the well bore. The filter has a larger average grain size and usually a smaller coefficient of uniformity than the aquifer material. This permits use of a larger screen slot size and consequent larger open area so that entrance velocity is lowered and head losses to the well are reduced. The filter has a considerably higher permeability than the formation so that the effective diameter of the well is increased to some extent. Both these factors tend to increase the efficiency and specific capacity of a well and tend to reduce the possibility of excess sand production.

6.1 Filter Selection and Construction Practice

The grain size and gradation of the filter are selected to stabilize the aquifer material and to permit only the fine fractions to move into the well during development. Thus, after development, a correctly filtered well is virtually "sand free" (free of formation particles), and a narrow annulus of the formation adjacent to the filter has its permeability increased to some degree.

Generally, the thinner the filter the better. Actually a correctly designed filter 0.5 inch (13 mm) thick would be adequate, but the mechanical difficulties of satisfactorily placing such a filter preclude its use. From a practical standpoint, filter packs are usually about 3 to 8 inches (75 to 200 mm) thick. Planned borehole diameter has to be increased accordingly to accommodate the filter pack annular size. Thicker filter packs present problems in developing (and later rehabilitating) wells properly, and encourage vertical flow in the pack.

Wells in some unstable, weathered rock aquifers benefit from a formation stabilizer even if fine sand or silt pumping is not a problem. In this case, a stabilizer pack prevents dislodgment of rock fragments into the well, or possible crushing or perforation of the intake screen. A stabilizer pack may also prevent overlying fine-grained materials from closing off aquifers. While the purpose for the filter pack varies from that of a filter designed for exclusion of fine particles, general pack selection and installation criteria apply.

6.1.1 Filter Pack Selection

Filter packs should be designed to retain the formation material as follows:

(1) Construct sieve analysis curves for the aquifer intervals selected for screening. The filter pack grading is based on the layer with the finest material. In some cases where layers are particularly fine, it is beneficial to blank off these zones.

(2) Multiply the 70-percent size of the selected sediment by a factor between 4 and 10 depending on the uniformity coefficient. Use 4 to 6 if very uniform and the 40 % retained size is 0.010 (0.25 mm) or less. Use a 6 to 10 multiplier in semi-consolidated or consolidated units where there is a low uniformity coefficient. Place the result of this multiplication as the 70-percent size of the filter material (**Figure 18**).

(3) Draw a curve with a uniformity coefficient of < 2.5 intersecting the 70-percent point on the formation sieve analysis curve for the selected interval.

(4) Select a commercial filter pack closely matching this curve and having the right physical and chemical characteristics.

(5) The screen slot size selected should retain 90 % of the filter pack.

(6) Calculate the volume of filter pack needed.

The filter pack should consist of clean, well-rounded grains that are smooth and uniform. The filter material should be siliceous (recommended Mohs Scale hardness > 7) with a limit of 5 per cent by weight of calcareous material (determined by testing with HCl). The filter should be obtained from a known source with adequate quality control and should consist of hard, rounded particles with an average specific gravity of not less than 2.5. Not more than 1 percent by weight of the material should have a specific gravity of 2.25 or less. The uniformity coefficient of the filter pack mix should be no more than 2.5 (**Figures 19A, B, C**).

The filter should contain not more than 2 percent by weight of thin, flat or elongated pieces (pieces in which the largest dimension exceeds three times the smallest dimension) determined by hand picking; and should be free of shale, mica, clay, organic soil components (e.g., topsoil or peat) and organic impurities of any kind. The filter particles should contain no iron or manganese, or other constituents in a form or quantity that will adversely affect the water quality. Filter pack material should be washed and dried.

Samples of filter material to be furnished by a supplier should be tested prior to commitment for use on site. Samples of filter material, including sieve analysis, must be submitted in advance of delivery and placement. The filter material should be delivered to the site upon approval in a form acceptable to the well contractor in time for installation with the casing and screen. Filter material should be protected from the elements and from contact with the soil or other sources of contamination by a suitable covering.

6.1.2 Filter Pack Placement

The annular space between the well screen and the wall of the hole should be filled with clean, disinfected, selected filter material to form a bed around the well screen. Every precaution should be taken which will ensure the proper placing of the filter

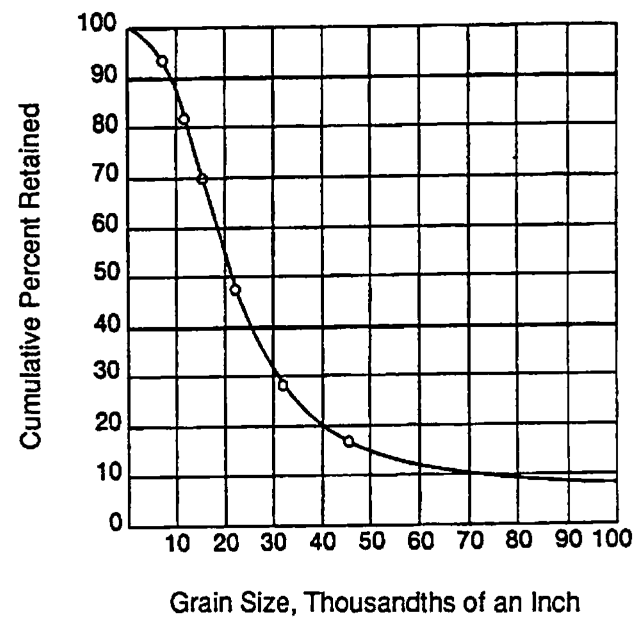


Figure 18. Plotting the percent of the sample retained on each sieve provides a graphic illustration of the grain-size distribution.

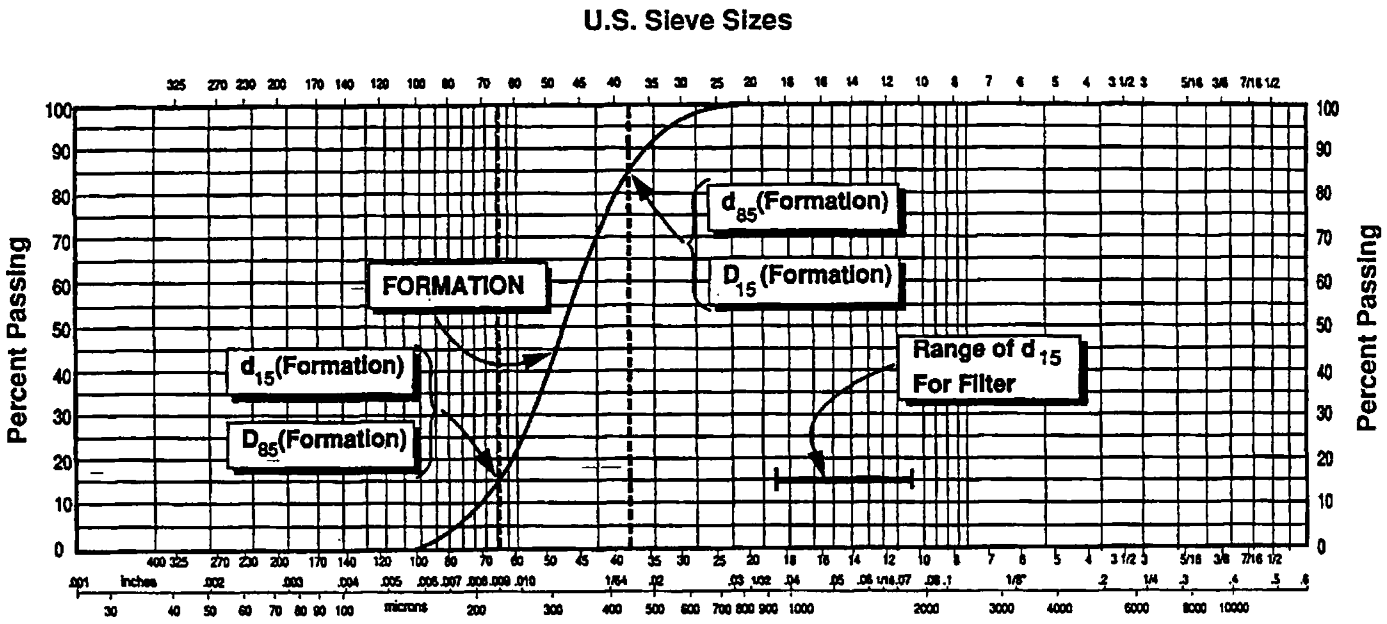


Figure 19A. Filter Pack Selection.

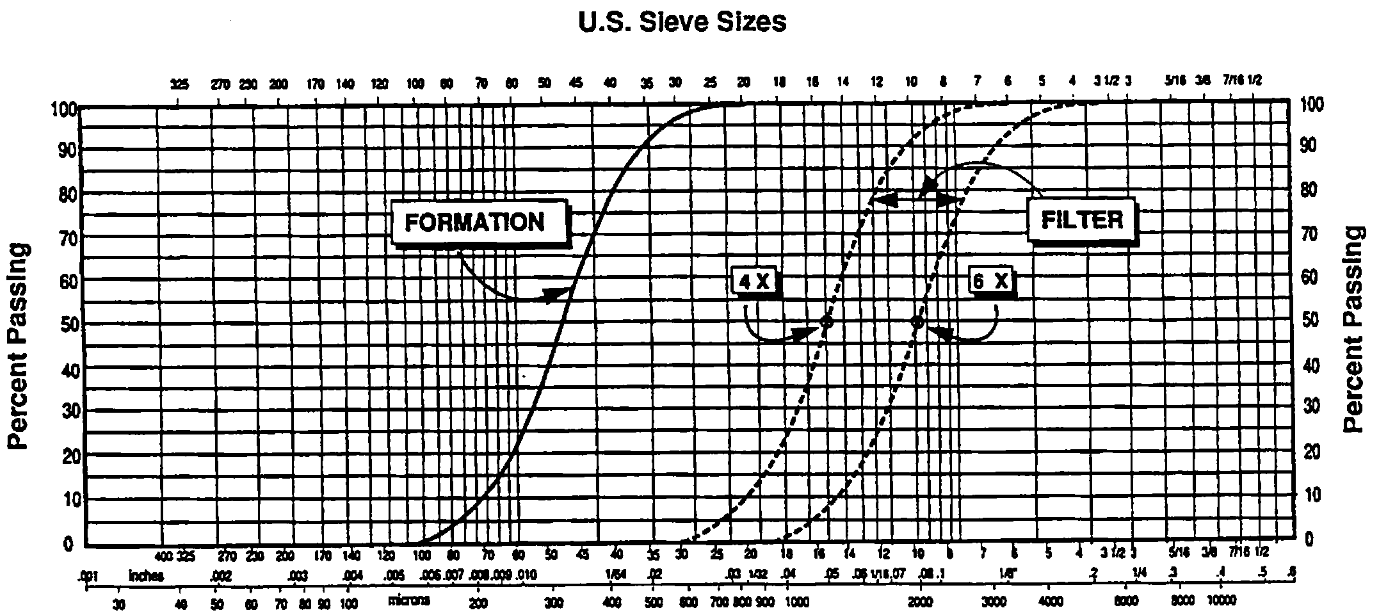


Figure 19B. Filter Pack Selection.

Figures are from the *Handbook of Ground Water Development*.

U.S. Sieve Sizes

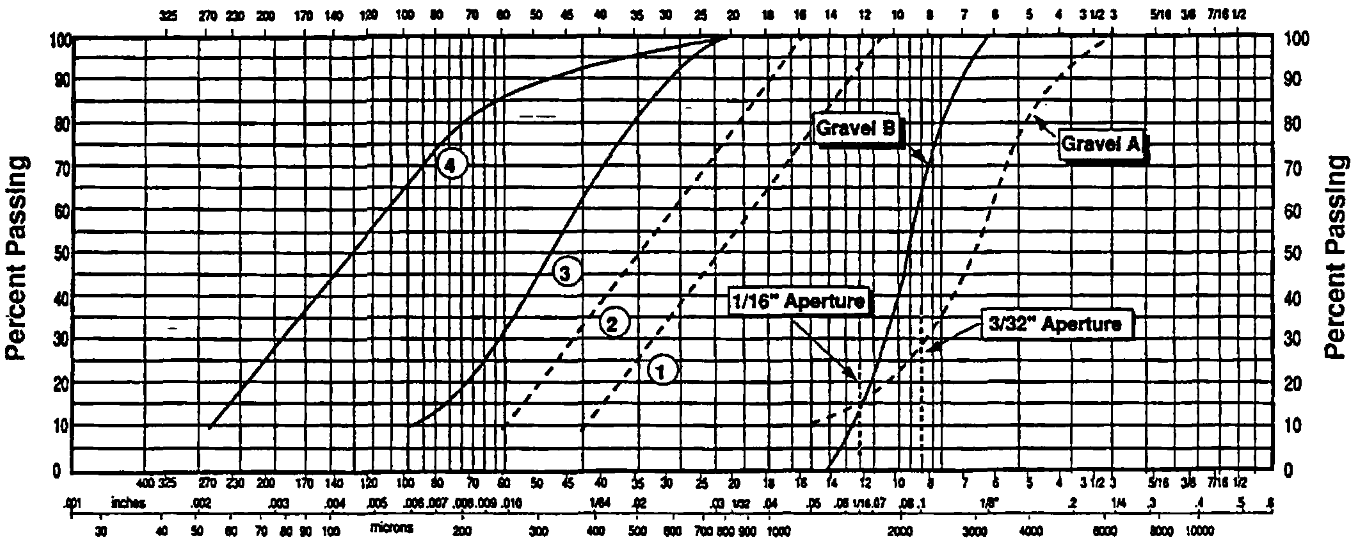


Figure 19C. Gravel Pack Selection.

Figure is from the *Handbook of Ground Water Development*.

material continuously from the bottom of the well to a point above the well screen without separation of the materials as they are introduced into the well.

In a shallow well with 6 inches or more of annular space and 5 or 6 feet (1.5 or 1.8 m) of screen, the filter material can be poured in to give a satisfactory installation. This should be tested and a switch made to tremie pouring if difficulty arises.

In deeper wells with longer screens, the pack should be placed with great care to avoid bridging and segregation of the filter material. If placed by gravity, the material should be introduced at a metered, uniform rate. Frequently it is placed via a tremie pipe. Other effective way of placing the filter pack include washing or pumping the filter material in with water (as a slurry). Once installation of the filter material is started, it should proceed at a uniform rate until completed from the bottom of the well to a selected point above the screen. Check the depth of the pack periodically and compare the volume introduced to the expected volume needed.

If more than one grade of filter material is to be installed in the well simultaneously, the grades of gravel should be mixed at the surface before introduction into the well. Regardless of the method of mixing used, there must be no chance of contamination of the filter material during mixing.

Documentation of the filter pack should include:

(1) Supplier's name, address and source location

(2) Size designation

(3) Gradation curve or percent passing each sieve

(4) Gravel packed intervals

(5) Quantity of gravel placed

(6) Chemical composition of gravel.

Per ANSI/AWWA A100, the filter pack material should be disinfected during installation. In single-aquifer water supply wells, the filter pack material should be disinfected by maintaining and circulating a chlorine residual of at least 50 mg/L, as tested at suitable intervals. In multiple-aquifer completions, the pack may be disinfected by adding 0.5 lb (0.23 kg) of granular or tablet calcium hypochlorite per ton of gravel, distributed as uniformly as possible. Filter pack may also be presoaked in a chlorine solution prior to introduction into the well bore. A disinfection tube run from the surface to the gravel pack provides another means of disinfection that can also be used later for maintenance treatment.

When placing a filter in a well, care must be taken to assure that any filter material that enters the well screen during placement is removed during development.

6.2 Length of Artificial Filter

The filter material should extend a distance at least 2-1/2 times the largest diameter of the well above any screen to the base of the screen interval. Filter packs can settle 10 to 20 %, especially with long screens. The length of settlement due to filter pack compaction in the annulus should be estimated and compensated for. For example: a filter pack is to be installed with a 12-in. screen, 50 ft in length, in a 24-in. hole. The "2-1/2 times" rule would provide five ft (24 in. x 2.5) of filter pack reserve above the screen top. If there is 20 % settlement, the top of the pack would be five feet below the top of the screen.

Finer sand should be placed between the top of the filter pack and the grout seal, according to state and local regulations. The size of the barrier sand should be such that it will not infiltrate into the filter material.

For multiple-zone completions, finer pack may be installed between defined pumping zones to prevent vertical channeling in the filter pack. The filter material should extend from a point equal in distance to at least 2-1/2 times the largest diameter of the well below the lowest screen to the same distance above the highest screen.

References

American Society for Testing and Materials. *Annual Book of Standards, ASTM, West Conshohocken, PA. Specifically:*

D 421 "Standard method for dry preparation of soil samples for particle size analysis and determination of soil constants."

D 422, "Standard method for particle-size analysis.

D 5092 "Standard practice for design and installation of ground-water monitoring wells in granular aquifers".

American Water Works Assn. *AWWA Standard for Water Wells, ANSI/AWWA A100, AWWA, Denver, CO.*

American Water Works Assn. *AWWA Standard for Gravel Pack Installations, (component of ANSI/AWWA A100), AWWA, Denver, CO.*

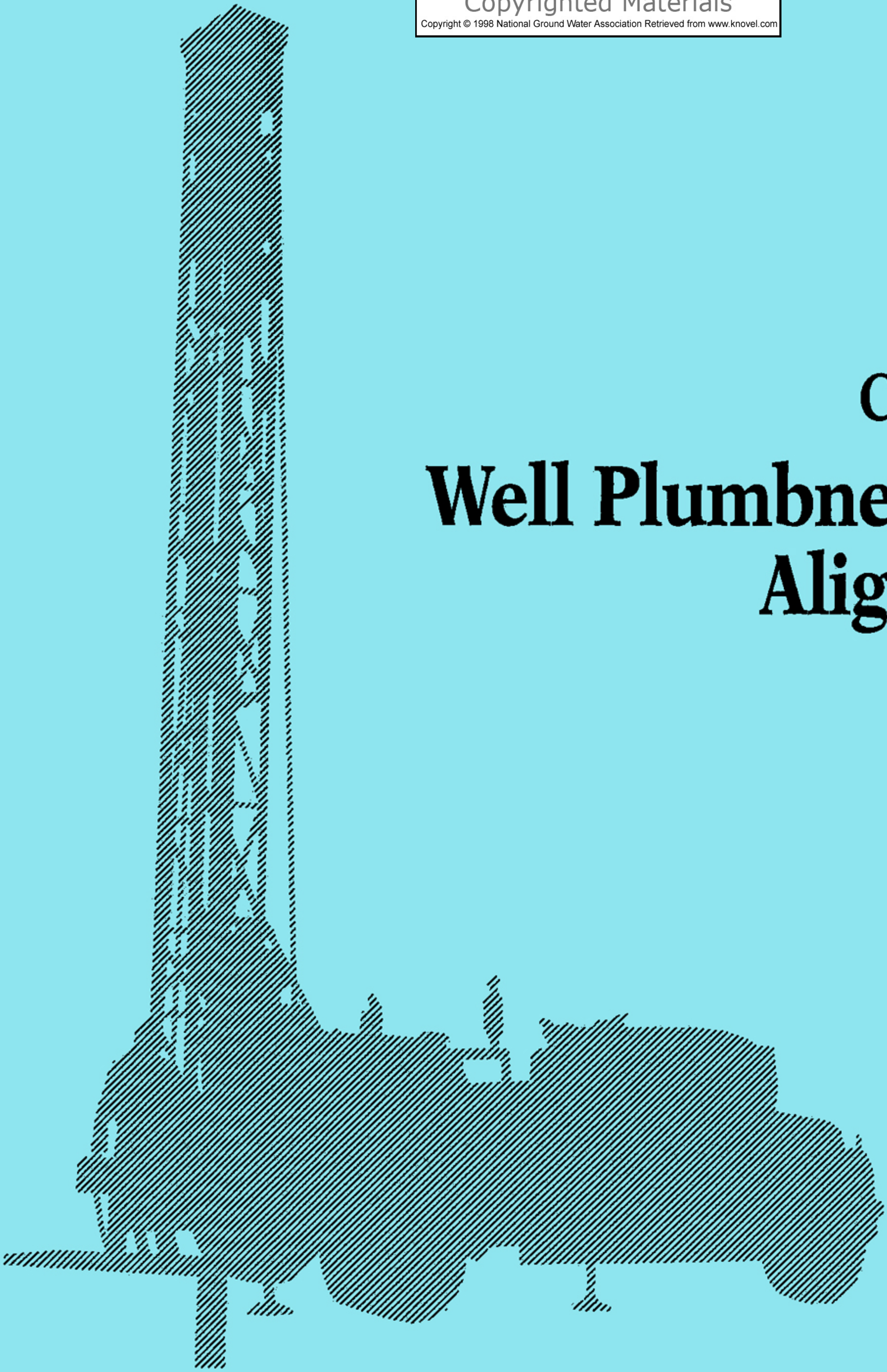
American Water Works Assn. *AWWA Standard for Filtering Material, ANSI/AWWA B100, AWWA, Denver, CO.*

Borch, M.A., S.A. Smith, and L.N. Noble. 1993. *Evaluation, Maintenance, and Restoration of Water Supply Wells. American Water Works Association Research Foundation, Denver, CO.*

Driscoll, F. 1986. *Groundwater and Wells, Johnson Division, St. Paul, MN.*

NWWA Committee on Water Well Standards. 1975. *Manual of Water Well Construction Standards, EPA - 570/9-75-001. Office of Water Supply, Washington, DC.*

Roscoe Moss Co., 1990. *Handbook of Ground Water Development. Wiley-Interscience, New York.*



Chapter 7
Well Plumbness and Alignment

7 Well Plumbness and Alignment

7.1 Importance of Plumbness and Alignment

Plumbness and alignment of a well are never perfect. In relatively shallow holes, particularly those where the smallest inside diameter of the well is considerably larger than the maximum outside diameter of pumping equipment in the well, some deviation in plumbness and alignment seldom causes serious problems.

Plumbness and alignment become critical on deep holes and/or where a vertical lineshaft turbine pump is to be permanently installed in the well. Manufacturers of turbine pumps state that their pumps will operate satisfactorily when considerably inclined from the vertical. However, a well badly out of alignment and containing kinks, bends, or corkscrews is not acceptable because such deviations cause severe wear on the pump shaft, bearings and discharge casings. Submersible pumps also may lay against one side, causing excessive wear on the pump housing, cables, and sometimes the well screen. Another problem to watch out for is contact of a hot motor with the external diameter of plastic casing. Under extreme conditions, misalignment might make it impossible to get a pump into or out of the well.

Conditions that cause wells to become crooked or out of plumb include the nature of the material penetrated while drilling, trueness of well casing, tension of cable tool drilling line, and pull-down force on drill pipe in rotary drilling (Table 7.1).

Table 7.1
Some Causes of Borehole and Well Misalignment

Categories	Scenarios	Solutions
Formation causes	Stratified units oriented other than 90° from vertical	Using knowledge of conditions to plan and execute drilling (same for each of the following).
	Vertical and angled fractures in rock	Increase well diameter margin of safety.
	Changes in formation hardness in unconsolidated materials (particularly if lying at angles)	
	Presence of boulders in soft media	
	Highly fluid soft materials	
Borehole drilling method causes	Not maintaining tension at impact in cable tool drilling line	Check periodically at surface and also with dummy downhole.
	Not checking verticality when driving casing	Moderate pulldown —
	Excessive pulldown pressure in rotary and auger drilling (corkscrewing)	Use rotary drill collars and stabilizers instead to put force closer to the bit. Practice moderation in hole penetration rate.
	Excessive "chatter" or bounce in downhole hammer	Be alert to sounds, maintain steady pulldown pressure. All: Make sure bits are sharp, properly shaped and gauged, and fully operating (e.g., all cones rotating).

Solutions for the problems vary as widely as do the conditions which cause the problems, but generally lie within reasonable care and skill in borehole drilling and well construction. With the proper tools, preparation and skills, wells sufficiently straight and plumb for suitable pump installation and service may be constructed in almost every situation.

The existing well construction standard in widespread use, ANSI/AWWA A100, prominently features an alignment standard for well acceptance (Table 7.2).

Table 7.2
ANSI/AWWA A100 Plumbness and Alignment Standards

Plumbness	Maximum allowable horizontal drift from vertical: ⅔ smallest I.D. per 100 ft (30 m).
Alignment	A. 40-ft (12-m) pipe not >0.5 in. (12 mm) smaller than casing I.D. will move freely throughout tested interval.
	B. 40-ft (12-m) dummy assembly (3 rings: each end and middle, 12-in. wide) not >0.5 in. smaller than casing I.D. will move freely throughout tested interval.
	C. Difference between actual centerline (surveyed) and proposed pump centerline not >½ difference between well I.D. and proposed pump maximum O.D.
Depth standard applies to:	Top of well to maximum depth specified (e.g., pump setting depth or base of casing).

Use of such a test is not going to be necessary in relatively simple wells such as domestic supply water wells or shallower, single-casing commercial or municipal wells. They are recommended for deeper wells where there may be some question about the verticality or alignment, and these factors matter (e.g., in pump setting). There is no single set of triggering criteria for specifying these tests, with specifying mostly a matter of professional judgment and preference. In any well where there is substantial doubt based on preliminary information (borehole TV survey or problems with pump setting), tests should be run.

It should be noted that not all boreholes and wells drilled for water supply are necessarily intended to be absolutely vertical and plumb. Some water supply wells may be intentionally directionally drilled at angles other than 90 degrees. These are not specifically considered in this discussion. For directional completions, drillers should follow good practice in borehole navigation and well completion according to the standards of directional drilling.

7.2 Methods of Testing

A basic plumbness and alignment standard and test might be that the completed well is sufficiently plumb and straight so that there will be no interference with installation, alignment, operation or future removal of the permanent well pump. The standard for acceptance would be that the pump is successfully installed with sufficient clearance and does not touch the casing at any time during installation. Good quality control by the driller should include a periodic check of the plumbness of the cable or drill string suspended in the borehole.

Prior to running casing in deep holes, a drift-direction survey (see following) can be run to see the direction that the hole is heading to allow an estimate to be made of how the casing will run.

If casing is being driven, its plumbness or verticality should also be check at each joint with a level in at least two right-angle orientations. Alternatively, surveys in the casing show the verticality and straightness of the completed hole. This is accomplished by tabulating and plotting a series of displacement and drift measurements by depth to give a hole profile.

The mirror observation method can be used for checking verticality, if a plumb-bob is lowered down the hole or casing joint. By checking the position of the plumb line at the collar of the hole when the bob is observed to just touch the wall, a rough check of verticality is made.

An accurate indicator of deviation is a heavy bailer on a light weight bailing line. Measuring hole deviation with the bailer is accomplished by aligning the bailing sheave over the center of the hole. In this way, the bailer hangs accurately in the center of the collar. Then, as the bailer is lowered down the hole, the movement of the line at the collar of the hole shows not only the extent of the drift but also its direction: a movement first to one side and then back and over to the other side, shows that the hole is dog-legged.

An objective plumbness and alignment test may also be specified as part of construction, with a standard that all casings and liners be set round, plumb, and true to line as defined by the specifications. The test for plumbness and alignment is made following construction of the well, and before test pump equipment is installed. Deviation from vertical is expressed in terms of dip or deviation angle (degrees from a true vertical) and azimuth (the compass direction of the deviation) (**Figure 20**).

If a test is specified for acceptance, it should be part of the written specifications for well construction. If any contractor subcontracts drilling, the contractor should inform the subcontractor that testing is a prerequisite for acceptance, because meeting an objective test standard will affect drilling practices and costs.

7.2.1 Pipe or Dummy Test

Alignment is tested by lowering a test pipe into the well to a depth specified (e.g., below expected pump setting depth or total depth). The test pipe consists of a section of pipe 40 feet (12 m) long or a dummy of the same length (see Table 7.2). The outer diameter of the pipe or dummy should not be more than 0.5 inch (12 mm) smaller than the inside diameter of that part of the casing or hole being tested when the casing diameter is a nominal 10 inches (250 mm) or less. When the nominal diameter of the casing being tested is 12 inches (300 mm) or greater, the outer diameter of the test pipe or dummy cannot be more than 1 inch (25 mm) smaller than the inside diameter of that part of the casing or hole being tested. When lowering the dummy into the casing, it should pass freely the entire depth of the well interval to be tested (or the total well depth) in order for the well to be accepted (**Figure 21**).

7.2.2 Plummet Test

The test for plumbness can also be made with a plummet. In this test, a hoist is constructed so that the center of the cable pulley is exactly 10 feet (3 m) above the top of the well. The pulley must be so located that the plumb line "A" will come off its outer edge exactly over the center of the well casing (**Figure 22**). The centerline should be measured and marked for use as a comparison in the test. To measure drift and drift direction, establish a North mark on the casing collar.

The plumb ring or plunger is 0.25 inch smaller in diameter than the inside diameter of the well casing. The plummet can be made from a piece of sheet steel or a short piece of pipe. Whichever is used, it must be heavy enough to keep the plumb line taut to the total depth in the well to be tested (not buoyant in any water column). The hub of the ring must not be solid as the water must pass through it as it is lowered in the well.

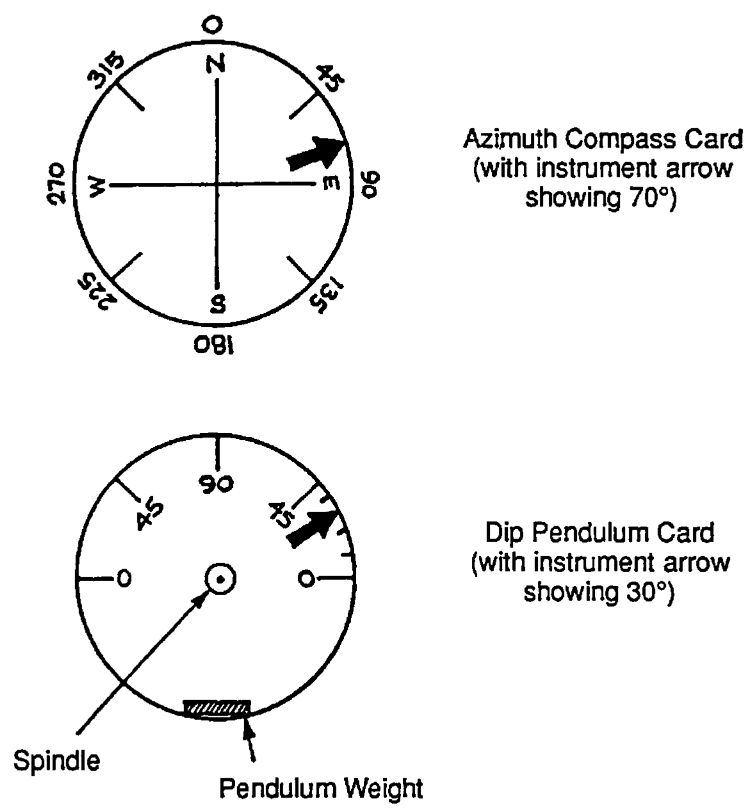


Figure 20. Azimuth Compass Card and Dip Pendulum Card.

Figure is from the *Australian Drilling Manual*.

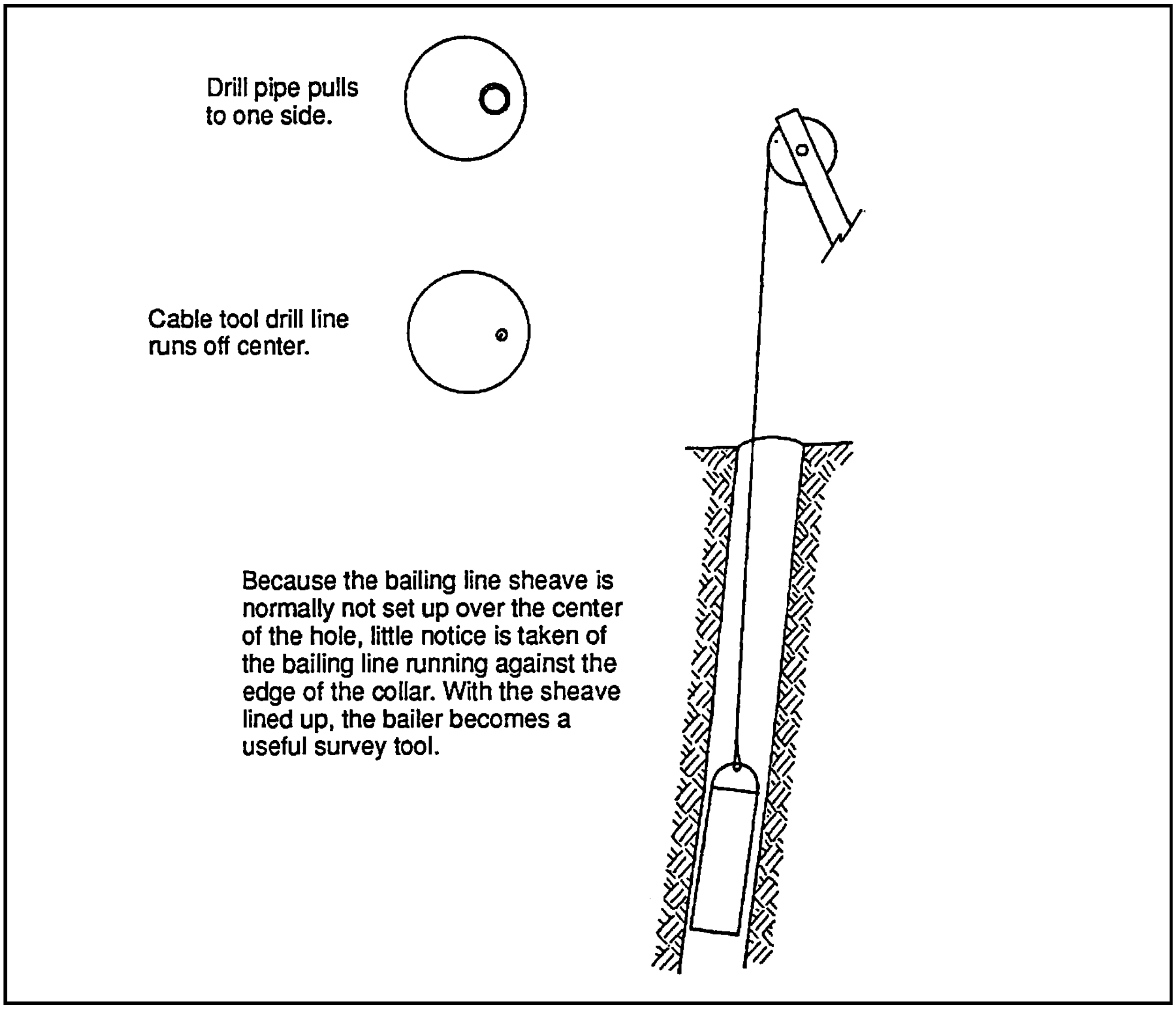


Figure 21. Pipe or Dummy Test.

Figure is from the *Australian Drilling Manual*.

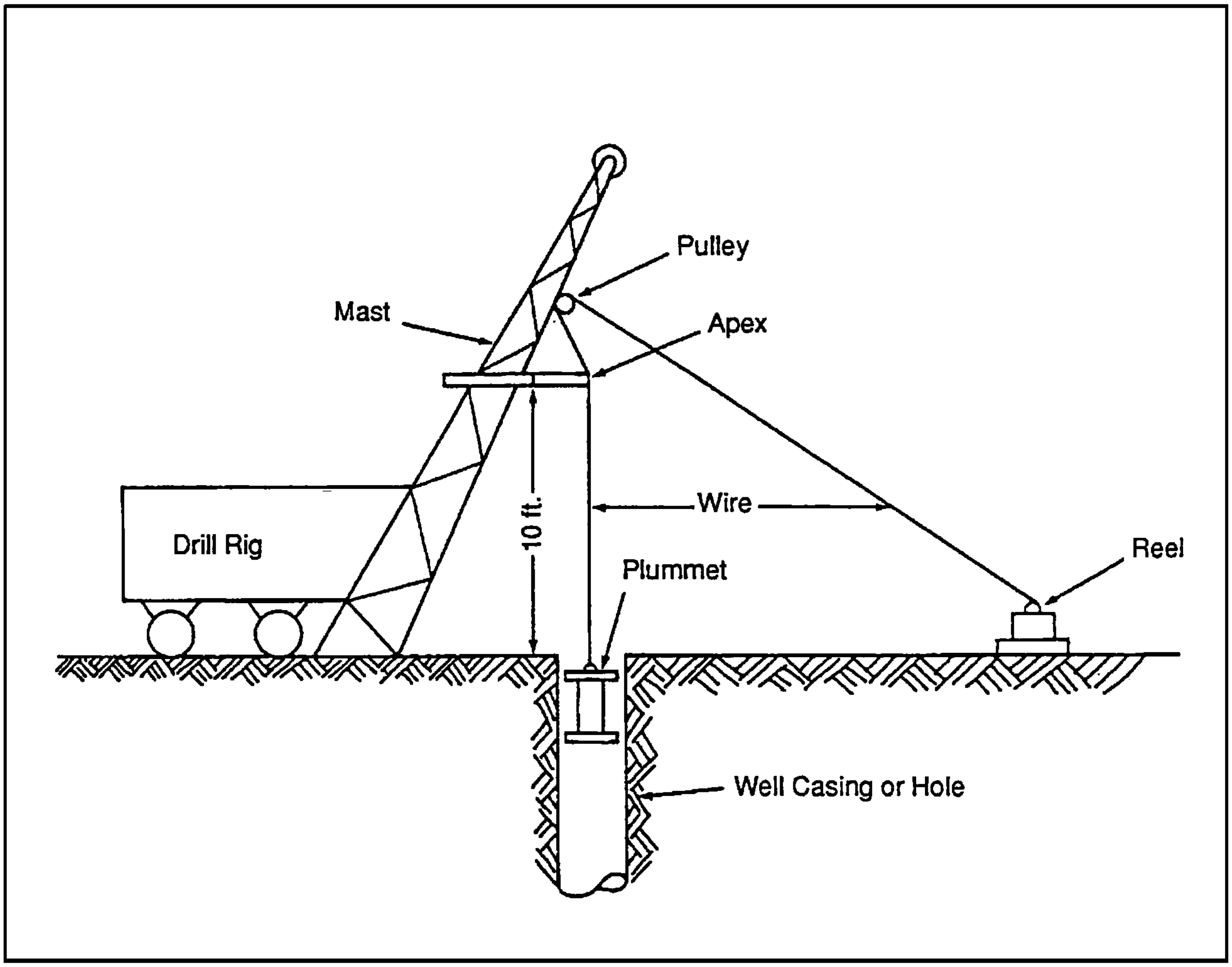


Figure 22. Plummet Test.

Figure is from the *AWWA Standard for Water Wells (AWWA-A100-84).*

The hole through which the plumb line passes must be in the exact center of the ring. Knots or marks should be made every 10 feet (3 m) on the plumb line, to indicate the depth the ring has been lowered in the well.

The well characteristics are determined by lowering the plumb ring 10 feet at a time and taking a reading at each location. If the plumb line passes exactly through the center line at any location, the well is plumb at the depth the plumb ring is suspended. However, if the line does not pass through the centerline, the well at that depth is out of plumb by an amount equal to distance from the plumb line to the centerline, plus an equal distance for each 10 feet that the plumb ring is below the floor level.

7.2.3 Drift Indicator Surveys

A mechanical drift indicator (**Figure 23**) may be run in the hole and the drift determined at intervals of 50 feet (15 m) of depth to the total depth of the hole. If a deflection of less than one degree is indicated, the well is deemed to be in proper plumbness.

Records of deflection readings and all other-pertinent information must be kept and made part of the permanent well log and record.

(1)Pendulum Drift Indicators: The close control on verticality often required in water wells may be determined with a long-pendulum (small angle) drift recorder. Readings, accurate to one tenth of a degree, are provided by instruments with a range of up to 2 degrees. As the range is increased, reading accuracy becomes lower. Both mechanical and photographic instruments are available.

(2) Mechanical Units: Mechanical units record by punching a small hole in the target card. A clockwork mechanism triggers the punching mechanism. The chart is turned between readings. Punch marks are made in a compass card calibrated to read the azimuth direction. Directional accuracy is poor when the hole is near vertical.

(3) Photographic Units: A similar drift angle accuracy combined with an azimuth angle correct to the nearest whole degree, is obtained from a photographic directional recorder (**Figure 24**).

Photographic type survey tools (both single and multishot) can be equipped with ANGLE UNITS suitable for surveying holes at all dip angles. The angle unit for flatter holes (0- to 80-degree dips) uses a different style of chart.

Multiple shot instruments record a series of photographs of the angle unit readings. The units are electrically operated from self-contained batteries. The tool may be run on rods, but usually is lowered on a wire line. Wire line surveys are recorded both running in and coming out of the hole to provide check readings.

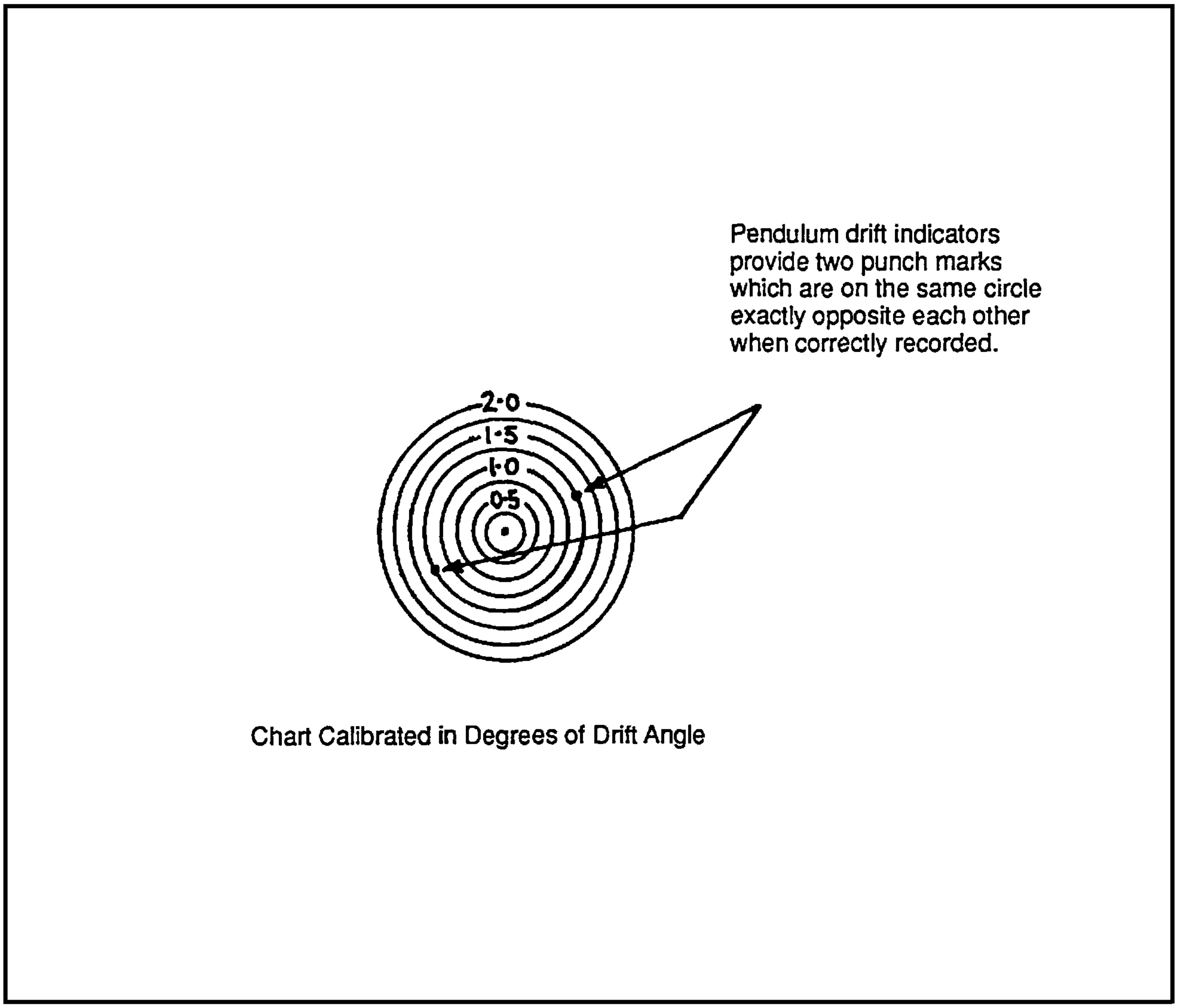


Figure 23. Pendulum Indicator.

Figure is from the *Australian Drilling Manual*.

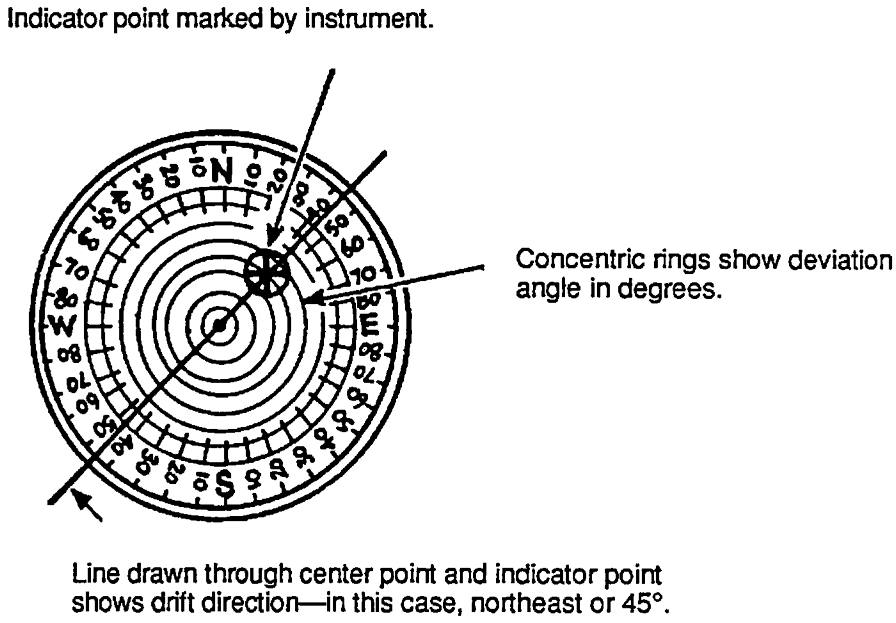


Figure 24. Azimuth and Drift Indicated by Photograph Direction Instrument.

Figure is from the *Australian Drilling Manual.*

The instrument takes readings either every one minute or every two minutes. The cycle time is selected to allow the crew to reposition the instrument between readings. A careful record must be kept to show the depth of the instrument at each reading.

Multiple shot surveys usually are run after the hole is completed. They provide a complete record of the hole with readings taken at 10-ft, 5-m, or other suitable intervals convenient to the surveyors.

Gyroscopic Survey Instruments: In magnetically complex formations or when a survey must be conducted inside drill rod or steel casing, azimuth readings can be taken using a gyroscope to orient the instrument. High speed gyroscopes (40,000 RPM.) are available to run in holes as small as 1.6-in. (40-mm) diameter, although 3 inches (75-mm) is standard. Gyroscopes are delicate and expensive instruments which should be handled only by those trained in their operation. Two difficulties arise when using gyroscopic tools:

(1) If the direction given by the gyroscope axis is to be truly constant, the gyroscope must be completely free of forces tending to turn the axis. This means that the effects of gravity on the gyroscope must be exactly balanced.

(2) The gyroscope orientation is constant in space. Because the hole being surveyed is moving with the rotation of the earth, the constant direction given by the gyroscope appears to be changing (at the equator it completes a full rotation in 24 hours). This change is less significant as the latitude increases. It can be allowed for in calculating hole position from the readings.

To check on this drift in direction when the gyroscope comes out of the hole, it is reoriented to the bench mark used before it was run. Gyroscopes usually are run in association with multiple shot survey tools.

The survey record must include information on (1) hole location, (2) date and time of survey, and (3) depth and time each reading is taken.

Photographic hole alignment survey tools have been developed to overcome the problems of magnetic and gyroscopic surveys. An alignment survey will not record the actual azimuth and dip of the hole at the survey point. An alignment survey measures the changes in direction (both azimuth and dip) along the hole. The azimuth and dip at the collar of the hole are measured using surface survey methods.

7.2.4 Electric Well Surveys

Electrical survey tools providing a surface readout are available to provide (1) alignment surveys in cased holes or (2) magnetically controlled azimuth and drift angle surveys in open holes or holes cased with non-magnetic casing.

These tools will operate in holes as small as 2-inch (50-mm) in diameter. Centralizers are used in larger holes. Their accuracy permits alignment surveys, reading a drift of as low as 20 mm per 100 meters of hole depth. The instrument provides a surface readout on North-South and East-West coordinates similar to the results of the plumb bob verticality survey.

References

American Water Works Assn. *AWWA Standard for Water Wells, ANSI/AWWA A100, AWWA, Denver, CO.*

Australian Drilling Industry Training Committee, 1997. *Drilling: The Manual of Methods, Applications and Management. Lewis Publishers, Boca Raton, FL.*

NWWA Committee on Water Well Standards. 1975. *Manual of Water Well Construction Standards, EPA - 570/9-75-001. Office of Water Supply, Washington, DC.*

Roscoe Moss Co., 1990. *Handbook of Ground Water Development. Wiley-Interscience, New York.*

Chapter 8
Well Development

8 Well Development

8.1 Purpose of Well Development

Practically all methods of drilling cause compaction of unconsolidated materials in an annulus of variable thickness around a drill hole. In addition, fines are driven into the wall of the hole, drilling mud invasion may occur to a greater or less extent, and a mud cake (if used) may form on the wall of the hole.

In consolidated formations, similar compaction may occur in some poorly cemented rocks, where cuttings, fines and mud are forced into fractures, bedding planes and other openings, and a mud cake forms on the wall of the hole. All of these conditions reduce the permeability of the formation adjacent to the well and act to reduce the yield and increase the drawdown per pumping yield.

Well development is the final well construction step that (1) removes formation damage caused by the borehole drilling process, and (2) establishes the most optimal hydraulic contact possible between the well and the aquifer formation supplying water. Proper well development breaks down the compacted borehole wall, liquefies jelled mud, and moves both mud and formation fines into the well, from which they are removed by bailing or pumping. This action creates a more permeable and stable zone about the screen or intake bore.

The stabilization of the formation adjacent to the well intake that is achieved by development can practically eliminate sand pumping, and contributes to a more efficient well, longer well life, and reduced operation and maintenance costs. In addition:

Proper well development can sometimes make a poor well into a good one.

Without proper development, an otherwise excellent well may never be satisfactory. Proper development will improve most wells regardless of type or size. Only under unusual circumstances (or because of improper methods) will it do harm.

Care must be taken in performing development to avoid applying forces on the casing, screen and grout that are beyond their capacity for resistance. Causing an excessive difference in hydrologic pressure between the outside and inside of a casing, for example, may result in casing distortion (Chapter 3). Sharp shock loading or unloading of some well screens may cause distortion or collapse. Tools should not impact sharply against casing joints or screen rods.

8.2 Methods of Development

Numerous methods of development are available and the literature contains considerable discussion of the suitability of each method for various types of formations. The more commonly used methods of well development are pumping, surging, fracturing, and washing (including jetting). Each of these general methods have specific variations in methods and tools.

An important factor in any method is that the development work be started slowly and gently, increasing in vigor as the well is developed. Well development methods generally require the application of sufficient energy to disturb the natural formation or filter pack so as to (1) free the fines and allow them to be drawn into the well, and (2) cause the coarser fractions to settle around and stabilize against the screen. This is usually accomplished by the surging of water into and out of the well and the formation. Hydraulic jetting operates somewhat differently, depending upon a high velocity water jet discharging through the screen. The jets disturb both the filter and formation and the water (following the path of least resistance) returns to the well above and below the jets, carrying the fines into the well.

8.2.1 Pumping or Bailing Method

Continuous overpumping. This simplest method of development involves uninterrupted pumping at a rate greater than design capacity. The intention is to dislodge formation damage that would not be brought out in planned pumping. A major disadvantage of continuous overpumping is that it does not provide for a return surge into the formation. Fines moving toward the well tend to pack against the screen and/or filter pack, and may reduce capacity, or cause compacted zones around which incrustation may develop later. In general, overpumping is not recommended as a primary development method, but as a last, polishing step..

Interrupted overpumping (rawhiding). Interrupted pumping may be done with a pump capable of pumping at rates up to two times the design capacity, without a check valve or foot valve, so that backwash occurs when the pump is shut off. The pumping is carried out in a series of steps. For example, pumping can be accomplished in five steps at rates of 1/4, 1/2, 1, 1-1/2 and 2 times the design capacity. At each pumping rate, the pump is turned on for 5 minutes then shut off to backwash over a minimum of 2 hours or until such time as acceptable standards are attained. Rawhiding can provide reasonable results, but in many cases, the surging action is not vigorous enough to obtain the best results. In addition, as with overpumping, the development effect is concentrated at the top of the screen or near the pump intake. Finally, other mechanical development methods (discussed below) accomplish better results in less time.

Surging and bailing (utilizing bailer). Surging can be accomplished by utilizing the cable tool bailer as a surging device. Bailing has an advantage over direct pumping since the action of plunging the bailer rapidly into the water column causes a repetitive back surge (such as produced in a slug test). As the bailer fills and is withdrawn, water and fines flow into the well. Bailing is a first-stage development method prior to introducing more effective surging methods for final development.

8.2.2 Mechanical Surging And Pumping Method

Surging and bailing (including surge block). Final or polishing development with cable tool equipment is accomplished by surging and bailing the well. The surging is done by a single or double solid (or valved) surge block or swab. To avoid sand-locking during development, surging starts at the top of the screened interval and progressively downward to the bottom of the lowest screen in the well and repeated as necessary. As fines are drawn into the well and settle on the bottom, they accumulate and block the screen or intake area. When about 10 to 40 percent of the total screen length is blocked, the well is bailed to the bottom to remove the accumulated fines before resumption of surging. On completion of development the well is cleaned to the bottom and bailed clear. Development may be finished during initial test pumping.

Surging and pumping (flushing). This development process involves a modified surging tool or swab (double-flange swab) which incorporates a piece of suction pipe in a valved double block . Airlift or suction pumping can be done simultaneously with the surging. Where pressure develops below the tool (tight or pressurized formation), installing a bypass through the double-flange tool increases effectiveness. Pumping rates up to about 1/2 design capacity are used in smaller wells. For higher capacity wells (12-in. screen or larger), 600 to more than 1000 gpm can be circulated.

As with surging-and-bailing, surging starts at the top of the screen in the well and proceeds downward through the producing zone, and repeated as necessary. Fines drawn into the well can be pumped out periodically when an accumulation develops. Upon completion of the development work. the well is cleaned to the bottom.

Wireline swabbing. This method can be used on larger-capacity wells, using a tool consisting of a heavy scow or sand-pump bailer fitted with a swab flange and run on the sand line of a cable tool rig. The well is first cleaned out by bailing, then the swabbing tool is run. The swabbing tool is most effective in open borehole or gravel-wall louver-screen wells.

Both repetitive surging and bailing and surging and pumping or swabbing provide a vigorous and controlled in-and-out flowing motion that provides effective development in a timely fashion. Surging methods are preferred over methods such as jetting that apply direct horizontal force for development of rock and louver-slot screen wells in some parts of the U.S., since it is the backflow along the more tortuous flow paths in these wells that provides the cleaning and particle-sorting effect.

These tools also take advantage of the economical hourly costs and reciprocating motion provided by the cable tool rig. Development can also, of course, be accomplished with other kinds of pressurizing and pumping equipment.

8.2.3 Hydraulic Jetting Method

Development is accomplished by simultaneous high velocity, horizontal-jetting and pumping. The jet pushes water into the screen, gravel pack, and formation, and the water returns to the well around the jetting tool. Pumping keeps the head in the well low enough that water returns, and removes fines from the well without stopping for bailing.

Jetting works best with (and is recommended for) high open-area, V-slot screens where there is least resistance to jet flow. On the other hand, screen designs such as bridge and louver slots that cause deflection of the jet flow cause distortion and dampening of the jet force. More jetting application time or additional surging agitation may be needed for these well designs.

The outside diameter of the jetting tool should be one inch less in diameter than the screen inside diameter. The lowest effective exit velocity of the jetting fluid at the jet nozzle is considered to be 100 ft/sec and preferably 150 to 200 ft/sec (46 - 61 m/sec). Velocities above 200 ft/sec do not provide any additional benefit and may cause abrasion even in metal screens. A working pressure of 200 psi (1,380 kPa) is recommended for metal screens and 100 psi (690 kPa) for PVC screens. Jetting of PVC screens should only be done with abrasion-free water.

Jetting proceeds from the bottom of the screen to the top. Pumping from the well is conducted at a rate of 5 to 15 percent more than the rate at which water is introduced through the jetting tool. Water to be used for jetting should contain less than 5 ppm suspended solids. The tool is rotated slowly (at a speed less than one rpm) and positioned at one level for not less than two minutes, and never left stationary. The tool is then moved to the next level (recommended no more than 6 inches vertically from the preceding jetting level).

Several passes may be made until the water is relatively clear. Accumulation in the bottom may be pumped or bailed out at the end of each jetting pass.

8.2.4 Air Development Method

Single pipe system open to atmosphere. Development is accomplished by the utilization of a single pipe air pumping system using the casing or the bore hole itself as the eductor line. To be effective, the compressors, air lines, hoses, fittings, etc. should be of adequate size to pump the well by the air lift principle at 1.5 to 2 times the design capacity of the well.

The process works much like rawhiding in concept. The well is initially pumped with air until the well is developed to the point that it yields clear, sand-free water. Then the air is shut off and the water in the well allowed to return to a static condition. This process of lifting and dropping of the column of water is repeated until the well no longer produces fine material when it is surged and backwashed as described above (**Figure 25**).

For best results, the bottom of the air line should be placed at different levels in order to facilitate development of all intake areas and multiple water producing zones, and the process repeated until all zones yield water free of turbidity when surged and backwashed.

As with rawhiding, single-pipe air development may develop insufficient force to develop some wells. It also introduces the possibility of leaving air blocks within the filter pack or at the top of the screen. This method should be considered an expedient method only, used as an initial step in further development, or alone for less demanding well development (new wells drilled by air hammer for domestic use, for example).

Decompression method: Single-pipe system closed to atmosphere. In this variation, a valve is installed on a discharge line leading from the top of the casing. Then an air line is secured into a blowing tee or ell affixed to the valved air connection on the top of the casing, which is sealed (**Figure 26**). A pressure gauge and relief valve must be installed at the top of the casing when this system is used to reduce the risk of injury and well damage due to overpressurization. To prevent air from entering the water-bearing formation, a separate pipe, open to the atmosphere at the top, is installed in the well to a point 10 feet (3 m) above the water-bearing zone.

Air is introduced into the well, forcing the column of water in the well down. When the water level in the well is forced down to the bottom of this air-release pipe, the discharge valve is opened and the water allowed to rise back to the static level. This procedure may be repeated as needed until the airlifted flow comes clear.

Airlift method: Two-pipe system. The development process is carried out by the utilization of an air-introducing pipe and an air-and-water eductor line. The compressors, air lines, hoses, fittings, etc., should be of adequate size to pump the well by the air lift method at 1-1/2 to 2 times the design capacity of the well.

The well is initially developed by the single-pipe system closed to atmosphere system (see above), with the air line introducing air into the eductor line at a point above the bottom of the eductor line. When the well yields clear, sand-free water, the air line is lowered to a point below the bottom of the eductor line and air introduced until the water between the eductor pipe and the casing is raised to the surface. At this time the air line is

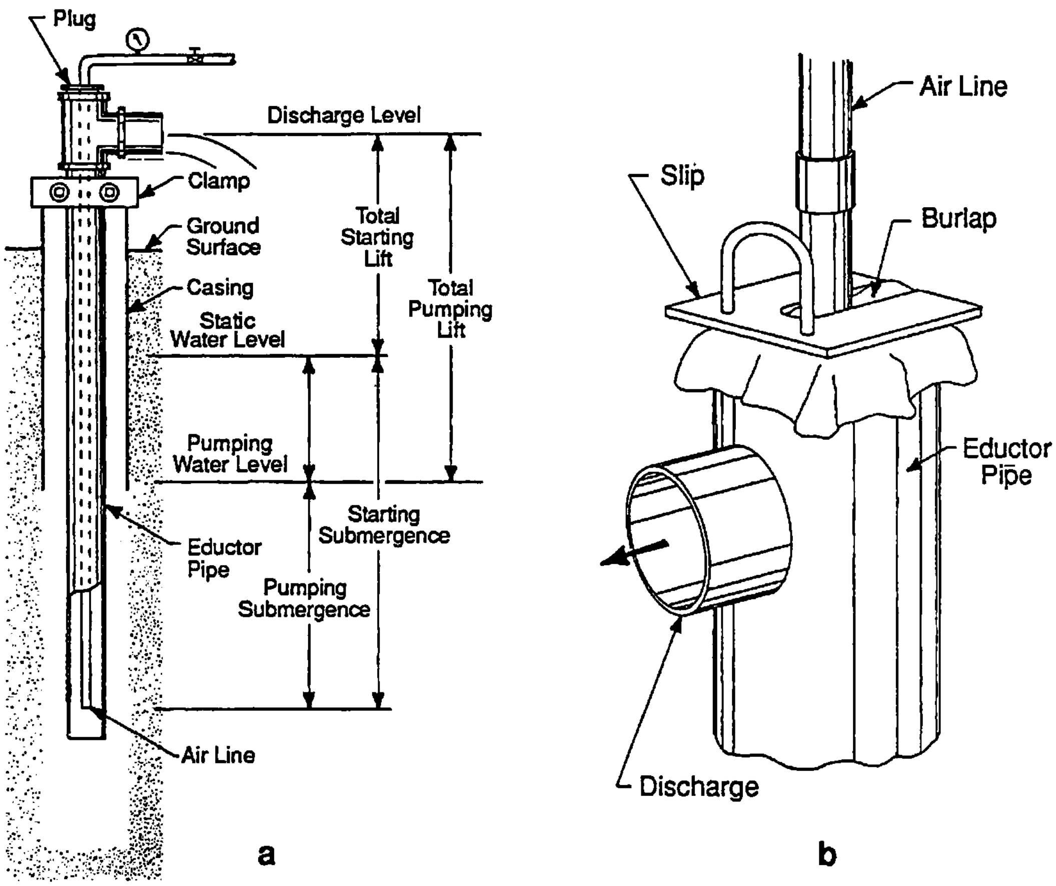


Figure 25. Terms and Equipment Used in Air Lift Pumping

Figure is from *Groundwater and Wells*.

Single-pipe, closed-to-atmosphere air development installation. Note: valve installed on the larger-diameter discharge line leading from the top of the casing, and pressure gauge and relief valve installed at the top of the casing on the relief line to prevent overpressurization.

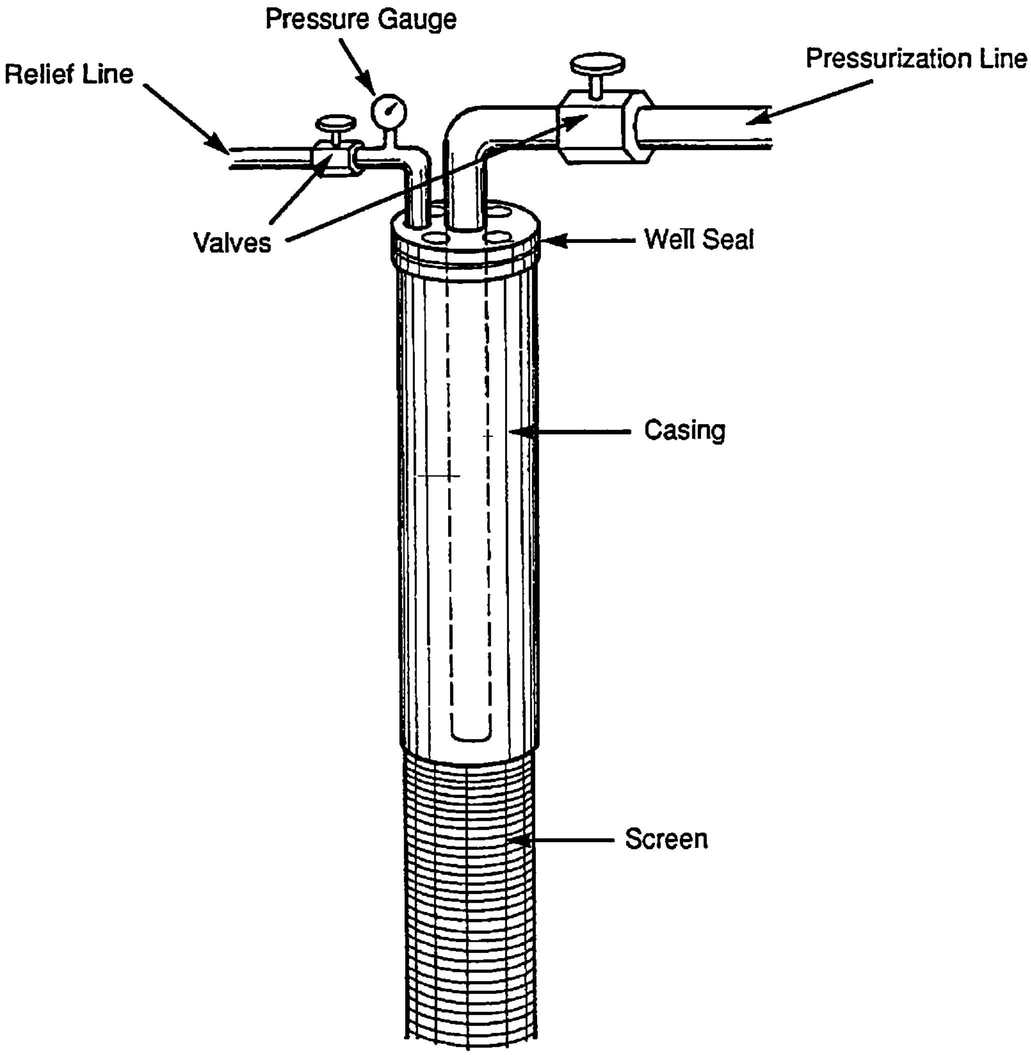


Figure 26. Installation of Pressure Gauge in Casing Seal.

raised back up into the eductor line causing the water to be pumped from the well through the eductor line.

The procedure of alternating the relative positions of the air and eductor line is repeated until the water yielded by the well remains clear when the well is surged and backwashed by this technique. This system should only be used in driven or cement-grouted wells due to the risk of channeling in bentonite grout.

Isolation tools. The combination double-surge and airlift tool described above (Section 8.2.2) provides a means of using the benefits of airlift pumping, while concentrating the force of development in a small area. They are designed more for cleaning and stabilizing rather than pumping as such. Surging is begun at the top of the intake area, and proceeds downward.

8.2.5 Development Aids

Washing with water. Clean, clear, chlorinated water may be circulated to remove sediment from the well. A pump of sufficient size is needed for the washing process, agitating the formation by turbulent flow for the purpose of preventing bridging of the sand particles and removing a large portion of the finer material. This is done as a final step after other physical development.

Chemical augmentation of development to remove clays. Where applicable and required, mud dispersing (deflocculating) agents may be used. Hexametaphosphates and sodium acid pyrophosphates or trisodium polyphosphates are often prescribed for this purpose. Alternatives include polyacrylamide dispersants, which do not contain phosphates that enhance microbial growth in ground water.

The solution is mixed at the surface, tremied in, agitated with a bailer or pump, and left to react (about 8 hr). The spent solution is then pumped clear, and testing shows that chemical is depleted. Spent solution should never be discharged into surface water bodies or to sewers without consultation with and approval of wastewater treatment operators.

Polyphosphates have three major drawbacks in use:

(1) The potential that clays may slough when they lose structure and cover the aquifer face, causing blockage especially on fine, semi-consolidated formations.

(2) In cold ground water (< 55 F), some polyphosphates may form a gelled precipitate that is very difficult to remove.

(3) Polyphosphates that are not removed cause accelerated biofouling development, resulting in accelerated well deterioration.

In general, the use of mud dispersants, especially polyphosphates, should be a last resort when mechanical development has been ineffective and excessive wall cake formation is identified as the cause of the blockage. This condition is minimized if proper drilling fluid control has been practiced.

Acidizing to increase limestone permeability. Acidizing with hydrochloric acid is sometimes prescribed to enlarge solution openings in fissured limestone. A wellhead seal is placed on the casing, with a tubing string run through it. The tubing ends near the top of the intake area of the well. A valve is installed in the tubing string above the casing seal. Another valve and pressure gauge are installed in the casing seal as in Figure 26.

A quantity of HCl (usually equal to the bore volume below the casing) is pumped in, followed by enough potable (coliform-free, not chlorinated water to displace the acid out of the borehole. The casing pressure developed from the CO_2 released as HCl reacts with limestone is closely monitored and a valve is used to release excess pressure in the casing. Completion is indicated by a noticeable drop in pressure over time, and often occurs within 1 hour.

Insoluble precipitates can develop, and are a problem with limestone facies that have significant shale content. Precipitate development is limited by limiting acid contact time in the borehole. Spent acid solution should be pumped to containment and released to appropriate disposal only when neutralized. Risks include:

(1) This system should only be used in driven or cement-grouted wells, because channeling in bentonite grout develops readily in most wells.

(2) Gelatin should be avoided as an inhibiting agent due to the fecal coliform content typical of industrial gelatin products. Coliform bacteria can be injected many feet into fractured formations.

(3) Acid contaminants such as arsenic or metals may result in poor water quality results. Only very (new) clean (water treatment grade) acid products should be used.

8.2.6 High-Pressure or "fracturing" Procedures

Hydraulic fracturing. Hydraulic pressures applied rapidly in a focused fashion will improve the effective area of a well by opening up natural fractures in crystalline and sedimentary rocks, and washing out drilling damage around the hole.

The zone is sealed by a packer assembly. Inflatable or compression-set solid rubber packers are commonly preferred. Pressure is applied by pumping water into a sealed zone at pressures ranging from somewhat less than 1000 psi to >3000 psi (<6900 kPa to >21,000 kPa) using a high-pressure piston pump. There is no fixed pressure recommendation. The pressures chosen depend on local experience and the nature of the rock to be treated.

Two packer strategies are used: single packers and straddle packers. With single packers (the more common), the packer is set at the top of the aquifer zone and water injected. After pressure rise, fall, and pumping, the packer is reset lower if necessary and the process repeated. By proceeding from top to bottom, the top part of the formation, which is usually more fractured, is opened first. The straddle packer procedure provides more a more focused application of force. In this case, water is forced into the formation between two packers set typically 10 to 50 ft (3 to 16 m) apart. This treatment starts at the bottom and moves upward, minimizing the threat of rock fragments dislodging and interfering with the packer setting and removal.

Hydraulic fracturing has developed an extensive track record in recent years, and is the development method of choice in hard rock aquifer situations over much of the world, particularly crystalline-rock areas of North America and southern Africa. Field experience shows that this method combines relatively high success with low risk of both personnel and in-ground hazards. However, in hydraulic fracturing, casings grouted with bentonite or otherwise subject to movement under the forces applied should be isolated from the high-pressure water flow by a packer set its full length in the rock, not in the casing.

Liquefied CO_2 Injection. Another variation on pressure methods to open rock fractures and stimulate production is the injection of alternating liquefied and gaseous CO_2. This method was developed as a more systematic way to apply the effects of cryogenic CO_2 than introducing "dry ice" (solid CO_2) in a closed casing and borehole as traditionally practiced.

The controlled combined liquefied-gaseous CO_2 process has four steps as follows:

(1) A packer is set.

(2) Injection of cryogenic liquid CO_2 at pressures as low as two bars and no more than about 35 bars. This induces freezing in the water column, opening fractures.

(3) Allowing time for penetration into the formation and reaction. The gas expands into the formation, further opening fractures.

(4) After application, venting and depressurization.

(5) Repeating as necessary.

The advantages of the process include:

(1) The injectant is chemically reduced and not reactive with organic molecules.

(2) It does not work under high pressure, so that fracture opening is minimized.

(3) The material, compressed CO_2. is relatively safe to handle.

The best use of controlled CO_2 injection is probably development or redevelopment in rock wells and redevelopment in more robust screen situations with significant encrustation. The force applied by the expanding gas is readily dissipated in hydraulically highly conductive aquifers. Casings must be firmly sealed into the formation with cement. As with hydraulic fracturing, it is probably best to avoid use with smaller, shallower bentonite-grouted screened wells, and to isolate the casing in rock wells by seating the packer full length in the rock.

8.3 Planning and Evaluating Well Development

Determination of the adequacy of development is largely a matter of experience and judgment but generally involves (1) the final production of water sufficiently sand and turbidity free to meet the standards of use, and (2) a pumping well yield closely approximating the potential of the formation and screen as calculated. At its initial completion and final development, pumping water from a well should be free of residues from drilling fluid and grout and any chemicals used in development. Development should proceed until these conditions are met.

8.3.1 Testing for Sand in Water

The sand content (actually a total sediment content) may be determined by averaging the results of 5 samples collected over the course of a final constant-rate pumping test (keeping the rate as constant as possible). The following time sequence is recommended during the final pumping test:

(1) 15 minutes after start of the test;

(2) after 25 % of the total planned test time has elapsed;

(3) after 50 % of the time has elapsed;

(4) after 75 % of the time has elapsed;

and (5) near the end of the pumping test.

Averaging takes into consideration the observation that even properly developed wells may generate markedly more sand during start up, with sand output declining rapidly over 10 to 20 minutes.

It is also useful to record and graph the results over the test period to observe evidence of voids or incorrect pack/aquifer ratios that may be corrected by further development. In a performance step test (see Chapter 9), samples may be taken after the initial 10 minutes of each step and near the end to better pinpoint problem zones.

A recommended minimum volume of water sample collected for testing for sand content is a volume determined by the formula: test rate of flow in gpm multiplied by 0.05 (gpm_{test} x 0.05). A practical maximum volume required for wells test pumped at more than 1000 gpm is 50 gallons (U.S.) (or convenient SI equivalent), with the minimum required for wells tested at less than 20 gpm being 5 gallons (U.S.) (~20 L).

Samples may be collected in the following manner. When the circular orifice meter (Section 9) is used to measure flow rate, the sample may be withdrawn from a manometer connection. When other devices are used for measuring flow rate on wells of a lower production rate (or if a propeller meter is being used), a sample may be collected directly from the full and open discharge. When using a Rossum Sand Tester (**Figure 27**), the device is installed on a small-diameter pipe tapped horizontally in the well discharge at the pipe centerline close to the pump head, and immediately after the discharge valve, or other turbulent zone. The sample must be allowed to settle not less than 10 minutes before the liquid is decanted.

The sand (sediment) content in ppm is read directly via devices such as the Imhoff cone or similar device with gradations (accurate to 50 ppm). One-liter subsamples are collected during initial testing. In final testing, sediment volume may be measured in any accurate graduated container.

The most accurate device is the Rossum Sand Tester, which is accurate to 0.5 ppm. It is a time-weighted average test of sand content. When installed as described above, a 0.5 gpm (1.9 L/min) sample is forced to flow through the tester. Sand particles separated by centrifugal action are collected in a graduated container.

Turbidity meters may be used where overall fluid clarity is critical in the raw water. Colloids not measurable by sand-settlement methods can be troublesome. Electronic nephelometers with an accuracy range of about 0.1 to 40 NTU (turbidity units) are commonly used, although turbidity can be estimated visually against a standard.

8.3.2 Sand and Turbidity Content Limits

Sand content: There is no absolute universal standard for "sand-free", but experience has provided practical limits set by end use:

(1) Wells supplying water for flood-type irrigation and where the nature of the water-bearing formations and the overlying strata are such that pumping the following amount of sand will not seriously shorten the useful life of the well: Limit-15 ppm (by volume).

(2) Wells supplying water to sprinkler irrigation systems, industrial evaporative cooling systems, and other uses where a moderate amount of sand is not especially harmful: Limit-10 ppm (by volume).

(3) Wells supplying water to homes, institutions, utilities, and industries: Limit-5 ppm.

(4) Wells discharging directly into municipal water treatment or distribution mains (without filtration or settling) should produce ≤2 ppm sand.

(5) Wells supplying water to be used directly in contact with or in the processing of food and beverages: Limit-1 ppm.

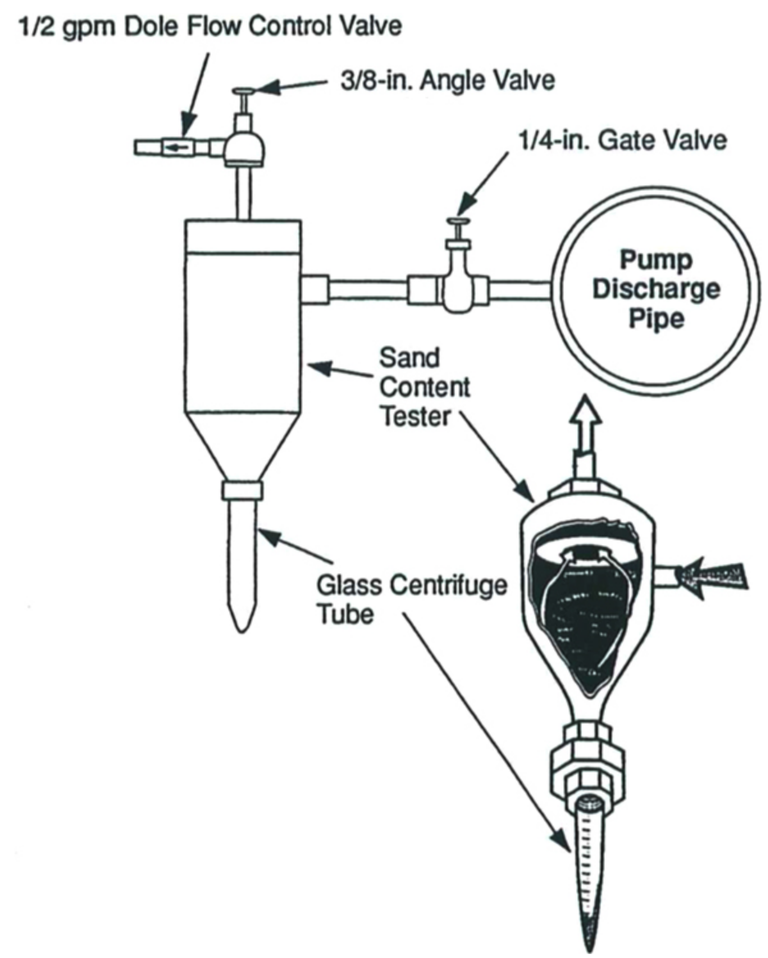


Figure 27. Rossum Sand Tester.

Figure is from the *Handbook of Ground Water Development*.

These limits are reasonable goals achievable with good well design, construction and development. Sand production less than 1 ppm over a pump cycle of several hours is certainly achievable from properly designed, constructed, and developed wells.

Turbidity: A reasonable standard for raw well water output at well acceptance is often quoted as 5.0 NTU. For municipal water systems, final product water turbidity of < 0.1 NTU is the standard. Critical beverage and industrial processes (e.g., electronics) may also have specific low-turbidity standards.

If the water requirements of the process or system being supplied by the water well demand sand content less than about 0.7 to 1 ppm (v/v) or turbidity <5.0 NTU, and these limits are not achievable by well technology and operation, then filtration should be specified.

References

American Water Works Assn. *AWWA Standard for Water Wells, ANSI/AWWA A100, AWWA, Denver, CO.*

ASTM. Guide for the Development of Ground-Water Monitoring Wells in Granular Aquifers, *1996 Annual Book of ASTM Standards, Vol. 4.09, ASTM, West Conshohocken, PA, pp. 344-358.*

Australian Drilling Industry Training Committee, 1997. *Drilling: The Manual of Methods, Applications and Management. Lewis Publishers, Boca Raton, FL.*

Borch, M.A., S.A. Smith, and L.N. Noble. 1993. *Evaluation, Maintenance, and Restoration of Water Supply Wells. American Water Works Association Research Foundation, Denver, CO.*

Driscoll, F. 1986. *Groundwater and Wells, Johnson Division, St. Paul, MN.*

Helweg, O.J., V.H. Scott, and J.C. Scalmanini, 1984. *Improving Well and Pump Efficiency, American Water Works Assn., Denver, CO.*

Fountain, J. and P. Howsam. 1990. Predicting and interpreting well behaviour and well efficiency. in: *Water Wells: Monitoring, Maintenance, Rehabilitation (Proc. of International Groundwater Engineering Conference, Cranfield Institute of Technology, Cranfield), P. Howsam, ed., E&FN Spon, London, UK. pp. 180-194.*

List, E.J. Analysis of Development Methods for Gravel Envelope Wells, Roscoe Moss Co., Publication #26-FS/383.

NWWA Committee on Water Well Standards. 1975. *Manual of Water Well Construction Standards, EPA - 570/9-75-001. Office of Water Supply, Washington, DC.*

Roscoe Moss Co., 1990. *Handbook of Ground Water Development. Wiley-Interscience, New York.*

Smith, S.A. 1989. *Manual of Hydraulic Fracturing for Well Stimulation and Geologic Studies. National Water Well Association, Dublin, OH, 66 pp.*

Smith, S.A. 1994. Monitoreo del mantenimiento preventivo, y metodos de tratamiento para control del bioensuciamiento en pozos y sistemas de agua: progresos recientes en america del norte. *Proc. Conference del XV Congreso Nacional del Agua, La Plata, Argentina (4/94).*

Chapter 9
Well Testing for Performance

9 Well Testing for Performance

Pumping tests can provide data useful in the long-term operation and maintenance of wells, such as pumping rates versus drawdown (specific capacity), well efficiency, sustained and transient yield, pump depth setting and aquifer hydraulic characteristics. The type of tests chosen at any time are dependent upon the information desired, intended use of the well, costs, and logistical considerations.

New well design and estimates may be made based on tests of test wells, or of existing wells, at a specific location (if the existing well hydrogeology can confidently be compared to the new well location). Pumping test data analyses are often compared to analyses of formation samples and geophysical logs to check their validity.

NOTE: Although the focus of this discussion is on well construction, pumping tests may also be conducted on existing wells and equipment for documenting the "in place" operation of a well and water system. For this type of testing, it is important to note the operational cycle of the system and document the performance of the well over time. When doing this, if at all possible, allow the water system to operate in its normal mode. Note the time and frequency of pump cycling. Note the corresponding pressures, flow rates, drawdown and recovery. Additional information may include pump and motor power use, noise and vibration, and water physical-chemical quality. Pump testing of a well and water system on a periodic basis is part of the foundation of a preventative well maintenance program, used to detect problems in time to make repairs, treatments, or other changes.

In selecting the type of pumping tests to be used, the drawbacks as well as the benefits must be known and considered for any test contemplated. Performance test requirements should be consistent with the dimensions of the well, the capacity of the well, and the rate at which it will be pumped when placed in service. Care must be taken to avoid excessive pumping rates with respect to both the productivity of the aquifer and the requirement of the user. Lastly, but probably most important, the tester should not have rigid preconceived opinions on what the well/aquifer system will yield. This rate should be determined based on careful analysis of data from properly conducted tests.

Typically, for small installations, the well contractors usually has sole responsibility for the testing, while for larger capacity and critical wells such as those for public water supply, the well contractor will more likely work with a hydrogeologist or geological engineer who will analyze pumping test data. Regardless of the responsibility involved, certain basic practices should be followed in making any well test, and care and accuracy are very important for test data to be of any value.

9.1 Pumping Tests General Requirements

Depending on the size and intended use of the well, initial testing for performance may range from a simple bailing test of relatively short duration to a completely instrumented test involving "step," "continuous" and "variable rate" testing lasting 72 hours or longer.

After development is completed, if a pumping test is to be conducted, a test pump capable of pumping more than the planned test yield is installed in the well. All logistical matters should be worked out prior to scheduling a test time (e.g., obtaining a generator of appropriate capacity or line power, where to take water level measurements, how to divert pumped water, permissions as necessary). Nearby pumping wells which may affect the test results must be accounted for.

The power and pump system should be test run prior to the planned test and the dynamic water level allowed to return to the non-pumping dynamic (static) condition. At this time, the response of the pumping well and proposed observation wells (as needed) can be observed. Exact horizontal distances to observation wells should be measured and recorded. Changes in the test plan or corrections in equipment should be made at this time. The test should not be started until the static level has recovered after development and pre-testing has been completed. Diligent care must be taken to measure water levels before, during and after performance testing.

The test is conducted at the specified rate and duration. For bailing tests, the procedure should be as uniform as possible. Test measurements are to be taken in the manner specified by the data requirements of the test and at the required time intervals. Recovery readings of water level in the well are started immediately upon shutdown of the test-pump and taken at specified time intervals thereafter.

The amount and rate of drawdown and recovery of the water level with time are the most critical items of data needed to evaluate the initial specific capacity of the well (including well and formation loss factor values) and the hydraulic characteristics of the aquifer.

Whoever is taking and recording water level and flow measurements should be trained in the operation of the equipment and its operation under test conditions, capable of making necessary adjustments and performing routine troubleshooting or repairs to maintain the test operation. Non-professional or non-licensed personnel should be under the supervision of a ground water professional (licensed water well contractor, hydrogeologist or geological engineer).

9.2 Types of Well Tests

With small-capacity wells which will operate intermittently or irregularly, testing should continue until an apparent stability of bailing or pumping level is achieved. The test should at least match the peak pumping condition (e.g., the need to pump 15 gpm for two hours) and achieve stability or acceptable pumping water level. Recovery should be measured to assure that permanent dewatering did not take place during the initial test.

For constant-rate well-acceptance or aquifer testing, pumping should be continued at a uniform rate of discharge until the cone of influence reflects any boundary condition which could affect future performance of the well. This probably will not greatly exceed 24 hours for an artesian well, and 72 hours for a water table well. The duration and details of such tests are often governed by the requirements of state water resources or environmental agencies, or other local political jurisdictions. Consensus (ASTM) standards also exist as guides to practice.

For variable-rate (step) tests, the pumping rates chosen should bracket (be lower and higher than) the planned production rate and span a sufficient range to permit professional calculation of turbulent well loss, and projected specific capacity. Step tests may be used over a period of time to establish changes in well loss, or to compare actual performance to theoretical performance factors.

9.2.1 Rig-Based Test Methods

Bailing Test Method. A bailer of known volume and length only slightly smaller in diameter than the casing I.D. is selected. The well is then bailed until the water level can no longer be lowered. The driller then lowers the bailer until it hits the water (a fast falling bailer makes an audible sound when it hits the surface), and marks the bailing line at a point level with the top of the casing when the bottom of the bailer is just touching the water. A second mark is then made one bailer length above the first.

The driller then rhythmically bails, lowering the line precisely to the second mark on the cable each time, then raising the bailer to the surface, noting the elapsed time per round trip. Each time the bailer emerges from the well, the driller checks to make sure the bailer is full. If the bailer is not full, it is not to be lowered deeper; however, the rate of bailing is to be slowed until the bailer comes out full each time. The bailing rate, in gallons per minute (or equivalent SI units), equals the volume of the bailer divided by the time (min) per round trip.

On occasion there may be less depth of water in the well then the length of the bailer. In such instances it is manifestly impossible to bring the bailer out full on each trip or to lower it below a certain point. Instead, the driller measures the amount of water in the bailer and relates it to a timed interval of 1 minute for each time the bailer leaves the bottom of the well.

Air Blow Test Method. The well is tested for 30 minutes by introducing air in sufficient quantity to blow the water out of the well. The discharge end of the air line is lowered to the bottom of the hole.

A deflector is placed at the top of the well to deflect the water downward outside the well. A dike or other diversion is constructed around the well to contain the deflected water, and a discharge pipe placed near the top of this dike to allow the water to discharge through it. A container of known volume is used to collect water from this discharge for a measured period of time and the flow rate (gpm, L/min) calculated from this information and recorded. A V-weir can also be installed in the dike to measure water flow.

Air Lift Test Method. The well is tested by the air lift method, using an eductor pipe submerged 60 percent. Submergence is the length of the eductor pipe from its open lower end to the pumping level as related to the total length of the eductor pipe (**Figure 28**).

Sufficient air to provide an eductor pipe velocity of from 1,000 to 2,000 feet per minute (300-600 m/min) is needed. The air should be as finely divided as possible as it is introduced into the water. A series of upward-pointing jets placed in the air line improves the air dispersion.

Flow is controlled, diverted and measured as described for the "air blow test method".

Drawdown in a well in which an air-lift pump is working is measured between the casing and the educator pipe by any of the conventional methods. If air flow is monitored carefully during the airlift testing procedure, the drop in pressure can be used to determine drawdown while pumping. As the air is turned on initially, the pressure in the inductor pipe will rise steadily until the pipe has been evacuated. The pressure will rise until air bubbles are formed at the bottom of the inductor pipe. The absolute value of the maximum air pressure will determine the depth of submergence (psi/2.43 = ft of submergence). As pumping continues, the pressure maintained for a steady volume of air will drop if the well draws down. As the well draws down, the submergence will be less and thus the pressure needed to blow bubbles at the end of the inductor pipe is less.

9.2.2 Pumping Test Methods

General: To assure successful completion of a test, the pumping unit should be selected to be the appropriate size for the well test, based on preliminary rig-based tests or past history. The pump should be complete with prime mover of ample power, controls and appurtenances, and be capable of being operated without interruption for a period of

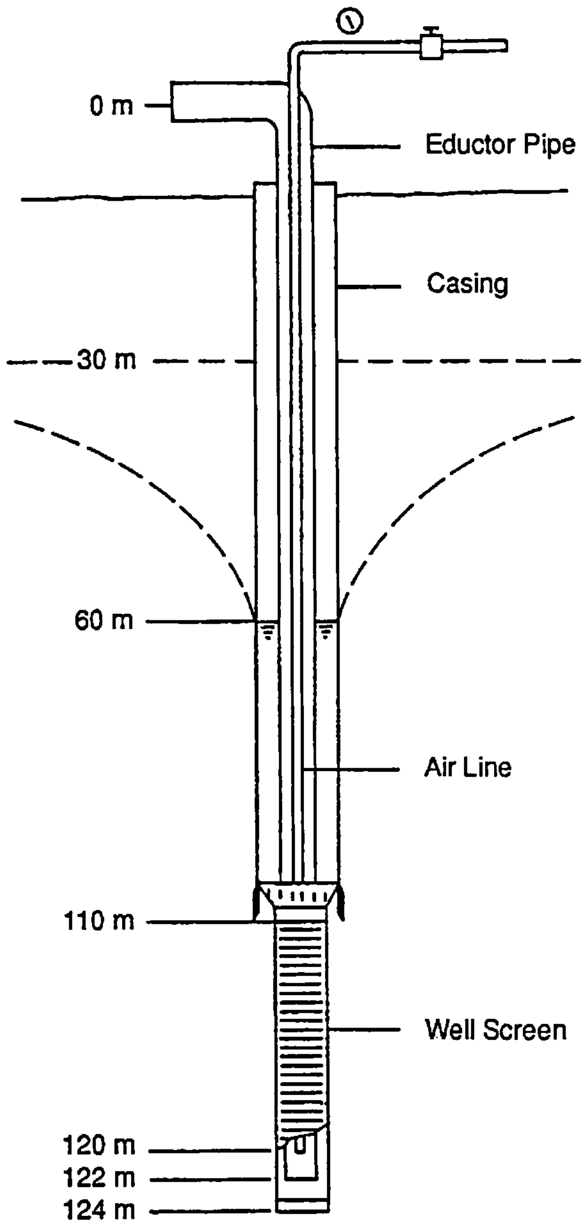


Figure 28. Air Lift Test Method Installation.

Figure is from the *Australian Drilling Manual.*

hours sufficient to complete the test. The pump intake is set at the depth of the lowest producing zone and pumped at the design rate for the prescribed period. The pumping discharge is equipped with satisfactory throttling devices (valves), to permit adequate flow control and an accurate means of measuring flow under the test conditions. Water levels are taken and flow measured by competent personnel using accurate methods.

Prior to starting the pump, sufficient water level measurements should taken in the production well and all observation wells to establish a reliable non-pumping dynamic (static) water level condition. These measurements are recorded as part of the pumping test.

The discharge is measured with an accurate totalizing meter and stopwatch, a circular orifice meter, or a Venturi meter, or any method acceptable for the test and those ultimately evaluating it. Discharge is maintained within plus or minus 5 percent of the designated rate over the period of the test (10% short-term variation) by means of a gate or ball valve or other throttling device. Discharge should be checked and adjusted as needed throughout the test. The discharge and time of measurement must be recorded each time it is checked and a note made of any adjustments. For proper interpretation of measurements made during pumping or recovery, a static or non-pumping dynamic water level trend must be established. This is done by making periodic reliable non-pumping dynamic (static) water level measurements in the pumping and observation wells for a period of time at least equal to the duration of the proposed test and prior to its start. Where at all possible, water levels should be recorded in feet and 1/10s of feet or meters to two decimal places with an accurate water level recorder. Discharge should be accurately measured and maintained within 5 percent of the testing rate over the duration of the pumping test, with short term variation not more than 10 % of the pumping rate (**Figures 29 A,B,C,D**).

Drawdown is measured according to a pre-set schedule acceptable to those using the pumping test data (e.g., hydrogeologists). The schedule should have closely spaced measurements early in the test, declining in frequency on an approximately logarithmic scale. At least ten measurements should be taken over any log time period (10 in first 10 minutes, 10 over next 100 minutes, etc.). One recommended schedule: 0 to 10 minutes-every minute; 10 to 45 minutes-every 5 minutes; 45 to 90 minutes-every 15 minutes; 90 to 180 minutes-each half hour; 180 minutes to the end of the test-each hour. Later stretches of stabilized tests, particularly for artesian aquifers, may permit less frequent measurements. Should the measurements not be made exactly at the times specified, it is important that the actual time of each measurement be recorded. On completion of pumping, recovery measurements are made according to the drawdown schedule.

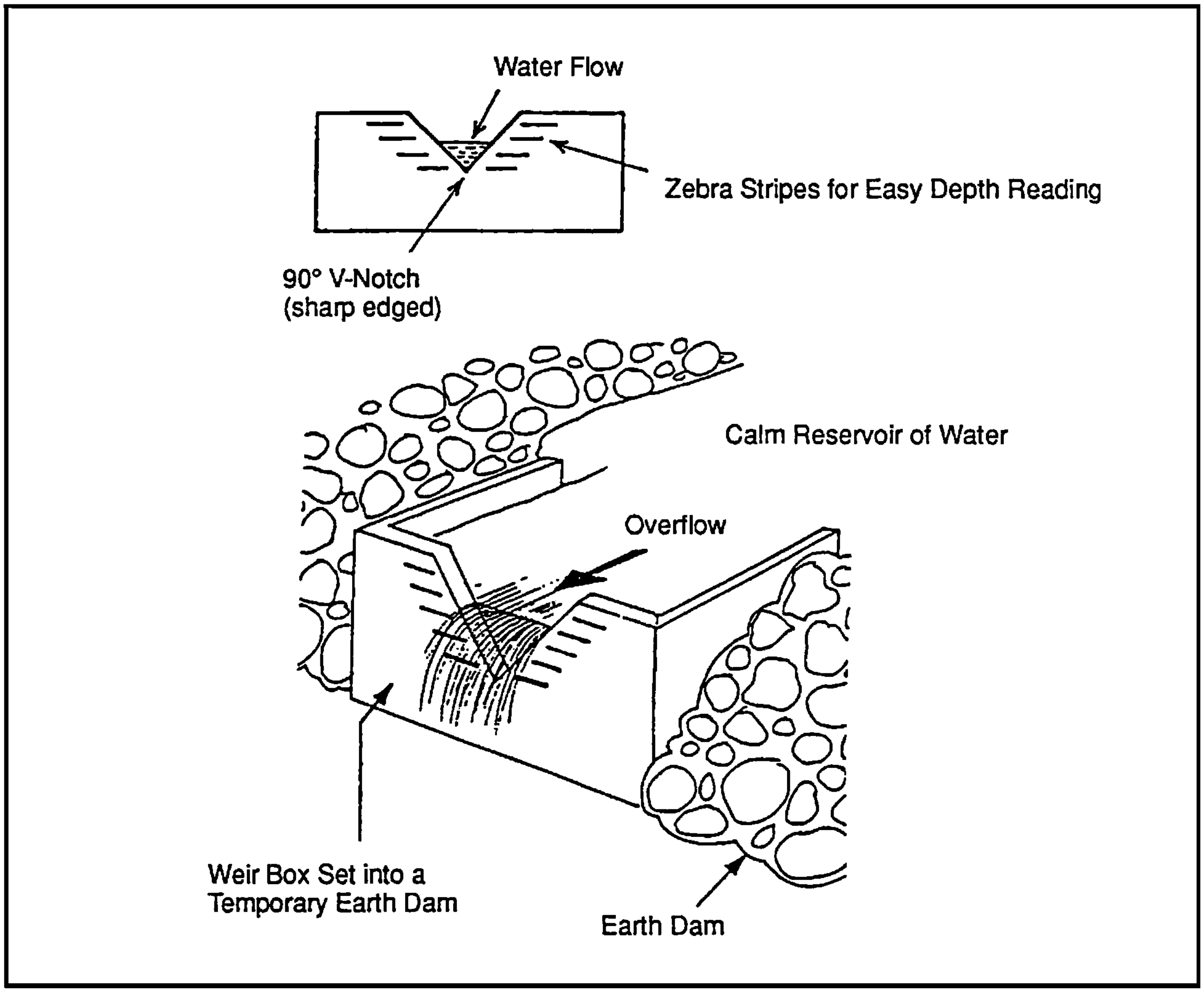


Figure 29A. V-Notch Weir.

Figure is from the *Australian Drilling Manual.*

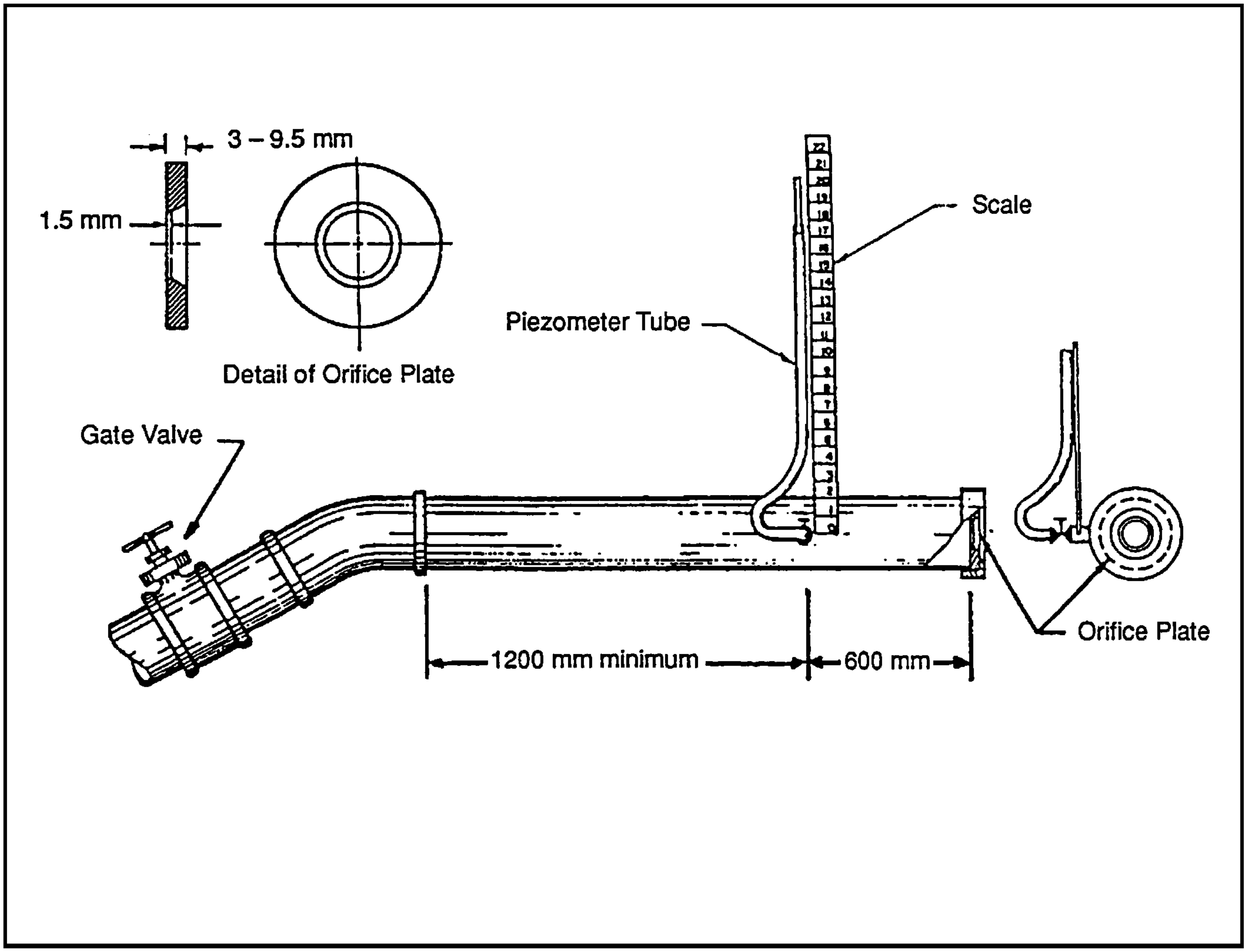


Figure 29B. Orifice Weir.

Figure is from the *Australian Drilling Manual.*

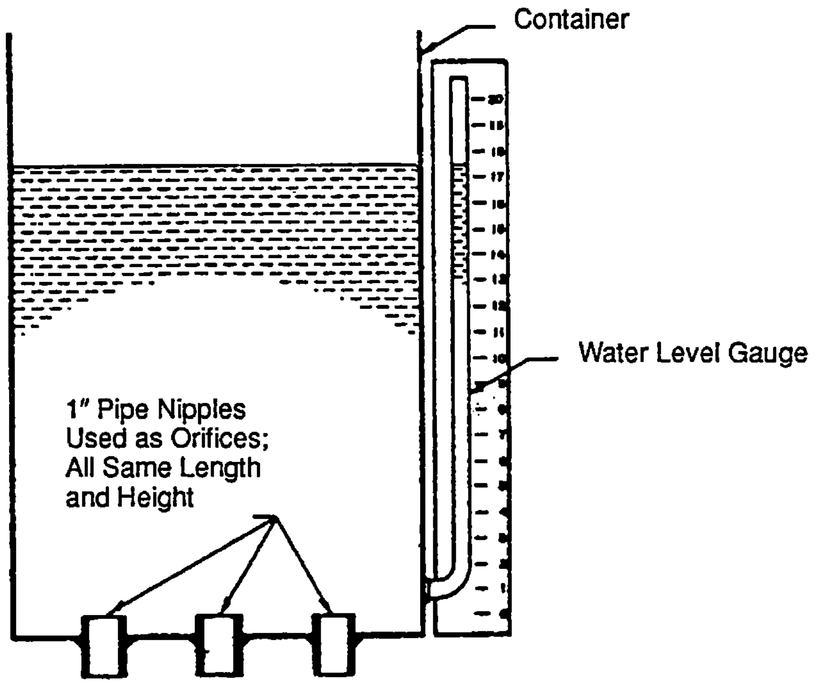


Figure 29C. Orifice Bucket.

Figure is from the *Australian Drilling Manual*.

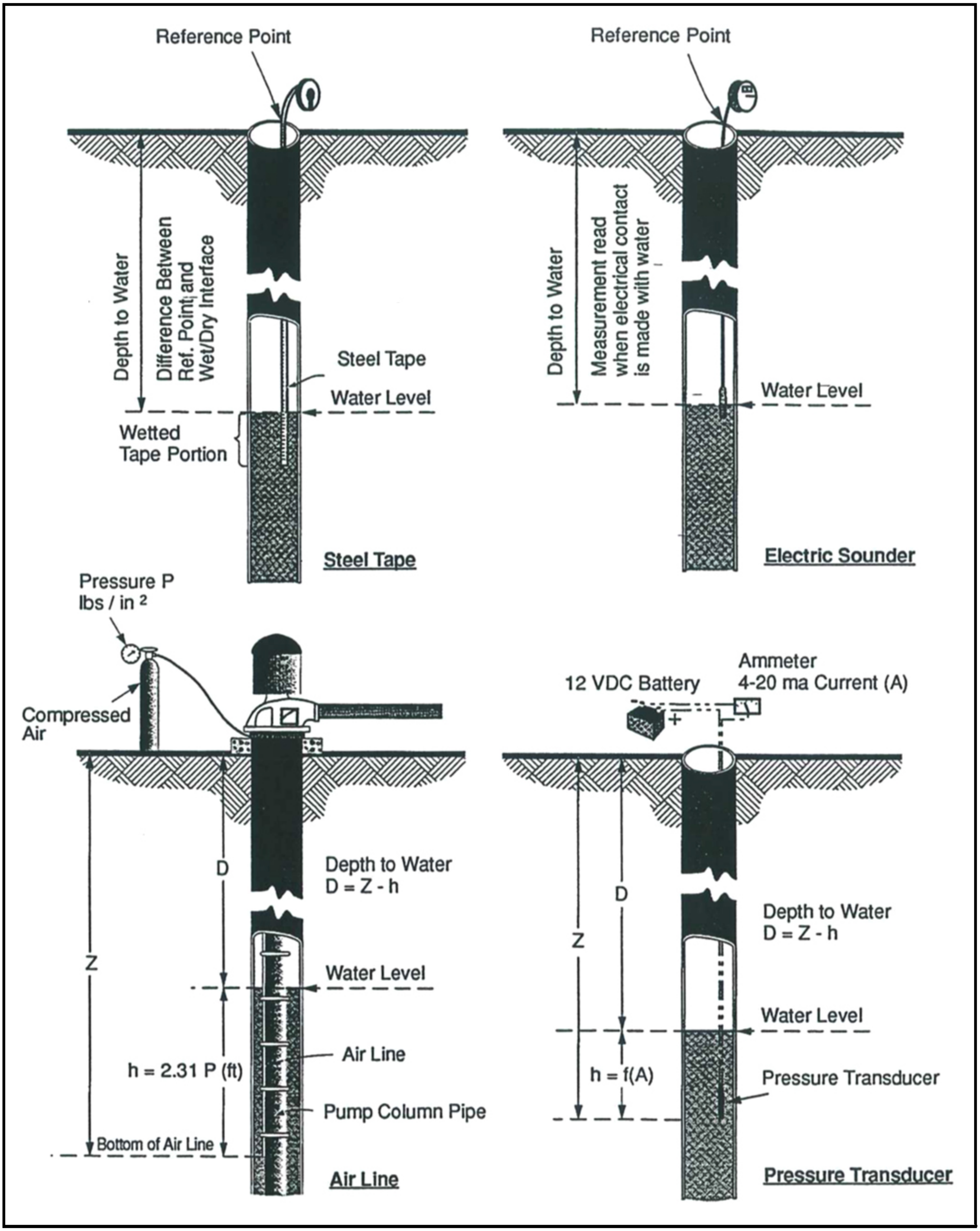


Figure 29D. Methods of Drawdown Measurement.

Figure is from the *Handbook of Ground Water Development*

Variable Rate (Reducing) Method. If the pump does not break suction for a period of 24 hours, the test is completed as a continuous rate test. The pump is operated at a rate expected to stress the well. If the pump breaks suction (or the PWL approaches the known pump intake level), the rate is slowly decreased until the pumping level stabilizes approximately 2 feet (0.6 m) above the pumping intake for a period of not less than 5 minutes. The pumping rate is then decreased 5 percent and the well pumped at this rate until the pumping level stabilizes for 1 hour. The discharge rate and drawdown thus established is then maintained for at least 4 hours. This pumping rate may be considered the available production rate of the well, and the observed pumping level during the test considered the production pump's pumping level.

Constant Rate Method. The constant-rate method provides information useful for well acceptance. The method also provides data to calculate aquifer hydraulic characteristics if well levels in observation wells known to be in hydraulic contact with the pumping wells are measured. The well is pumped at a pre-determined discharge rate that should not vary significantly for a set minimum of hours to meet the objectives of the test (well acceptance, defining boundary conditions, etc.). The test pump intake is set at least 5 feet (1.5 m) below the estimated lowest pumping level, and should have sufficient power and capacity to achieve the designated discharge rate. Drawdown measurements should be taken on a declining-logarithmic schedule as described above. For observation well level measurements to be reliable, drawdowns should mirror drawdown in the pumping well (show hydraulic connection) and be sufficiently large to be measured with confidence.

Conducting a constant-rate test with a fixed speed motor (e.g., a 3450-rpm submersible) requires that the pump and motor have sufficient capacity to pump the desired flow rate at the greatest expected drawdown. This is usually done by valving down output early in the test (producing backpressure on the pump) and opening the valve later as flow requires adjustment when drawdown increases.

Step-Continuous Composite (Step Test) Method. The step test is used for multiple purposes related to the performance of the pumping well itself. Examples:

(1) Provide more refined estimates of design pumping rates and projections of pumping water levels at increased rates,

(2) Assess well and formation loss and specific capacity at construction and periodically as a maintenance test, or before and after well cleaning and service.

Methods vary somewhat. Reliable tests have at least three steps and sometimes five or more. In a four-step test, the well is tested at rates of approximately 1/2, 3/4, 1 and 1-1/2 times the design capacity. Each step may be 60 to 100 min. (1 log cycle) in duration, or until stabilization (three measurements 10 min. apart show no change). Stabilization should be achieved. Drawdown measurements should be taken on a declining logarithmic pattern.

As with continuous-rate testing a 1/2-inch (13-mm) nominal diameter or larger straight and rigid drawdown tube should be installed from a point 2 feet (0.6 m) above the pump intake to the wellhead. The top of the pipe must be readily accessible to insert, remove, and read the depth to water measurements on an electric water-level sounder, which is the preferred manual drawdown measurement tube for a step test. Alternatively, a transducer-based recording system may be used to measure the static water level and drawdown in the well. A clearly marked convenient reference point is set at the top of the pipe.

Step-Pumping and Recovery Test. A variation of the step-continuous test includes a recovery period between steps.

After recovery from the step test is complete, a constant rate test may be conducted by pumping the well at the design rate or at maximum yield for a period of not less than 24 hours and until the pumping level remains constant for at least 4 hours, or until the well owner-operator or hydrogeologist terminates the test.

9.3 Test Planning Considerations

9.3.1 Suspended Tests

Whenever the specified conditions of the pumping test cannot be met, the test is suspended. Tests may resume after the water level in the pumped well has recovered to ~95 % of its original level. Recovery can be considered "complete" if any three successive water level measurements spaced at least 20 minutes apart show no further rise in the water level in the pumped well. The test may be resumed immediately afterward. The supervising professional (hydrogeologist, licensed driller, engineer) should make the decision as to whether recovery is sufficiently complete for test conditions.

9.3.2 Location of Discharge

Discharged water should be conducted from the pump to the nearest surface-water body, storm sewer, or ditch, as approved by the property owner and other affected parties if necessary, or to a sufficient distance to prevent recirculation of discharged water into the aquifer being tested. More care is required for water-table aquifer conditions and more permeable surface soils to assure that recharge immediately adjacent to the well does not affect pumping water levels through recharge. It is imperative to insure that no damage by flooding or erosion is caused to the chosen drainage structure or disposal site.

9.3.3 Record of Pumping Tests

Personnel conducting a pumping test must keep accurate records of the test and furnish copies of all records to others involved in the operation and approval of the well, including the well's owner-operator and regulatory or water resources agencies. The records should also be available to the owner or professional advisor (e.g., hydrogeologist) for inspection at any time during the test, and features explained if necessary.

For each well used in the test, the records must include physical data describing the construction features such as, but not limited to: well depth and diameter, complete screen description, length, and setting; a description of the measuring point and its measured height above land surface and/or mean sea level; the methods used in measuring water levels and pumping rates. An accurate description or sketch map of the well locations with identifying names or numbers and distances between wells or from bodies of water should be provided as a part of each set of records. Records of measurements must include the date of the test, the clock time and elapsed pumping time of each measurement, the depth to water below the measuring point, the pumping rate at the time of measurement, and any pertinent comments on conditions that may affect the measurements.

9.3.4 Measurement of Water Levels

Water levels can be measured with a steel tape, by flagging the bailer line, by reading pressure on an air line, with an electric sounder (preferably used through a 1/2-inch, 13-mm, or larger conduit), or calibrated pressure transducer.

Accuracy to within plus or minus 0.1 feet (15 mm) must be attained with values recorded to the nearest estimated 0.05 ft. Accuracy may be required under special conditions to within plus or minus .01 feet (3 mm). Personnel taking water level measurements should be familiarized with the specific operations of the test device to be used.

Bailer Line Method. The bailing line is marked and measured from the bottom of the bailer to a point which is even with the top of the casing when the bailer encounters water. On the last run of the bailer on a bailer test, this measurement is recorded as the "bailed down" level.

Air Line Method. A 1/4-inch (6-mm) rigid, straight tube free of air leaks is installed in the well with the test pump, terminating 5 feet (1.5 m) above the pump intake. The tube is fitted with an accurate altitude gage and air valve attached to it at the surface. The vertical distance from the bottom of the air line to the center of the gage is recorded. The line is then charged with air under pressure of at least 1 psi (0.1 Kg/cm^2) for each

2.31 feet (0.76 m) of air line and until the gage will read no higher, and the water level in the well computed by subtracting the altitude in feet registered on the gage from the length of the air line. This method is not recommended for small drawdowns due to its lack of precision.

Steel Tape Method. Water levels less than 300 feet (90 m) deep may be measured by chalking a weighted steel tape, lowering it a known distance into the well and determining the depth by subtraction of the submerged part of the tape as indicated by the wetted chalk mark. If the steel tape is to be lowered through a metal or plastic tube, the tube must be sufficiently large in diameter to permit free passage of the tape, and its bottom must terminate approximately 2 feet (0.6 m) above the pump intake.

Electric Sounder Method. The electric sounder is lowered in the well until an audible or visual signal indicates that the probe has contacted the water. The level on the tape at the test reference point is then recorded. Sounders should conveniently show feet and 1/10 feet or meters to two decimal places under field conditions, have both an audible and visual signal detectable under field conditions for optimal convenience, and be accurate to 0.05 ft or 15 mm. One specific tape should be used throughout the test for a specific well to avoid bias due to differences among tapes.

In the pumping well and in observation wells where cascading water may interfere with accurate drawdown measurement, a 1/2-inch (13-mm) or larger diameter straight, rigid pipe is installed in the well from the surface to 2 feet (0.6 m) above the pump intake. The upper end of the pipe is arranged to that an electric sounder and line may be easily inserted, lowered, raised and read. Static water level, drawdown, and recovery measurements are made through this pipe, which should have a clearly marked and readily accessible reference point at the top.

Automatic Electronic Transducer Method. In this method, a pressure transducer capable of detecting the difference in pressure due to changes in water level in a well is lowered to just above the pump in the pumping well or fixed depth in observation wells. The transducer output signal is recorded as depth to water surface. This method permits automatic data collection at very small and fixed intervals. Data may be collected from multiple points in a signal data recorder and may be collected unattended by personnel. Sounders should be checked for accuracy prior to installation, and connections and data recorder operation checked to assure that they are in order. Unattended tests should be manually checked periodically to assure proper operation.

9.3.5 Collection of Water Samples

Water sampling and analysis are discussed in Chapter 11 of this manual. Well project planning should coordinate necessary project tasks such as well testing and sample collection to meet the goals of each.

9.3.6 Pumping Test Standards

As in well construction, standards in well testing permit users of the data to have confidence in the validity of the test data, and to know how they were collected. Individual states and other jurisdictions may have specific well test requirements that should be adhered to. This chapter may be used as guidance as well. Existing consensus standards relevant to well pumping tests have been published by ASTM. Most relate to the analysis of hydrogeologic testing data and other project-level factors (minimum data elements to identify a site, for example). Several are directly relevant to the performance of the tests themselves (Table 9.1):

Table 9.1
ASTM Standards Relevant to Well Pumping Tests

Standard Designation	Title and Significance in Pumping Tests
D 4043	Standard Guide for Selection of Aquifer-Test Method in Determining Hydraulic Properties by Well Techniques: Which test analytical method to choose for a specific aquifer situation (affects how the test is conducted).
D 4050	Standard Test Method (Field Procedure) for Withdrawal and Injection Well Tests for Determining Hydraulic Properties of Aquifer Systems: How to conduct a pumping test.
D 5716	Standard Test Method for Measuring the Rate of Well Discharge by Circular Orifice Weir: Specifics of how to construct and use an orifice weir. Note that some variation in the illustrated design is permissible and still provide valid data.
D 5737	Standard Guide for Measuring Well Discharge: A general guide to using flow measurement devices, including open-channel methods.

The above testing discussion is consistent with D 4050. As with all consensus standards, they are guidelines and not to be construed as having regulatory weight. Also, tests are most likely to be valid if conducted and supervised by trained and experienced ground water professionals. It is reasonable, based on professional judgment, to vary practice to meet the practicalities of the test situation while still obtaining valid data. Reference to the standard in a well testing report suggests that the testing personnel conformed with the standard, and any deviation from it should be noted. Other standard test methods and standard guides may be in development, and are published annually by ASTM. Standards are by ASTM practice reviewed and updated as necessary every five years. It is recommended that ground water professionals be familiar with these and other relevant standards.

References

ASTM. Guide for the Development of Ground-Water Monitoring Wells in Granular Aquifers, *1993 Annual Book of ASTM Standards, Vol. 4.08, ASTM, West Conshohocken, PA.*

ASTM. Guide for the Development of Ground-Water Monitoring Wells in Granular Aquifers, *1996 Annual Book of ASTM Standards, Vol. 4.09, ASTM, West Conshohocken, PA.*

Borch, M.A., S.A. Smith, and L.N. Noble. 1993. *Evaluation, Maintenance, and Restoration of Water Supply Wells. American Water Works Association Research Foundation, Denver, CO.*

Driscoll, F. 1986. *Groundwater and Wells, Johnson Division, St. Paul, MN.*

Herbert, R. and J.A. Barker. 1990. Predicting and interpreting well behaviour and well efficiency. in: *Water Wells: Monitoring, Maintenance, Rehabilitation (Proc. of International Groundwater Engineering Conference, Cranfield Institute of Technology, Cranfield), P. Howsam, ed., E&FN Spon, London, UK. pp. 114-129.*

Queensland Dept. of Primary Industries. General arrangements and details: Orifice bucket, standard weir boards, aluminium orifice meter. DPI South Region, Toowoomba, Q., Australia.

NWWA Committee on Water Well Standards. 1975. *Manual of Water Well Construction Standards, EPA - 570/9-75-001. Office of Water Supply, Washington, DC.*

Roscoe Moss Co., 1990. *Handbook of Ground Water Development. Wiley-Interscience, New York.*

Chapter 10
Well Disinfection

10 Well Disinfection

While well siting regulations, standards, and good practice in well location and construction serve to minimize contamination, further precautions in the form of disinfection during and after construction is recommended. Well disinfection is a necessary part of final well completion to remove any coliform bacteria or pathogens that may have been introduced during the well construction process.

The following disinfection procedures are intended for basic sanitation as a part of well construction and service, and not for well rehabilitation or maintenance disinfection to remove biofouling. These procedures are considered separately in other publications referenced at the end of this chapter.

The disinfection practices described are also intended for the removal of transient and accidental introduction of relatively low levels of "foreign" microorganisms, and not to counteract persistent contamination from an outside source, or to exclude native microflora. The effect of disinfection practices on various potential pathogens (including viruses) and native microflora varies considerably and is poorly documented. Most disinfection experience in ground water construction relates to removal of coliform bacteria.

Contaminants in the form of grease, oil, soil and other foreign substances can harbor and protect microorganisms from subsequent disinfection and must be removed for effective disinfection. Generally mechanical extraction, swabbing and pumping have proved effective for most cleaning requirements. Cleaning and disinfecting chemicals should only be employed where responsible and competent authority has approved their use, the amount to be used and the method to be employed.

Well drilling equipment and tools should be kept clean and a conscientious effort made to prevent the transporting of foreign material from one well site to another. Water used for the drilling fluid should be clean and free of organic material and/or minerals which would impair the qualities of the drilling fluid. This does not preclude the use of approved commercial organic drilling fluid additives, but they need to be removed to below detection levels prior to final disinfection.

Where test pumping equipment is to be utilized, such equipment should be installed prior to or during disinfection and be thoroughly hosed, scrubbed or otherwise cleaned of foreign material.

10.1 Chlorination Purpose and Application in Well Construction

Normal water well disinfection practice is to utilize a chlorine solution prepared with either calcium hypochlorite (powdered or tablet form) or sodium hypochlorite in liquid form. Liquid chlorine (under pressure and fed as a gas), may also be used with appropriate training and equipment. The effectiveness of a chlorine solution is generally misconstrued to be the theoretical amount of free chlorine in the solution. The effectiveness of the solution is primarily related to the amount of hypochlorous acid (HOCl) present and not to the total free chlorine, commonly referred to in regulations dealing with well chlorination. Because the formation of HOCl is retarded at higher pH values, and standard chlorine compounds increase pH, a 100 ppm chlorine solution -- prepared with neutral (pH 7) water -- may be a less effective germicide than a 50 ppm solution prepared with water of lower pH. Effectiveness is also related to the amount of contact time. With a contact time of 8 hours, or more, chlorine solutions of 50, 100 or 200 ppm apparently provide adequate effectiveness against pathogenic organisms.

It should be noted here that appropriate compounds of iodine, bromine, ozone or other disinfectants may also serve as disinfectants in place of chlorine, but have practical drawbacks for purposes of primary well disinfection.

The following paragraphs represent special conditions rather than normal disinfection practice:

(1) Where the ground water has a low pH value, caution should be exercised with the use of chlorine as a disinfecting agent if a lengthy contact period is anticipated due to the highly corrosive nature of a chlorine solution with a low pH value.

(2) As noted previously, continuous or periodic disinfection during the construction of a well may be desirable. In such instances care is required to ensure that disinfection not interfere with the work of construction (e.g, drilling mud properties).

(3) Interim chlorination with a solution of 5 to 10 ppm of free chlorine is advisable when several days will elapse between well completion and the carrying out of normal disinfection required by regulatory agencies. While not normally acceptable for final disinfection by most state regulatory agencies, a chlorine dose of 5 to 10 ppm should provide adequate protection where prolonged contact time -- days rather than hours -- is assured. Where domestic wells are complete weeks before permanent pumping equipment is installed, an interim disinfection with a 5 to 10 ppm concentration should be carried out with the solution remaining in the well for the entire interval between well completion and the time the permanent pump is installed.

Scheduling of disinfection should not normally pose a problem regardless of the type of well involved except where sampling for analysis of volatile or synthetic organic compounds is anticipated (well acceptance testing for public wells governed by the Safe Drinking Water Act). If VOC or SOC testing is not anticipated, disinfection should immediately follow completion of the well. For public water supply wells (SDWA testing), chlorination should be delayed until SOC and VOC samples are taken, but should precede installation of the permanent well pump. If chemical sampling of a chlorinated well must be repeated, chlorine should be pumped out below instrument detection (<0.01 mg/L) before samples are taken.

It is of major importance in well disinfection to insure adequate distribution of the disinfecting agent in the well and also to that part of the well above the static water level. Usually a solution is prepared prior to placement of the disinfectant into the well. However, where disinfection with a dry chlorine compound is necessary or permitted -- without first preparing a liquid solution (e.g., in treating flowing artesian wells) -- appropriate means must be provided to achieve a relatively even application of the compound to the bottom of the well screen or intake area and throughout the well. Pellets or powdered chlorine compound must be used with a mechanical carrier.

Unless the chlorine is evenly distributed, the disinfectant may move laterally rather than to the bottom of the well. An appropriate tremie device -- hose or pipe -- should be employed to insure proper distribution of the disinfectant. Agitation through use of a bailer, surge block, or by intermittent stopping and starting of a test pump is recommended to force some of the solution into the water-bearing formation around the well. However, agitation is not an alternative to adequate distribution of the concentrated chlorine solution in the first place, because even distribution may not be achieved by agitation.

If a test pump is available during disinfection, it provides a convenient means for application of the disinfecting solution to the dry part of the well through a hose. The discharge piping of either a test pump or permanent pump can incorporate a tap and hose connection on the pump side of a valve. Intermittent pump operation for surging will not interfere with hose application of the solution to dry parts of the well, or in keeping such parts wet for an adequate period of time. When a pumped supply of dilute chlorine solution is not available for this purpose, a separate tank and gravity system will be needed.

Although partial disinfection of the well system may be done during testing, a final disinfection must be the final act of well completion, eliminating any chance of contamination.

10.2 Well Chlorination Specifics

10.2.1 Disinfectants

For the most part, chlorine-containing compounds approved for potable water use (as certified by NSF International or other appropriate agency) may be considered the primary disinfectants of choice for water well applications. Other compounds approved by state or local regulatory agencies for potable water use may be used as disinfectants.

The disinfectant must be recently purchased and delivered to the work site in original closed containers bearing the original label indicating the percentage of available chlorine to assure maximum effectiveness during treatment (all formulas and calculations assure the chlorine compound conforms to its labeled properties). Chlorine compounds in dry form should not be stored for more than one year and storage of liquid compounds should not exceed 60 days. During storage on site, disinfectant containers must be kept closed and should be stored away from exposure to direct sunlight. Otherwise, the disinfectant will lose potency, and unacceptable byproducts, such as chlorate, will be formed.

Warning: All chlorine compounds are powerful oxidants. If spilled on grease or oil, the potential for explosion or ignition exists. Contact with cloth, rubber, some plastics or skin may cause deterioration and irritation. Avoiding skin contact is recommended. Chlorine corrodes metals and degrades submersible pump wire, and should be flushed from surfaces. All chlorine compounds should be handled with appropriate ventilation. Breathing chlorine dust or concentrated hypochlorous acid vapors may cause damage to mucous tissues. Liquid Cl_2 must be handled with all safety precautions by personnel trained in its use with appropriate safety and emergency procedures in place. All containers should be rinsed and recycled properly in cooperation with the chemical supplier.

A widely used standard for sufficient chlorine in new well or well-repair disinfection (unless superseded by a more strict governmental regulation) is a quantity of chlorine compounds sufficient to produce a minimum of 50 mg/L available chlorine in solution when mixed with the total volume of water in the well (ANSI/AWWA C654). A 50 ppm solution should result from utilizing quantities of chlorine compounds, proportion to the depth of water, as listed in Table 10.1.

Table 10.1
Chlorine Compound Required to Dose 100 Feet of Water-Filled Well at 50 mg/L

Borehole or Casing Diameter (inches)[1]	Volume per 100 ft of Water Depth (gallons)[1]	Amount of Calcium Hypochlorite[2] (65% available HOCl)	Chemical Compound Sodium Hypochlorite[3] (12 trade percent[4] Available HOCl)	Liquid Chlorine (100% Available Cl_2) (lb)[1]
4	65.3	0.7 ounces (oz)[1]	3.5 fluid ounces (fl oz)[1]	0.03
6	146.9	1.5 oz	7.8 fl oz	0.06
8	261.1	2.7 oz	13.9 fl oz	0.11
10	408	4.2 oz	1.4 pint (pt)	0.17
12	587	6.0 oz	2.0 pt	0.25
16	1,044	10.7 oz	3.5 pt	0.44
20	1,632	1 lb 1 oz	0.7 gal	0.68
24	2,350	1 lb 8 oz	1.0 gal	0.98
30	3,672	2 lb 6 oz	1.5 gal	1.53
36	5,287	3 lb 6 oz	2.2 gal	2.21
48	9,400	6 lb 1 oz	3.9 gal	3.92
60	14,690	9 lb 7 oz	6.1 gal	6.13

[1]SI (metric) conversions are provided in Table 10.2.
[2]Quantities of $Ca(OCl)_2$ based on 65% available chlorine by dry weight (16 oz = 1 lb).
[3]Quantities of NaOCl based on 12-trade-percent available chlorine by US liquid measure (1 gal = 4 qt = 8 pt = 128 fl oz).
[4]Trade percent is a term used by chlorine manufacturers: trade percent × 10 = grams available chlorine in 1 L of solution.
Source: Table A.1, Appendix A, ANSI/AWWA C654.

Table 10.2
SI (metric) Conversions for Well Chlorination

US Customary Unit	Conversion Factor	SI Equivalent
Inch (in)	× 25.4	millimeter (mm)
Feet (ft)	× 0.3048	meter (m)
US gallon (gal)	× 3.7854	liter (L)
US pint (pt)	× 0.9232	liter (L)
Fluid ounce (fl oz)	× 0.02957	liter (L)
Avoirdupois (wt) ounce (oz)	× 0.02835	kilogram (kg)
Pound (lb)	× 0.45359	kilogram (kg)

Source: Table A.2, Appendix A, ANSI/AWWA C654.

Note: Liquid sodium hypochlorite in a 12 percent solution is often sold for water and wastewater treatment plant use, as a commercial bleach, or for use with swimming pools. Using a "home use" chlorine bleach solution such as Clorox with a 5.25 % available NaOCl would require approximately 2.3 times as much product (2.3 gal per 1 gal).

To obtain a 100-mg/L solution (e.g., as recommended by the Illinois Department of Public Health), double the amounts indicated in Table 10.1.

Where a dry chemical is used it should be mixed with water to form a chlorine solution prior to placing it into the well for best distribution. Liquid chlorine should be metered with an appropriate chemical feed pump into water to form a solution prior to placing it in the well.

10.2.2 Interim Well Disinfection

Should a delay of three days or more be anticipated between the completion of the well and the regularly scheduled well disinfection, an interim disinfection should be applied unless chlorination may potentially interfere with VOC or SOC analytical results. Install an approved disinfecting agent in an amount equal to 10 percent of the amount required for final disinfection (amounts 0.1 x Table 10.1 values). Prepared solution in liquid form is placed in the well through a hose or tremie of sufficient length to extend to the bottom of the well. The hose is raised and lowered to achieve uniform distribution of the solution throughout the well.

10.2.3 Daily Operations Disinfection

Daily chlorination of the well may be employed during long and relatively slow well construction operations. The amount used should be sufficient to maintain a measurable residual in drilling fluid or the bore water column in cable tool drilling.

10.2.4 Well Completion Disinfection Procedure

Unless otherwise modified due to problems involved with the specific well or conflict with governmental regulatory requirements, one or more of the following disinfection procedures may be employed. For each method of well-bore disinfection, the disinfecting agent is left in the well (or applied) for a period of at least 12 hours. After a 12 hour (or longer) contact period (but not longer than 24 hr), the well is pumped to clear it of the disinfecting agent. Achieving the appropriate chlorine residual should be confirmed by testing with field chlorine test instruments.

<u>Pre-treating permanent equipment to be installed</u>: All installed equipment should be clean and free of soil or other contaminant material. Exposed surfaces may be treated with a 200-mg/L chlorine solution just prior to installation.

<u>Above-water-level chlorination</u>: All accessible portions of the well above the water level should be maintained in a damp condition with water containing the required concentration of disinfecting agent for a period of not less than 20 minutes.

<u>Emplace chlorine solution and chase with water</u>: Provided that reliable means exist for insuring that the disinfecting agent is uniformly applied throughout the entire water depth of the well without relying on subsequent mechanical or surging action for dispersing the disinfectant, the dispersion of the disinfectant may be assisted by pouring into the well a volume of water equal to the volume of the screen, after the disinfectant has been emplaced. This will cause the disinfectant to flow out of the well into the area adjacent to the screen.

Disinfection of Water Table Drilled Wells:

(1) Dry Chlorine Compounds. A perforated pipe container (capped on both ends), filled with the appropriate amount of a granular chlorine compound for the well, may be moved up and down the entire well bore until the material has dissolved. Confirm the final chlorine residual by testing.

Alternatively, dribble 5-g size tablets into the water column (avoiding lodging on the casing or equipment above the water level) and wait 30 min. or more to allow them to dissolve, then surge to distribute. Confirm the final chlorine residual by testing.

(2) Stock Solution (a). A stock solution sufficient to produce 50 ppm of available chlorine is added to the well at different intervals by tremie pipe from top to bottom and then agitated to distribute it evenly throughout the well.

(3) Stock Solution (b). A stock chlorine solution of 15,000 ppm is added to a continuous flow of water into the well to produce a 50-ppm concentration of available chlorine throughout the well.

(4) Prepared Solution. The chlorine solution of the appropriate concentration to disinfect the well is prepared on the surface in containers having an aggregate volume equal to at least twice the volume of water in the well and then rapidly discharged into the well so as to thoroughly flush that portion of the casing which is above the water level.

Disinfection of Flowing Artesian Wells:

(1) Dry Chlorine Compounds. A perforated pipe container, capped on both ends and filled with a granular chlorine compound, is placed at a point on or below the top of the producing horizon. This process is repeated as often as necessary to achieve and maintain the standard 50-ppm concentration for a period of not less than one hour.

(2) Controlled Flow Disinfection. Flow is first controlled by either capping or by a suitable standpipe.

(a) In the event the well is capped, a stock chlorine solution is injected under pressure by means of a drop pipe to the bottom of the well. The cap is equipped with a suitable one-inch (25-mm) valve. After the injection is complete, air is injected for agitation while simultaneously opening the valve in the cap permitting the chlorine solution to be dispersed to the surface. When chlorine is detected at the surface outflow, the valve is then closed and the flow stopped. The chlorine concentration is maintained at 50 ppm for at least six hours.

(b) In the event that flow can be controlled by a suitable standpipe, the chlorine treatment can be conducted as though the well was non-flowing.

(3) Stock Solution. A stock chlorine solution is applied for a period of not less than one hour at a point at or below the top of the producing zone. The rate of application

is such that the standard 50-ppm concentration is achieved and maintained during the application period.

Bored (including buried slab) wells:

Drilled wells typically do not provide a large amount of casing storage (<1.5 gal/ft in a 6-inch-diameter well). In some fine formations, it is customary to construct larger diameter (36-in.) bored wells. Some of these are completed well below the ground surface with a top slab and finished to the surface with casing.

The particular designs of these wells pose disinfection challenges:

(1) Assuring adequate chlorination of top slabs, pipe joints, and cement tiles.

(2) Because there is minimal water in the casing, and the aquifer has a low hydraulic conductivity, backflushing into the formation is difficult to impossible.

(3) Flushing a chlorine solution of sufficient concentration to disinfect the inside and gravel pack surfaces of the well may require two or three well volumes to be emptied. This may take 10 to 12 days.

(4) Hauling disinfectant water would require significant volumes of water. For example, at 53 gal. per ft., a 40-ft 36-in. diameter casing would require 2,120 gallons of solution.

In addition to chlorinating the gravel packs of these wells upon installation (see following), one recommended procedure involves:

(1) installation of two 1-in.-diameter PVC pipes from the surface, along the riser casing, and into the gravel pack (180° apart).

(2) After the well pump is installed, chlorine is mixed into the pumped water and circulated back down into the gravel pack. The chlorinated water flows through and fills the pack before penetrating the cement tile.

(3) The chlorinated water is circulated through each disinfectant pipe in turn for a minimum of 3 hr for a total of 6 hr, after which the well would sit for a minimum of 3 to 4 hr of contact time.

(4) The well is then flushed and ready for use.

10.2.5 Filter Pack Material Chlorination

Filter pack material being installed in new wells or replenished in existing wells should be chlorinated upon installation to minimize microorganisms introduced from the surface.

Warning: In all cases, one more good reason for filter pack to be free of organic materials is to avoid any potential for explosion when mixed with concentrated chlorine.

Filter pack material in new installation: Prior to installation, drilling fluid should be thinned and the fluid level maintained at the surface.

(1) Tablet procedure. Calcium hypochlorite tablets (5-g size) are mixed with gravel in a proportion of 1/4 lb to 1/2 lb (110 - 220 g) per ton of gravel, taking care to mix as uniformly as possible. The mixture is then fed by gravel chute to fill the annular space to the level desired.

(2) Chlorine residual in drilling fluid. When the drilling fluid is thinned, continue circulation and add chlorine to produce a chlorine residual of not less than 50 mg/L in the entire volume of the fluid within the borehole. The pack material is then fed by gravel chute to fill the annular space to the level desired. Chlorine residual is measured periodically and chlorine feed adjusted as necessary.

Filter pack being replenished: Immediately prior to installation, soak filter pack in a chlorine solution maintained at not less than 50 mg/L for at least 30 min.

Chlorinating existing gravel packs to remove suspected contamination: If a gravel chute is maintained in place, an attempt can be made to feed a solution of at least 100 mg/L chlorine down the chute. Feeding is continued at up to 20-50 gpm (70-190 L/min) until the chute can no longer accept water or until the volume fed is twice that of the annular space (fluid and pack material combined) in the filter pack zone.

Agitation required: Mixing granulated chlorine with filter pack material relies on ground water dissolving the chlorine in water to the appropriate concentration and moving the chlorine through the pack. The water seeping into the filter pack has very little agitation ability, so that mechanical agitation is required for adequate distribution.

10.3 Personnel Qualifications

Although simple in concept, well disinfection can be difficult in actual practice. Investigations into problems with well-owner chlorination indicates the following problems:

(1) Over-chlorination and damage to well equipment.

(2) Poor distribution of chlorine compound with available means of recirculation, with resultant damage to casing, pipe, pump and pump wire, and at the same time, inadequate mixing to assure disinfectant contact throughout the well.

(3) Lack of adequate mixing and surging, particularly for wells already biofouled, to remove disinfectant-neutralizing material and assure adequate distribution.

(4) Inability to understand or follow instructions.

Supervision or performance of chlorination by trained personnel are recommended. Testing should follow to provide quality assurance.

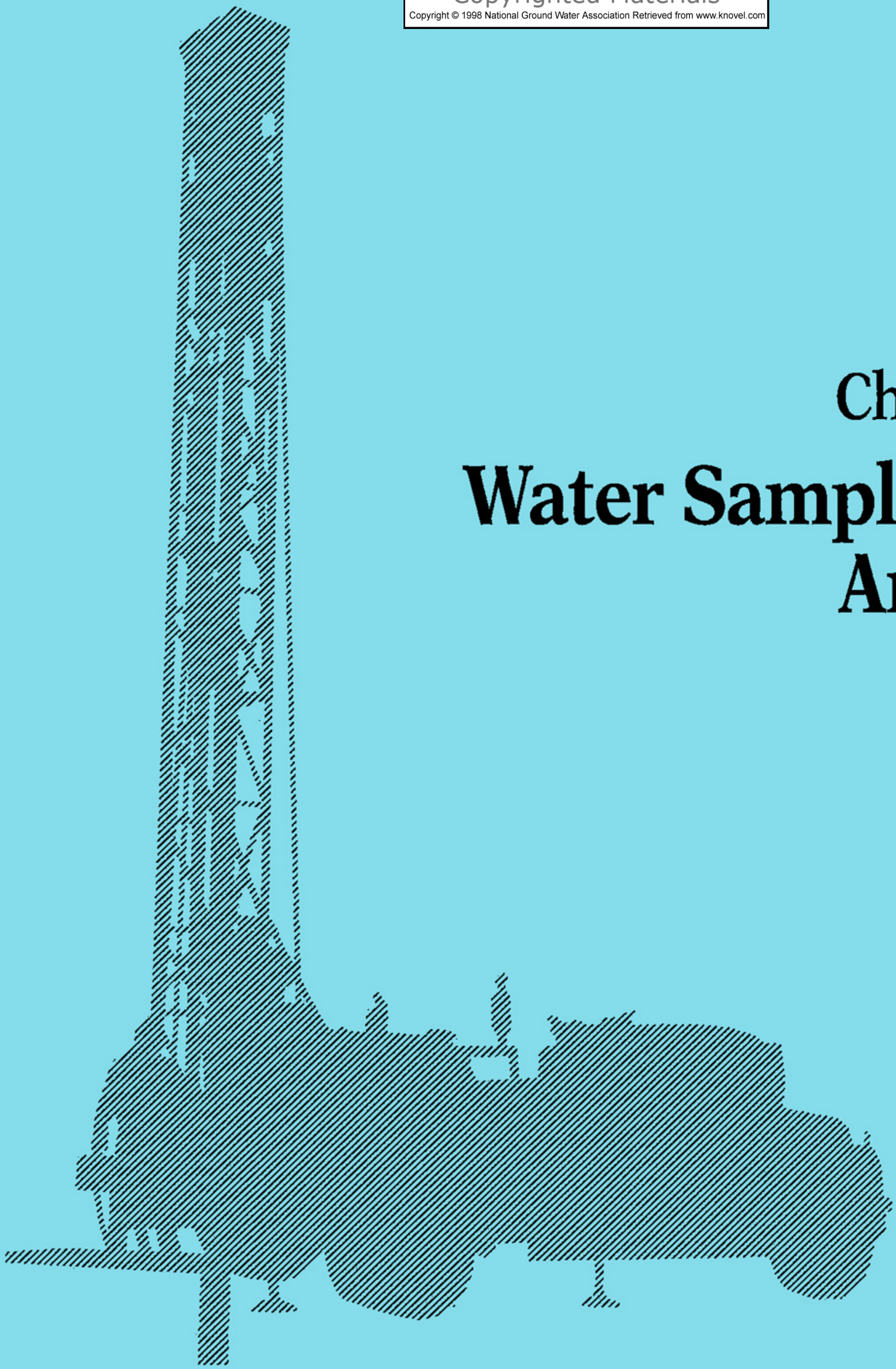
References

ANSI/AWWA C654. *AWWA Standard for Disinfection of Wells. American Water Works Assn., Denver, CO.*

Borch, M.A., S.A. Smith, and L.N. Noble. 1993. *Evaluation, Maintenance, and Restoration of Water Supply Wells. American Water Works Association Research Foundation, Denver, CO.*

Illinois Assn. of Groundwater Professionals. 1996. "Disinfection Program year-end report for fiscal year ending June 30, 1996." River Forest, IL.

NWWA Committee on Water Well Standards. 1975. *Manual of Water Well Construction Standards, EPA - 570/9-75-001. Office of Water Supply, Washington, DC.*



Chapter 11

Water Samples and Analysis

11 Water Samples and Analysis

11.1 Background and Practice in Sampling and Analysis for Wells

Ground water from wells is tested to evaluate the ability of a well to provide a quality of water suitable for intended uses. Presence of disease-causing microorganisms and toxic chemicals are the main concern for potable water supply. Damage to crops and industrial equipment from chemicals in the water is the main concern for agricultural and industrial water supplies. While planning and construction should minimize exposure to undesirable (and especially unnatural) components, testing verifies absence of undesirable micro organisms and chemicals. Thus, all wells should be sampled during and/or immediately following construction and development (this may be required by law, e.g., in public water supplies). Appropriate field and laboratory analyses are then made based on intended uses.

11.1.1 Chemical Quality

Chemicals in ground water are normally naturally occurring and reflect the (1) mineral composition of the aquifer, (2) past and current redox conditions, (3) conditions under which the aquifer was formed, and (4) its subsequent hydrogeochemical evolution. While most of these are not considered harmful and may indeed be healthful (e.g., magnesium), some natural constituents can potentially be health risks (e.g., arsenic, radionuclide salts, and radon).

In recent years, pollution of ground water by industrial chemicals as a result of human activities have become a major concern. Much of this concern centers around volatile organic chemicals such as benzene and other gasoline or kerosene (jet fuel) constituents, chlorinated solvents and other chlorinated organics associated with many industrial and cleaning activities, and agricultural pesticides. Locally, heavy metals, radionuclides, or distillates from improper ground disposal may cause ground water contamination. In addition, chemicals such as lead may leach from plumbing systems and fixtures, causing them to be present at levels above standards in samples taken from water supply systems.

Natural ground water quality usually varies with depth, especially as different water-bearing zones are encountered. Knowledge of the quality of water encountered while a well is being constructed is highly desirable, and in some instances imperative because such knowledge can affect decisions regarding continued construction, selection of materials, and modifications in construction or in the planned operation of the completed well. Common examples of quality related problems are: saline, contaminated, or undesirable (e.g., sulfide-containing) water zones to be excluded by casing or grouting;

corrosive waters affecting choice of casing and screen materials; iron-rich waters affecting screen settings; and selection of water treatment equipment.

The importance of establishing the quality of water available for each aquifer penetrated is often overlooked, though this information can be critical to meeting the needs of the well owner. Water quality determinations should be made when possible after penetration of each new source (water-bearing zones). In extensively developed areas, determination of quality may simply be a matter of verifying what has already been learned of water quality from nearby wells.

The usefulness of any water quality analysis depends on the collection of a representative sample. The cost of laboratory analysis can be wasted if sampling is done carelessly or by those without training or experience.

11.1.2 Bacteriological Quality

Ground water is not sterile, and in fact, aquifers are ecosystems containing microbial life. Only a very few species cause disease while others affect the quality of ground water and well performance.

Ground water may become contaminated with microorganisms from malfunctioning, leaking or poorly sited septic tanks, cesspools or sewers, or animal wastes. Some poorly protected and highly transmissive fractured-flow or karst aquifer settings are especially vulnerable to such contamination.

Microorganisms in ground water that are dangerous to human health (pathogens) are usually not tested for directly. Instead, indicator organisms are used. Indicator organisms are non-pathogens associated with potential for microbial contamination, but more numerous, easier to culture and detect, and usueally more resistant to disinfection than pathogens.

At the present time, the standard microbiological indicator method for judging the suitability of water for potable use is the total coliform test. "Total" coliform bacteria (some 50+ species) are common in the natural environment in soils, water, and on and within plants and animals, may be present in uncontaminated ground water. Detection of total coliforms in a ground water sample suggests that other, potentially harmful, contamination occurred and that pathogenic orgsims may be present. A positive total coliform test should be followed up by collecting another sample and testing for total coliforms and *E coli*. Current EPA standards generally call for less thatn 1 coliform per 100 mls of water sampled.

"Fecal" coliforms (including *Escherichia coli*), a subset of the total coliforms, are also widely present in the environment in minute quantities, but in large numbers in the intestinal tracts and feces of humans and other animals. Because these bacteria are discharged in bowel movements, any samples of water containing these bacteria are assumed to have been contaminated by feces. Thus, other pathogenic bacteria, protozoa, and viruses may be present, possibly causing human illness.

The weaknesses of coliform analyses in making judgments on the potability of ground water have been apparent for some time. Some pathogens such as *Giardia or Cryptosporidium* are more resistant to disinfection. The presence of viruses do not correlate well with coliform occurrence. Bacteria that grow in total coliform media may be natural inhabitants of aquifers and do not reflect fecal contamination. Despite these limits, coliform tests have remained the standard methods due to their overall effectiveness and practicality. Users of this manual should be alert to changes in indicator testing procedures and requirements in the coming years, particularly the addition of other bacteriological tests (e.g., fecal streptococcus) and bacteriophage (viral) testing. Depending on the vulnerability of the well site to fecal contamination, such tests may be warranted.

In addition to microbiological sampling for indicators of microbial potability, analyses may be conducted to determine the initial presence of biocorroding or biofouling microorganisms in the formation. These analyses, along with physical-chemical parameter analyses, are used to make decisions on the potential for corrosion and clogging of well components. Examples include widely used pre-packaged culture methods as well as more traditional laboratory-prepared analytical procedures. These methods lack regulatory weight and standard methods are not yet formalized, although a general practice exists.

Because the well construction process can introduce total coliform (or biofouling) bacteria to the producing zone, development and disinfection are important in assuring a tested-safe water supply and minimized biofouling potential (at least initially). Testing for bacteriological quality is the final step in well completion. The sample is collected from the pump discharge after the well has been disinfected and the chlorine removed by pumping.

It occasionally happens following "disinfection" of a well that became heavily contaminated during construction, that a positive (bad) result is reported by the laboratory. This calls for disinfection and testing to be repeated. Failure to obtain negative (good) results after a second disinfection is reason to question the disinfected materials and procedures used, the sanitary protection of the well, the existence of some persistent source of contamination (such as a malfunctioning septic tank system) or possibly the quality of the water in the aquifer. Sometimes a fecal coliform test can indicate whether the source is from waste-disposal activities.

If the well cannot be cleared of contamination, another source of water should be developed or steps taken to provide continuous chlorination of the water before use. The delays, extra work and cost associated with having to repeat well disinfection procedures are compelling arguments for using adequate quantities of disinfectant and doing a thorough job the first time.

11.2 Sample Collection for Analyses

A water sample taken from a well should be collected so that it represents the ground water quality in the aquifer to the extent possible. Ground water samples are collected during well construction to decide the as-built design of and materials used in the well, and to determine the potability and water treatment needs of the produced water. Quite often determination of quality must be made during the initial stages of construction to help decide whether or how to proceed with the work. Determinations may also be made to find out if water of undesirable quality has been encountered so as to exclude it, or to adjust or finalize the design of the well. These determinations are best made during the drilling and sampling phases of the construction.

11.2.1 Sampling Considerations for Chemical Analyses

The method used to collect samples for chemical analyses depends in part on the drilling method, the intended purpose and yield of the well, and the information desired. The simplest procedure consists of lowering a container into the well, allowing it to fill, and raising it to the surface. The bailer is such a device. More sophisticated devices for collecting samples at preselected depths have been developed. The so-called "thief" sampler that is tripped closed by a weight sent down the line, and the ball type sampler, are the most used of these devices. By collecting samples at selected depths, it is possible to obtain a quality "profile" of the well or borehole. Sampling with a bailer is common to the cable tool method of drilling, particularly where well yields are small, or where an operating pump is not yet available.

For wells of larger yield, pumped samples may be required. Many types of pumps are available. For water well sampling, the most common are those intended for production pumping, including submersible pumps, which are capable of producing minimally affected samples with proper use. Usually, samples are collected from the discharge during test pumping or after the production pump is installed.

In some instances the interval to be sampled is segregated by sealing-off the rest of the well, installing a screen in the interval and pumping, or setting a packer. Pumping is begun at a low rate, then increased.

Samples should be collected after the well has been pumped (or bailed) long enough to remove standing water, mud and other foreign material, including development and disinfectant chemicals, so as to insure that ground water has entered the well and the sample is representative of the water in the aquifer(s). While recommendations vary, removing three to five bore volumes helps to assure that nonrepresentative water is removed and formation water pumped for "representative" sampling. Periodic checking of purged water for electrical conductivity, pH and temperature (see following) can be used to make a judgment that aquifer water is being pumped. This typically is indicated if consistent readings are achieved over three to five measurements.

Care should be taken to assure that the sampling equipment and the sampling personnel do not introduce contaminants into the sample. The level of care required to avoid sample contamination is proportional to the sophistication and sensitivity of the analytical methods employed. For example, GC-MS analysis detects VOCs in samples in the low fractional parts-per-billion range. At a minimum, there should be no external source of contamination (e.g, oils and grease from drilling equipment or residues from prior sampling).

Sometimes, sampling requirements dictate that neither the construction of the sampling device nor method of delivering the sample to the surface may alter the physical or chemical characteristics of the sample (e.g., VOCs). Some chemical analyses may require field preparation, such as filtration or preservation of the sample. Although field preparation may only involve preserving the sample on ice (4 C), any field preparation should be done by qualified personnel.

11.2.2 Chemical Sample Quantities, Containers, And Preparation

Inorganic constituents and nontoxic metals (e.g., nitrate, calcium): Sample sizes vary from 50 ml to 500 ml in glass or plastic containers provided by a laboratory. Maximum holding times range from 24 hr to 30 days. Cooling of samples to 4 C is often required. Determine laboratory and regulatory requirements before sampling.

Toxic metals (e.g., lead and arsenic): The usual sample size is 100 ml in glass or plastic containers provided by a laboratory. Maximum holding time is usually 6 months when the samples are preserved with acid (commonly concentrated nitric acid). Most metals are strongly sorbed to clay, sand and silt particles. A turbid sample from an incompletely developed well may give anomalously high values for metals. In this case, the well should be completely developed or the sample filtered before analysis.

Organic contaminants (e.g., VOC, pesticides): Samples range from 25 ml to 1 L in special glass containers with special caps, supplied by the laboratory. Samples are preserved with preservatives (e.g., HCl) specific to the chemical analyzed, and generally cooled. Holding times range from 7 to 30 days when preserved. Sampling for VOCs requires minimizing aeration that strips volatiles. VOC containers must be completely filled without bubbles according to a specific practice. Samples should be collected by experienced, qualified personnel.

11.2.3 Chemical Sample Collection

Bailed Composite Sample Method. A water sample may be obtained by bailing at the time the water bearing formation is encountered, first removing as much as possible of the water which has entered from other sources. The samples should be taken at time periods specified by the project sampling plan. Bailers, if reused, must be decontaminated and rinsed with deionized water between sampling events.

Point Sample. A water sample may be obtained by use of a "thief" sampler, ball sampler or other similar device designated for collecting water samples at predetermined depths. Waters foreign to the depth or depths selected for sampling, and other extraneous matter, are removed as completely as possible prior to sampling, by pumping or bailing.

Discharge Sample Method. A water sample may also be taken of the water discharged during development or test pumping after the well has been pumped for a specified amount of time. Sampling for regulatory or final water treatment analysis should be delayed until after development chemicals have been removed and there is minimum visual evidence of mud or fines (such as sand, etc.) in the water.

Pumped Sample: Composite. A water sample is obtained by pumping from the elevation(s) designated with a submersible pump, air pump, or other device. The intake is set at the elevation(s) prescribed and the pump operated for the specified amount of time (minutes, hours, days). The sample should not be taken until the water being pumped is free of mud or other foreign matter. Sampling for VOCs, metals and organics should minimize aeration and turbulence.

Pumped Sample: Segregated (Drill Stem Test Sample). A water sample is obtained by pumping from the formation(s) designated. The interval to be sampled is segregated from the remainder of the well by inflatable packers or other means. If necessary, the interval is screened so as to prevent the influx of loose material. The sample should not be taken until the water being pumped is free of mud and other extraneous matter that might affect the chemical analysis.

11.2.4 Sample Collection for Bacteriological Analyses

The sample is collected from the pump discharge at well completion after the well has been disinfected and chlorine removed by pumping. Collection of samples for bacteriological examination must be done carefully to avoid contamination of the water, the bottle, or the cap. Preferably, sample collecting should be done by specially trained persons; some agencies refuse to accept water for analysis that has not been collected by authorized persons. Technical assistance and advice can usually be obtained from local or state health departments.

A sample of the water from the well should be collected and analyzed for total and fecal coliform organisms after all traces of development and disinfectant chemicals have been removed from the well. A sample of water of at least 100 ml is collected for analysis for the presence of coliform bacteria.

(1) A sterile 125-ml sample bottle, preferably one provided by the laboratory that will make the determination, is used. The sample bottle (usually containing chlorine-neutralizing sodium thiosulfate) must not be rinsed. Taking duplicate sanokes cab reduce sampling error and reduces the chance of sending a compromised sample.

(2) The choice of sampling point is important. Swivel and other possibly leaking taps should be avoided. Any aerators or attachments should be removed. In wellhead tests, taps should be inspected for cleanliness prior to disinfection and cleaned as necessary.

(3) The water should be allowed to flow to waste for several minutes to clear the service lines before the sample is taken. Most authorities recommend or require that the sampling point be flame sterilized or disinfected then reflushed prior to sampling.

(4) At sampling, the flow is reduced to a "pencil-sized" stream and the sample collected. It is extremely important that nothing except the water to be analyzed come in contact with the inside of the bottle or the cap; the water must not be allowed to flow over an object or the hands into the bottle being filled.

(5) If interfering amounts of residual chlorine are suspected to be present in the well, a field test for residual chlorine is desirable.

(6) The sample should be delivered cooled (4 C) to the laboratory as soon as possible, and in no event more than 30 hour (sometimes no more than 6 hr are permitted), after its collection. During delivery, the sample should be kept as cool as possible (4 C, not frozen).

If the laboratory analysis shows the water is not safe to use, disinfection and analysis should be repeated until negative results are reported by the laboratory, or until it is determined by competent authority that disinfection of the well cannot overcome the problem.

Sampling for indicators of biofouling is highly specific to the method used. Available prepackaged culture methods may either be inoculated directly from samples taken at the well, or subsampled from bacteriological sample bottles. Protocols appropriate for coliform sampling (use of sterilized 125-ml sample bottles, aseptic handling) are followed.

11.3 Analytical Considerations and Choices

11.3.1 Field Tests

Tests for chemical and physical quality of water, performed in the field, can be very helpful in making preliminary decisions affecting construction and in detecting the presence of certain substances that would otherwise be lost in the time it takes for the sample to arrive at the laboratory. A few such substances are: carbon dioxide gas, oxygen, and hydrogen sulfide gas (and total sulfides). To be valid, all these tests must be conducted according to procedures prescribed by the manufacturer of the test equipment employed, local health or water agencies, or as set forth in standard publications dealing with this method of analysis. Instruments must be calibrated, in proper working order (batteries, with clean, functional electrodes, etc.) and current reagents. Tests should be conducted by personnel familiar with the proper sampling and sample-handling.

Some physical parameters must be measured in the field to obtain wellhead values. These include redox potential (by a highly specific methodology), pH and temperature. The temperature and pH of the water should be taken immediately upon collection of the water sample and recorded in the driller's or site-supervisor's log.

Chemicals are usually added in the field to ensure the accuracy of iron and manganese determinations when the samples are brought to the laboratory for analysis. For this reason, determinations of different valence states of these metals (e.g., ratio Fe^{2+}/Fe^{3+}) must be made in the field.

Specific electrical conductance (conductivity) is one field test that provides an approximation of the mineral content of the water. Because the property of water to conduct electricity depends on the amount and kinds of mineral salts dissolved in the water, there is a direct correlation between the conductivity of the sample (indicated on the meter) and the total mineral content (calculated). Conductivity can be used in the field to determine if purged water has become stabilized formation water, or to profile changes in major ion content during drilling (e.g., looking for saline zones).

This same principle is sometimes applied in a different way when an "electric log" has been run in the completed bore hole. Resistivity (the reciprocal of conductivity) values and other data from the log can be used to determine in a general way the relative mineral content of the water in the formations penetrated by the bore hole. Accurate interpretation requires considerable experience and a knowledge of aquifer characteristics.

Some of the prior "convenience vs. reliability" trade-off of laboratory and field methods have been upset in recent years. Field methods for major ions, metals, and other constituents of specific interest are highly accurate in qualified hands.

With photoionizing detection instruments, qualitative detection of specific VOCs can be made in the field. For example, if a well may be potentially contaminated by tetrachlorethylene, but drilling on the site is attractive if contamination is not present, periodic sampling and on-site analysis during drilling and test-pumping, looking for a TCE peak, can be used to make "real time" decisions, that is, in time to decide whether or not to continue drilling or pumping.

Field qualitative or semi-quantitative analyses of many constituents are possible with immunoassay technology. These tests turn color in the presence of specific target constituents in the part per million to part per billion range. It is necessary to have some idea what may be present (e.g., atrazine versus alachlor, or PCBs) because of differences in detection. As with on-site VOC detection, these methods may be used for on-site decision-making without waiting for laboratory analyses.

Field determination of biofouling and biocorrosion microflora is possible with pre-packaged media. Incubation at room temperature is indicated, and cold incubation only slows, but does not change the reaction.

Field determinations for the presence of total coliform bacteria are possible using the membrane filter technique or chromogenic substrate test. Both require a reliable incubator (35 C). Considerable care and skill are required for membrane filtration, however, and the test is seldom run in the field unless transport is impractical. On the other hand, commercial chromogenic-substrate products are easy to fill and mix, and may be used for economic multiple sample provisional testing. Final judgment of the health-related bacteriological quality of the water should be based on tests made in approved, certified laboratories.

Despite advances in technology and experience, field tests for water quality should be confirmed by laboratory determinations, since laboratories typically have more stringent quality assurance-quality control protocols, and the legal weight of certification. All health-related parameters should be analyzed in a laboratory setting before final decisions are made on water potability or treatment. With greater portability of sophisticated analytical methods, the field-laboratory relationship is likely to continue to evolve.

11.3.2 Laboratory Tests

Laboratory tests should be performed by reputable laboratories, preferably those certified by the state or EPA.

A great variety of materials may be found in the ground either naturally or as a result of human activities. Rather than analyze for all possible substances (which would be costly and time consuming) only those which are known to be of significance should be determined. It has become standard practice to group constituents in logical combinations, for example, to form the common minerals or suspected pollutants such as VOCs.

Selecting constituents for which analyses should be made involve consideration of the intended use of the water, knowledge of nearby quality conditions, familiarity with requirements of state and local regulatory agencies, understanding of commonly accepted user criteria, and the exercise of good judgment.

Laboratory tests consist of those specified by the regulations of local and state government (on in reflection of federal or international -WHO - standards), the well owner or as required for the proposed use of the water (e.g., < 200 mg/L TDS for a bottled water). All laboratory tests must be performed by a laboratory approved by the well owner-operator or advisor, and certified in the specific constituents to be tested by the appropriate state agency.

Analytical techniques and methods acceptable in the United States are prescribed in *Standard Methods for the Examination of Water* and *Wastewater* by the U.S. Environmental Protection Agency. The most current information on USEPA methods may be reviewed and descriptions downloaded from the Internet (URL http://www.epa.gov/Standards.html).

All samples must be appropriately identified as to geographical location, date, time, method of collection, point of collection, other relevant particulars (e.g., water bearing formation, depth), and the name and affiliation of the sample collector and well owner.

11.3.3 Analyses for Specific Constituents

Public ground water supply standards (and relation to private water supply standards). The USEPA sets numerical limits called "maximum contaminant levels" (MCLs) for contaminants in finished water provided by public water systems. These MCLs are based on determinations of risk to human health and are maximum concentrations of a contaminant that may be present in a public water supply. MCLs are enforced by the USEPA under provisions of the Safe Drinking Water Act (SDWA), usually through state agencies. SDWA MCLs do not necessarily apply to domestic water supplies, although they may be adopted or used as guidance by state and local health agencies regulating private water supplies. State and local governments may have water quality requirements more stringent than the USEPA, and may have guidelines for industrial and agricultural water supplies.

Besides substances that specifically affect human health, substances such as chloride, hydrogen sulfide and iron can affect taste, odor, and the appearance of water (and treatment efficiency). Many states and local governments have numerical guidelines for maximum levels of these substances usually called "secondary contaminants." Both federal and state numerical limits are periodically updated and subject to change. The following analyses (Tables 11.1, 11.2, 11.3) are usually required or recommended for various ground water supply applications:

Table 11.1
Domestic Ground Water Supply Constituents Analyzed

Recommended/Required	Special Situations
Bacteria (total coliform)	Bacteria (fecal coliform)
pH	Bacteria (biofouling/biocorrosion indicators)[1]
Nitrates (NO_3-N)	Nitrite (NO_2-N)
Iron (total)	Lead
Manganese (total)	Volatile organic chemical scan[2]
Total hardness	Corrosivity (e.g., Langelier Index)
Alkalinity	Radioactivity (gross alpha), Radon-222
Conductivity (specific conductance)	Sodium
Chlorine residual	Hydrogen sulfide (or total sulfide)

[1]Indicators of future water system deterioration.

[2]Wells constructed from solvent-cemented PVC casing may show significant VOC, due to the cement, for long periods (months) after development and use, although this should be a rare occurrence. Should this contamination possibility be an issue, an approved solvent-free mechanical joining system should be considered.

Table 11.2
Irrigation Ground Water Supply Constituents Analyzed

Recommended Analyses	Special Situations
Boron	Bacteria (biofouling/biocorrosion indicators)[1]
Calcium	Potassium
Magnesium	Nitrate (NO_3-N)
Sodium	Iron
Sulfate	Lithium
Bicarbonate	Corrosivity (e.g., Langelier Index)
Chloride	Total dissolved solids
Conductivity (specific conductance)	Pesticides[2]
Adjusted sodium adsorption ratio (SAR)	Hydrogen sulfide (or total sulfide)[1]
pH	
Alkalinity	

[1]Indicators of future system clogging and deterioration.

[2]Analyses of pesticides can serve to document any pre-existing amounts in ground water or as a baseline against which to measure any changes in pesticide levels in ground water.

Table 11.3
Analyses for Design of Wells and Treatment Plant Facilities

Recommended Analyses	
Conductivity (specific conductance)	Corrosivity (e.g., Langelier Index)
Total dissolved solids	Chloride
pH	Carbon dioxide
Temperature	Nitrate (NO_3-N)
Iron (total)	Dissolved oxygen
Manganese (total)	Fluoride
Total hardness	Sodium
Alkalinity	Hydrogen sulfide (or total sulfide)
Redox potential (Eh)	Biofouling-biocorrosion indicators

11.4 Standards for Sampling and Analysis

Laboratory tests should consist of those specified by the regulations of local or state government for the proposed use of the water. Analytical techniques and methods should be as prescribed in the current edition of *Standard Methods for the Examination of Water and Waste Water,* or relevant, defensible ASTM, EPA, or USGS standards. All samples must be appropriately identified as to geographic location, date, time, method of collection, point of collection, water bearing formation(s), depth and diameter of well, water level and yield, and include the name of the sample collector and affiliation and the facility owner-operator.

References

Alcalde, R.E. and M.A. Gariboglio. 1990. Biofouling in Sierra Colorado water supply: a case study. in *Microbiology in Civil Engineering. P. Howsam, ed. FEMS Symposium No. 59, E.&F.N. Spon, London, pp. 183-191.*

APHA-AWWA-AWRA, 1996. *Standard Methods for the Examination of Water and Wastewater, 19th Ed., American Public Health Association, Washington, DC.*

Borch, M.A., S.A. Smith, and L.N. Noble. 1993. *Evaluation, Maintenance, and Restoration of Water Supply Wells. AWWA Research Foundation, Denver, CO.*

Cullimore, D.R. 1993. *Practical Ground Water Microbiology. Lewis Publishers, Chelsea, MI.*

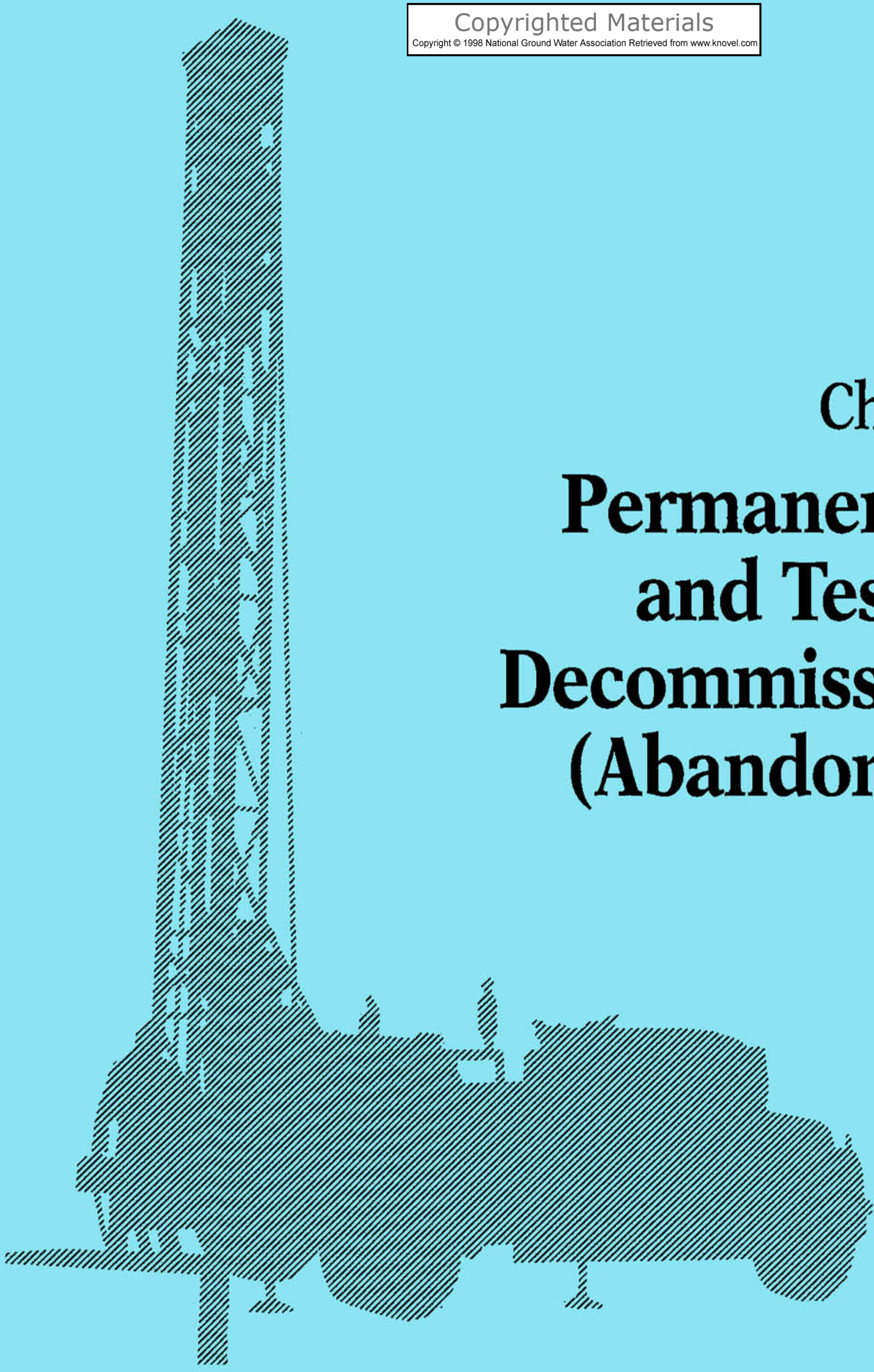
NWWA Committee on Water Well Standards. 1975. *Manual of Water Well Construction Standards, EPA - 570/9-75-001. Office of Water Supply, Washington, DC.*

Pitkin, S.E. 1994. "A point sample profiling approach to the investigation of groundwater contamination," Master of Science thesis, University of Waterloo, Waterloo, Ontario, Canada.

Smith, S.A. 1992. *Methods for Monitoring Iron and Manganese Biofouling in Water Supply Wells. AWWA Research Foundation, Denver, CO.*

Smith, S.A. 1996. Monitoring biofouling in source and treated waters: status of available methods and recommendation for standard guide. *Sampling Environmental Media, ASTM STP 1282, J.H. Morgan, Ed., American Society for Testing and Materials, West Conshohocken, PA, pp. 158-175.*

Soloyanis, S.C. 1996. A common sense sampling strategy to expedite hazardous waste site cleanup. *Sampling Environmental Media, ASTM STP 1282, J.H. Morgan, Ed., American Society for Testing and Materials, West Conshohocken, PA, pp. 21-31.*



Chapter 12

Permanent Well and Test Hole Decommissioning (Abandonment)

12 Permanent Well and Test Hole Decommissioning (Abandonment)

12.1 Purpose for Well and Borehole Decommissioning Sealing

Unsealed abandoned wells constitute a hazard to public safety, ground water quality and the preservation of the ground water resource. In addition to water supply wells, many types of holes or wells may affect aquifers. These include mineral exploration holes, seismic holes, solution or "in situ" mining wells, dewatering wells, temporary service wells, construction water wells, production wells, monitoring wells and/or other structures (regardless of location or intended life of the structure or hole) that affect the withdrawal from or quality of water in an aquifer. These should be permanently sealed as described herein for water supply wells. There are literally millions of such holes across North America. In some areas (notably highly populated areas or lands extensively explored for minerals or oil and gas), unsealed, open holes can be a serious threat to ground water quality and personal or physical safety.

The purpose of sealing an abandoned water well properly is to accomplish several objectives: (1) elimination of a physical hazard; (2) prevention of ground water contamination; (3) conservation of yield and maintenance of hydrostatic head of aquifers; and (4) prevention of the intermingling of desirable and undesirable waters. The sealing of such wells presents a number of problems, the character of which depends upon the construction of the well, the geological formations encountered, and the hydrologic conditions.

As with well construction, proper abandonment sealing should be performed or directly supervised by water well contractors with the appropriate licenses in the jurisdiction, and experience in the procedure chosen. Many jurisdictions require permits for sealing wells or borings and most require the filing of a report.

The basic concept governing the proper sealing (often referred to as "decommissioning") of abandoned wells is the restoration, as far as feasible, of the hydrogeologic conditions that existed before the borehole was drilled and the well constructed. This serves the purposes of removing the abandoned well as a conduit for loss of hydrologic pressure in confined formations, intermingling of ground waters of differing quality, and entry of contaminated and polluted water.

Any borehole or well that is to be permanently sealed should be completely filled in such a manner that vertical movement of water within the well bore, including along the annular space surrounding the well casing, is effectively and permanently prevented. If this is accomplished, the objectives for sealing wells will be fulfilled.

To seal an unusable or abandoned well or borehole properly, the hydrologic character of the ground water encountered by the well must be considered.

(1) If the ground water occurs under unconfined, or water table conditions, the chief problem is that of sealing the well with impermeable material to prevent the percolation of surface water through the original well opening, or along the outside of the casing, to the water table.

(2) If the ground water occurs under confined or artesian conditions, the sealing operation must confine the water to the aquifer in which it occurs: preventing loss of artesian pressure or cross-contamination by circulation of water to the surface, to a formation containing no water, or to one containing water under a lower head than that in the aquifer which is to be sealed.

12.1.1 Preparation for Abandonment Decommissioning Sealing

Prepare: The process of sealing a well or borehole begins with gathering information on the hole to be sealed. Sources include filed well construction logs, or project records for unfinished boreholes. These records provide the necessary dimensions and construction particulars (depth, diameter, casing type, screen if any, aquifer and aquitard zones). Where information is unavailable or unreliable, borehole measurements, borehole geophysical testing, or a borehole TV or gamma log survey provides the necessary information. Plan to seal the borehole from bottom to top.

Obstruction removal: The next step is to remove barriers to proper seal installation. Strong efforts should be made to remove all materials from a well which may hinder its proper sealing. This is especially important where specified zones must be sealed. Pitless adapters, pump parts, pipe, wire, fallen debris, etc., should be retrieved, bailed or developed out of the hole if possible.

Alternatively, in descending order of preference, if the obstruction cannot be readily removed, it may be (1) drilled up and bailed out (if large), (2) driven to the bottom (if it does not constitute a potential environmental threat), or (3) if it is sufficiently below the aquifer top and immovable, left in place and sealed in.

Screens: If a screen has been installed in the well by telescoping, its recovery is usually possible by installing a string of fishing casing from the top of the well to a sand hitch placed close to the bottom of the screen. Following the setting of the sand hitch, a lifting force, applied either by mechanical or hydraulic jacks, or multiple pulling lines from the casing reel of the drilling machine, will usually withdraw the screen from the well **(Figure 30A)**. **CAUTION: Formation material upthrust into the casing may occur.**

Casing: Casings should not be simply filled without considering the substantial flow that can occur through an unsealed annular space. While often difficult and time-consuming (thus raising costs) casing should be removed or substantially destroyed

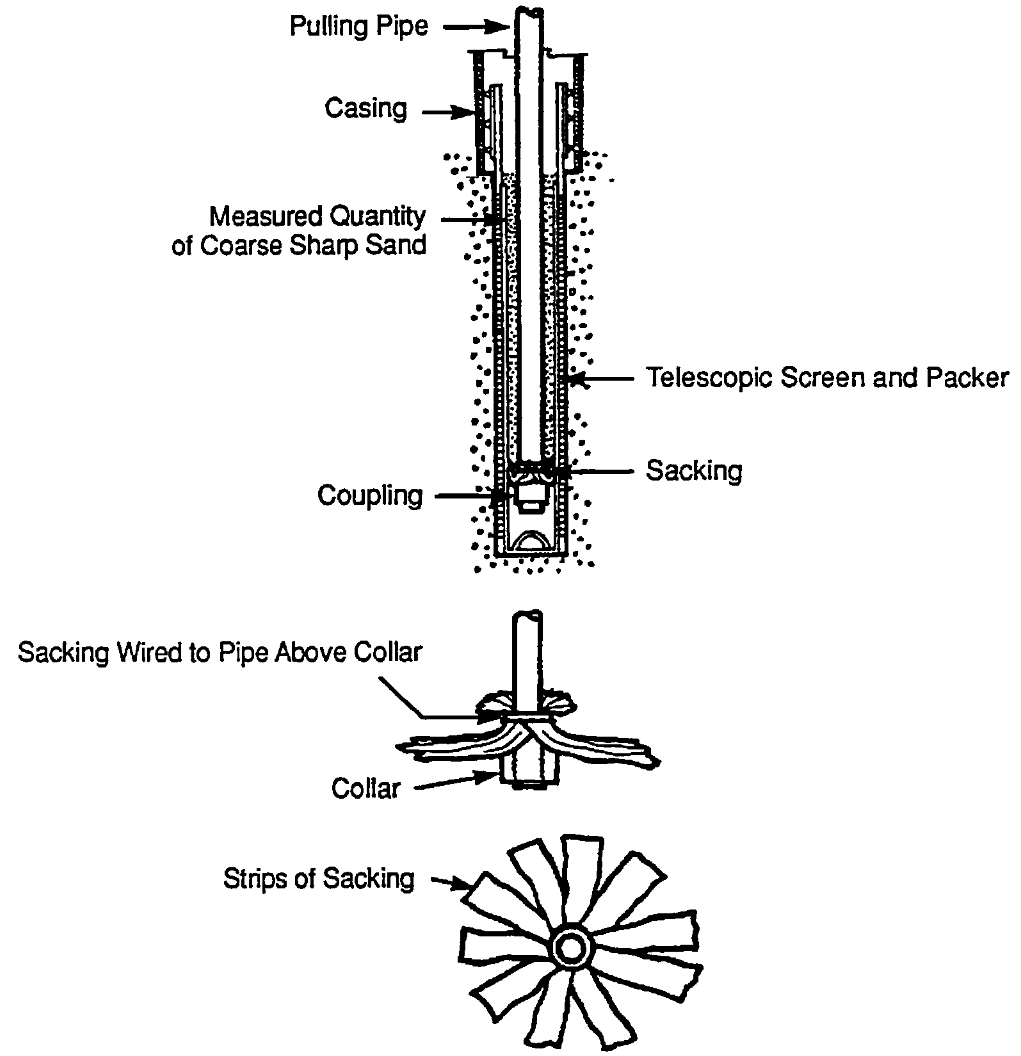


Figure 30A. Pulling the Screen with a Sand Hitch.

Figure is from *Well and Borehole Sealing*.

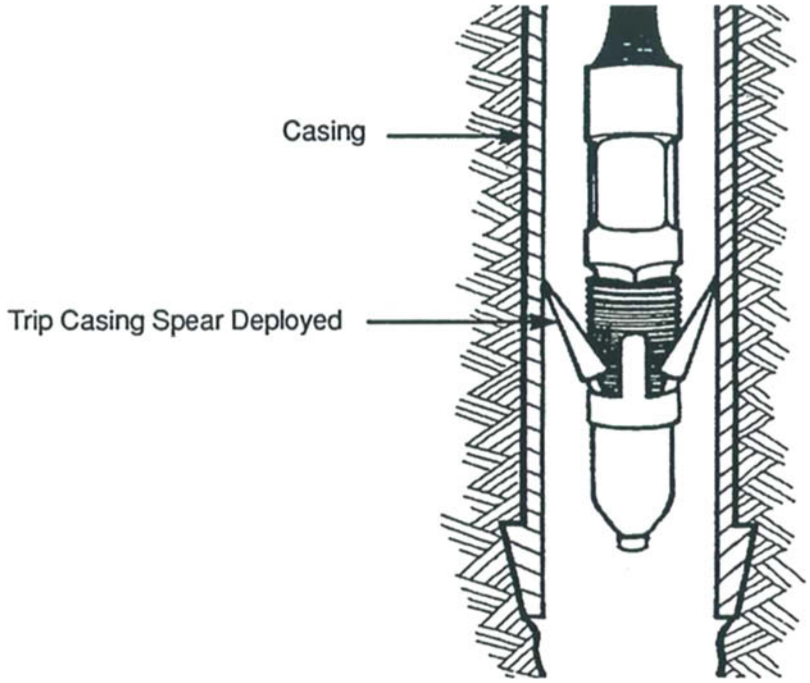


Figure 30B. Casing Spear.

Figure is from *Well and Borehole Sealing*.

wherever feasible so that open annular spaces are not left in an otherwise thorough grout job. Where casing cannot be totally or substantially removed with available methods, it should be ripped, perforated, or otherwise separated and pressure-grouted (Section 12.2.4). When the casing is removed, the sealing of the aquifer zone (screen area or open borehole) should be finished before removing casing completely, so that unstable formation material does not collapse into the hole prematurely.

In recovering steel casings extending to the surface, the least expensive and least hazardous method is to apply a lifting force to the casing by the use of jacks, or with the drilling machine, or with the two in combination (**Figure 31A,B**). Still more effective is the use of a jarring head applied at the top of the casing string and used in combination with lifting devices. For cases in which the steel casings cannot be removed, special techniques such as perforation of the casing and pressure grouting may be used (see Section 12.2.4).

Maximum recovery is usually obtained by using a trip-type casing spear actuated by a fishing cable tool string and used in combination with lifting device (**Figure 30B**). The trip spear is usually limited in its use to recently drilled wells or to those in which the casing is known to be in sound condition. The risk of failure associated with the use of a casing spear increases with the age of the well and the depth at which it is to be used.

The order of descent into the casing for a trip spear string of tools is: (1) trip spear; (2) fishing jars; (3) sinker bar or drill stem; (4) rope socket, which is attached to the drilling line. The swage could replace the spear in the above string of tools.

Where a drive shoe is attached to the bottom of a casing string to be extracted, it is often advantageous to separate the casing from the shoe. The preferred method for cutting casing is by use of a hydraulic or air-driven casing cutter. Some states do not permit the use of explosives inside the casing.

Where appropriate, plastic casings may be pulled from the base (to avoid separation at joints). In some cases, small diameter (< 5-in) casings may be drilled out using an appropriate rotary blade bit or split with a casing splitter (**Figure 32**).

It is always good practice to probe the well with a caliper tool or swage of the same diameter as the spear, cutter, or any valuable tool prior to inserting the tool into the casing. A downhole TV or caliper survey run prior to casing removal and sealing procedures provides the information necessary to plan the project. Weak or corroded joints that would likely separate during pulling, or corroded joints that may collapse on a tool can be pinpointed and evaluated. The length of casing, condition of a screen, or depth to water-bearing zones in rock can also be assessed.

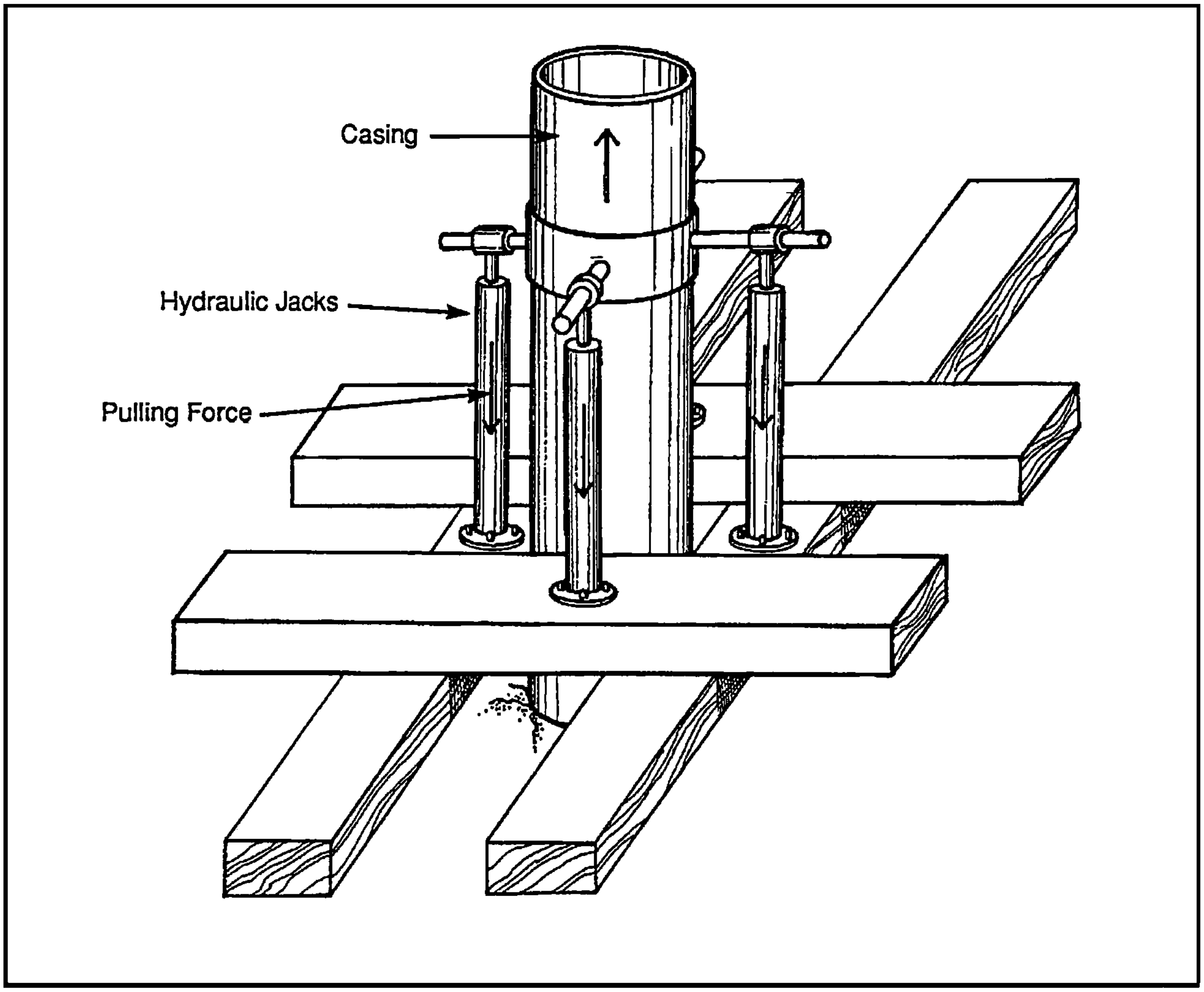


Figure 31A. Using the Jacking Method to Pull Casing.

Figure is from *Well and Borehole Sealing*.

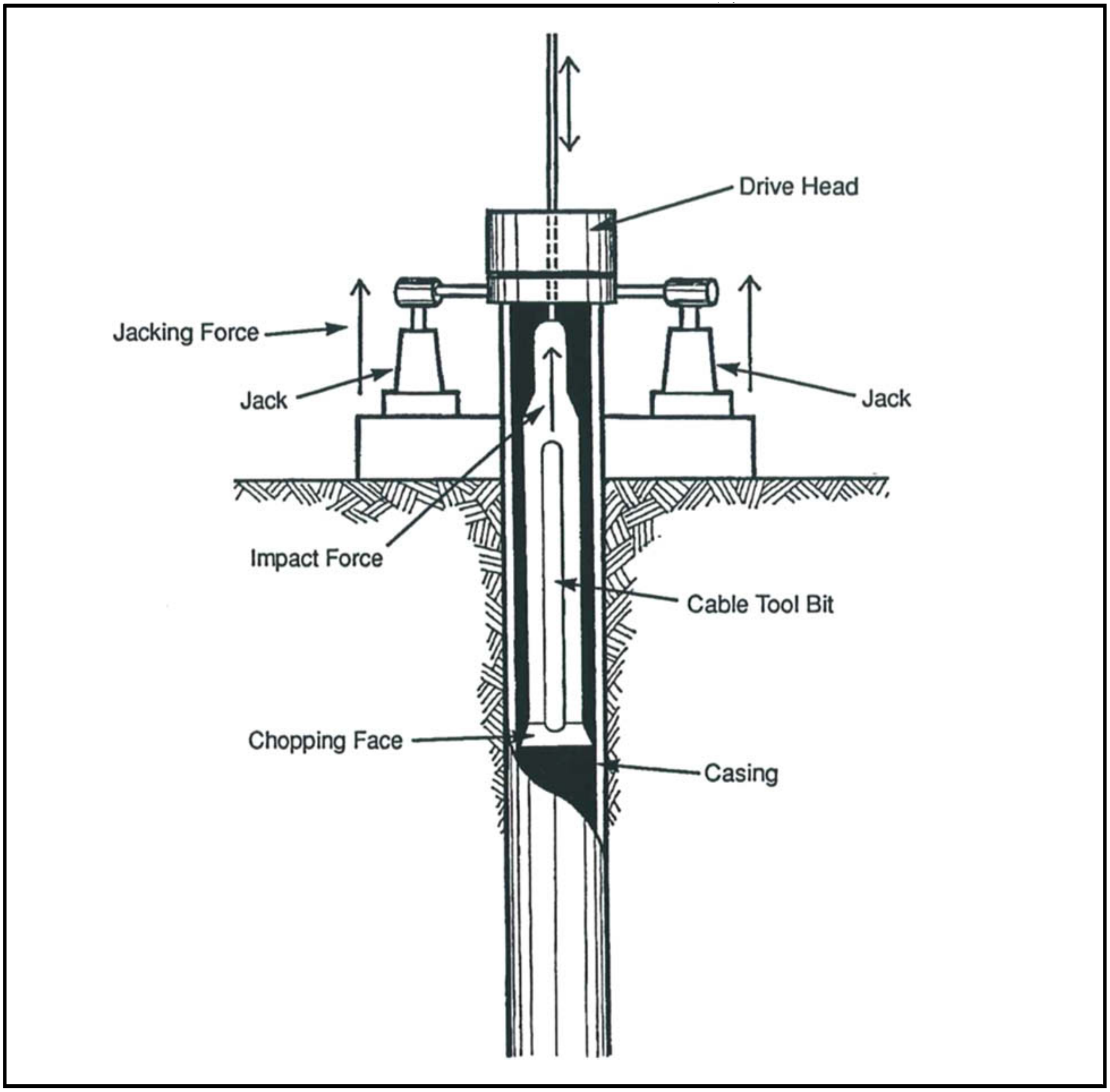


Figure 31B. Using a Combination of Hydraulic Jacking and Percussion with Cable Stem to Remove Casing.

Figure is from *Well and Borehole Sealing*.

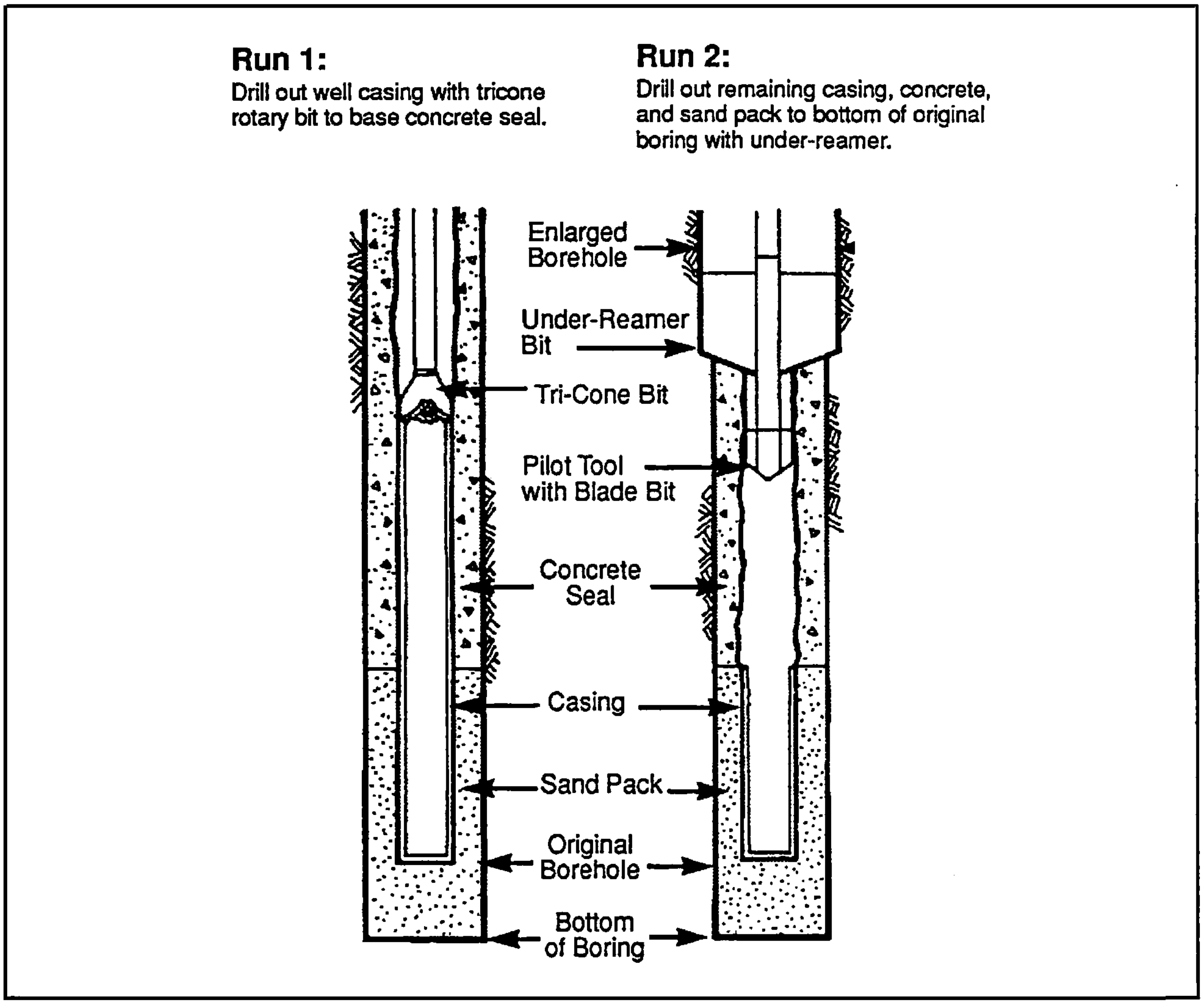


Figure 32. Borehole Overdrilling.

Figure is from *Well and Borehole Sealing*.

Once the well or borehole is prepared, it is a good idea that the well be shock chlorinated (100 to 500 mg/L) to reduce the presence of possible contaminant bacteria, and the chance that the sealed well might be a future source of inoculum for other nearby wells. This chlorination can be accomplished by feeding a sufficient amount of calcium hypochlorite prior to moving on to the sealing steps (Chapter 10).

12.1.2 Borehole Bridging

Bridging: Where permitted and to reduce cost of unnecessary backfilling of long sections of borehole or cavernous zones that may be impractical to grout, it is often desirable to establish a temporary bridge in the borehole upon which a permanent cement-based bridge can be placed (**Figure 33A**). This is a process that usually involves improvisation, and always requires skill and knowledge of the well structure and flow conditions. Representative techniques are described in Section 12.2.2.

12.1.3 Preparation To Plug Flowing Artesian Wells

The flowing artesian well with improperly sealed casing and with water escaping around the outside of the casing either to the surface or to another formation presents a special problem. Grout must be still for the initial set to take place, otherwise it washes out. A necessary first step in bringing the flow under control is to establish a permanent cement seal between the casing and the point or interval from which the water is escaping. This process should be conducted by a driller experienced with artesian well sealing.

In order to place this seal effectively, the flow must be stopped and the water level lowered in the well. This can be accomplished by several methods. Some of these are:

(1) Pumping the problem well, thereby producing the necessary drawdown to permit sealing to proceed.

(2) Pumping nearby wells, producing the same effect.

(3) Introducing high (up to S.G. = 1.6) specific gravity ("kill" or "control") fluids (e.g., barite mud or other weighted drilling mud) at the bottom of the borehole and filling the hole with the fluid until the driller determines that all flow ceases in the borehole.

The method or methods used will depend in part on the piezometric or shut-in pressure of the well and the depth to which the water level must be lowered.

The sealing of abandoned wells that have a rapid or high-volume movement of water between aquifers or to the surface requires special attention and ingenuity, and should be conducted by a driller experienced with the process. The movement of water may be sufficient to make the sealing with ordinary materials and by the usual methods impractical. In such wells large stone aggregates (not more than 1/3 of the diameter of the hole), or a well packer or bridge should be used to restrict the flow thereby permitting the

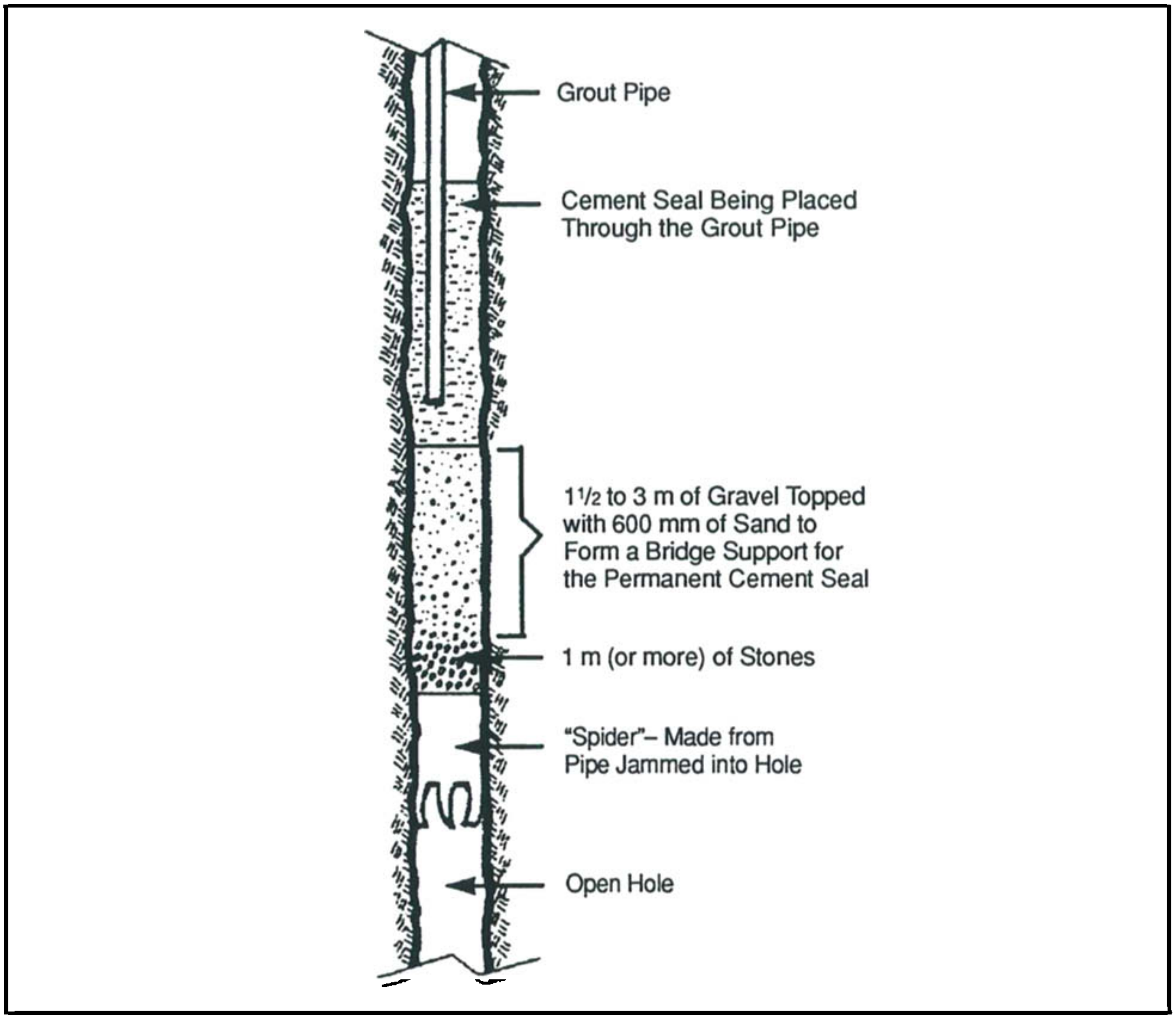


Figure 33A. Borehole Bridging

Figure is from *Well and Borehole Sealing*.

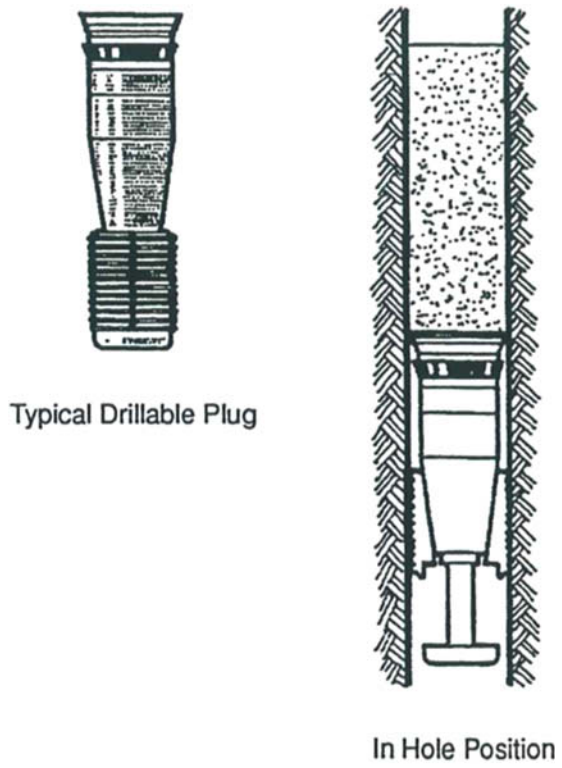


Figure 33B. Cement Plugging Tools.

Figure is from *Well and Borehole Sealing*.

placement of appropriate sealing material. If preshaped or precast plugs are used, they should be several times longer than the diameter of the well to prevent tilting. Any packer, bridge, or plugging material should be permanent and safe to leave in a potable water aquifer. **Figure 34** illustrates well plugging procedures in artesian wells.

Wells with large holes or little o r no grout or surface casing may be initially controlled by running a liner with a packer, or an interval packer to slow inflow, then proceeding with killing and sealing by pressure cementing.

In wells in which the hydrostatic head producing the flow is low and in which there is no escape of water below ground, the movement of water can be arrested by extending the well casing to an elevation above the artesian pressure surface. This permits the placement of sealants and fill materials, after which the casing may be cut off at or below ground level.

Once flow is under enough control to permit working in the well, final plugging can proceed. The flow of artesian wells to be sealed can best be stopped with neat cement or sand-and-cement grout piped in by tremie under pressure. Alternatively, a suitable well packer or bridge may be placed at the bottom of the confining formation immediately overlying the artesian water-bearing zone, and sealing finished with conventional cement-based grout placement.

12.2 Seals and Their Functions

Three basic types of seals -- distinguished by their functions -- may be used in proper permanent well or borehole sealing. They are:

Permanent Bridge-Seal: This is the deepest permanent seal to be placed in the well. This seal serves two purposes: (1) it forms a permanent bridge below which a considerable unplugged, fluid-filled hole may remain and upon which solid fill material may be safely deposited; and (2) it seals upper aquifers from any aquifer(s) which may exist below the point of sealing. Wherever possible, the bridge should be established on an aggregate or other stable fill base. Setting bridges is usually an improvised process that should be conducted by drillers experienced with it, and knowledgeable about the borehole. A TV survey would be highly recommended before attempting a bridge set.

In some cases, a temporary bridge may need to be set on which to establish the final seal. "Temporary" refers to its status as a bridge, not its residence in the borehole, which is permanent. There is a temptation to use expedient materials (e.g., springy bushes followed by cobbles and smaller aggregate), but this must be avoided. No organic materials (e.g., wood) should be used in either the temporary or permanent bridge, except for specially manufactured devices, which are acceptable and these greatly facilitate the work. These include cement plugging tools in which neoprene rubber or plastics are used

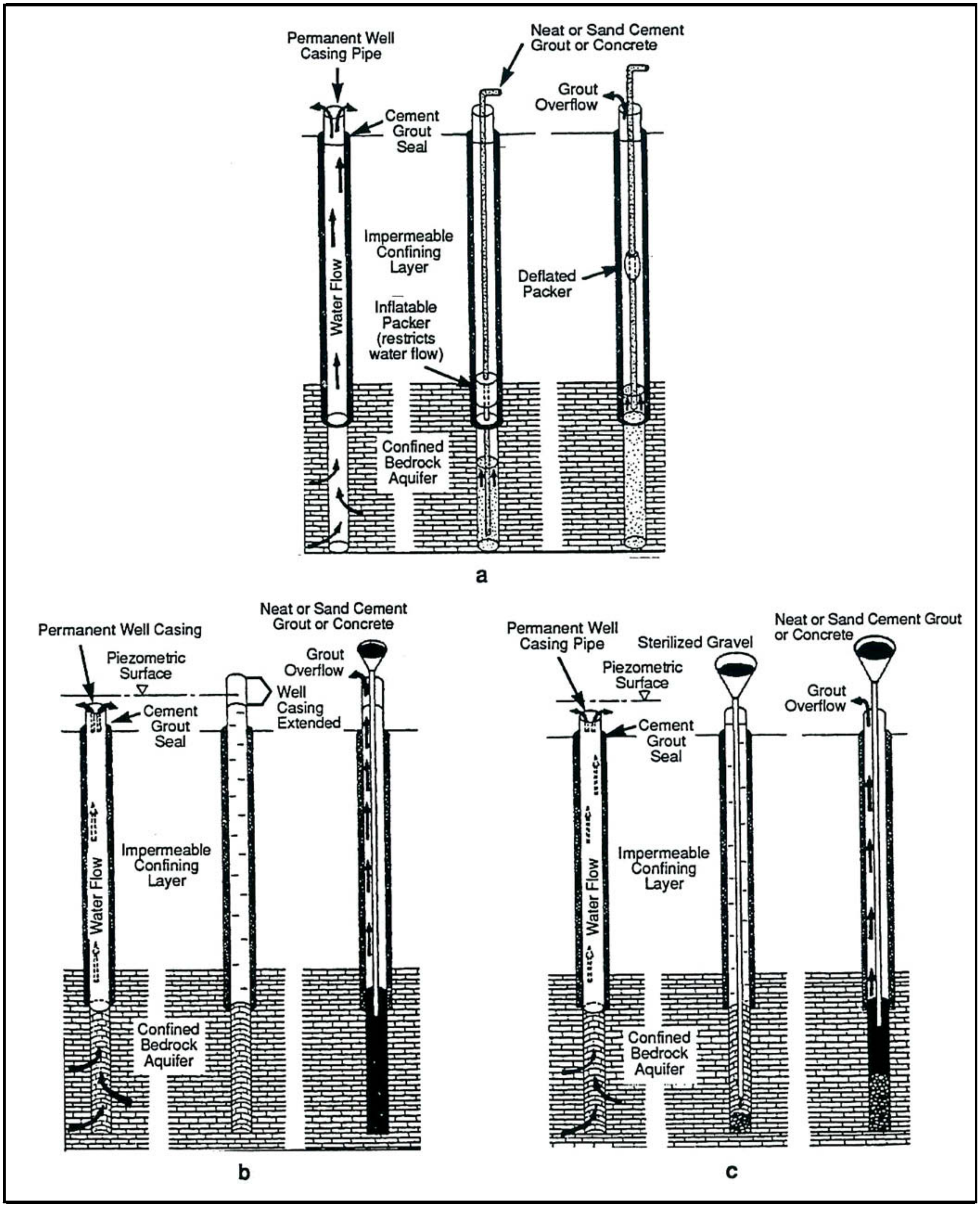


Figure 34. Well Plugging Procedures in Artesian Wells.

Figure is from *Well and Borehole Sealing*.

(**Figure 33B**). Some of these devices permit establishing a permanent bridge without first having to set a temporary one.

Intermediate Seal: This seal is placed between water-bearing formations which have, or are believed to have, different static heads. Its function is to prevent the interaquifer transfer of water (**Figure 35**).

Seal at Uppermost Aquifer: This seal is placed immediately above the uppermost aquifer penetrated by the bore hole. Its function is to seal out water from the surface and from shallower formations. In flowing artesian wells, it is designed to prevent the escape of water to the surface, or to shallower formations (**Figure 36**).

Each decommissioning effort should be considered as an individual problem, and methods and materials should be selected after detailed study of well construction, geology, and hydrology. Whenever there is doubt about either the construction or the hydrology and geology, the choices of materials and procedures should be those affording the greatest probability for successful and permanent sealing to protect the ground water resource.

12.2.1 Aquifer Fill Material

Aquifer zones, or long sections of the borehole, may be filled with disinfected, dimensionally stable aggregate or sand and gravel materials that are chemically inert in the aquifer material to be plugged. Use of suitable fill permits continued flow circulation within the aquifer interval. Aquifer fill materials should be clean (relatively free of clays and organic materials) before placement in the well. Material used to fill large, cavernous spaces should be large diameter (>1 inch). That used to fill other types of boreholes should be similar to the formation (unconsolidated aquifers) or about 0.25-inch (6-mm) aggregate for rock wells.

Enough space above the fill should be allowed to permit a secure seal between or above aquifer zone(s). The fill may be compacted mechanically if necessary to avoid later settlement.

Disinfection of aquifer fill materials is accomplished by using chlorine compounds such as sodium hypochlorite or calcium hypochlorite. Disinfection should be accomplished by dissolving sufficient chlorine compound to produce a calculated concentration of at least 100 ppm available chlorine in double the volume to fill the annular volume (see the gravel pack disinfection procedure in Chapter 10).

12.2.2 Permanent Bridges

Where approved, permanent bridges may be used to avoid having to fill very deep holes or cavernous spaces below the deepest point at which a permanent seal is required.

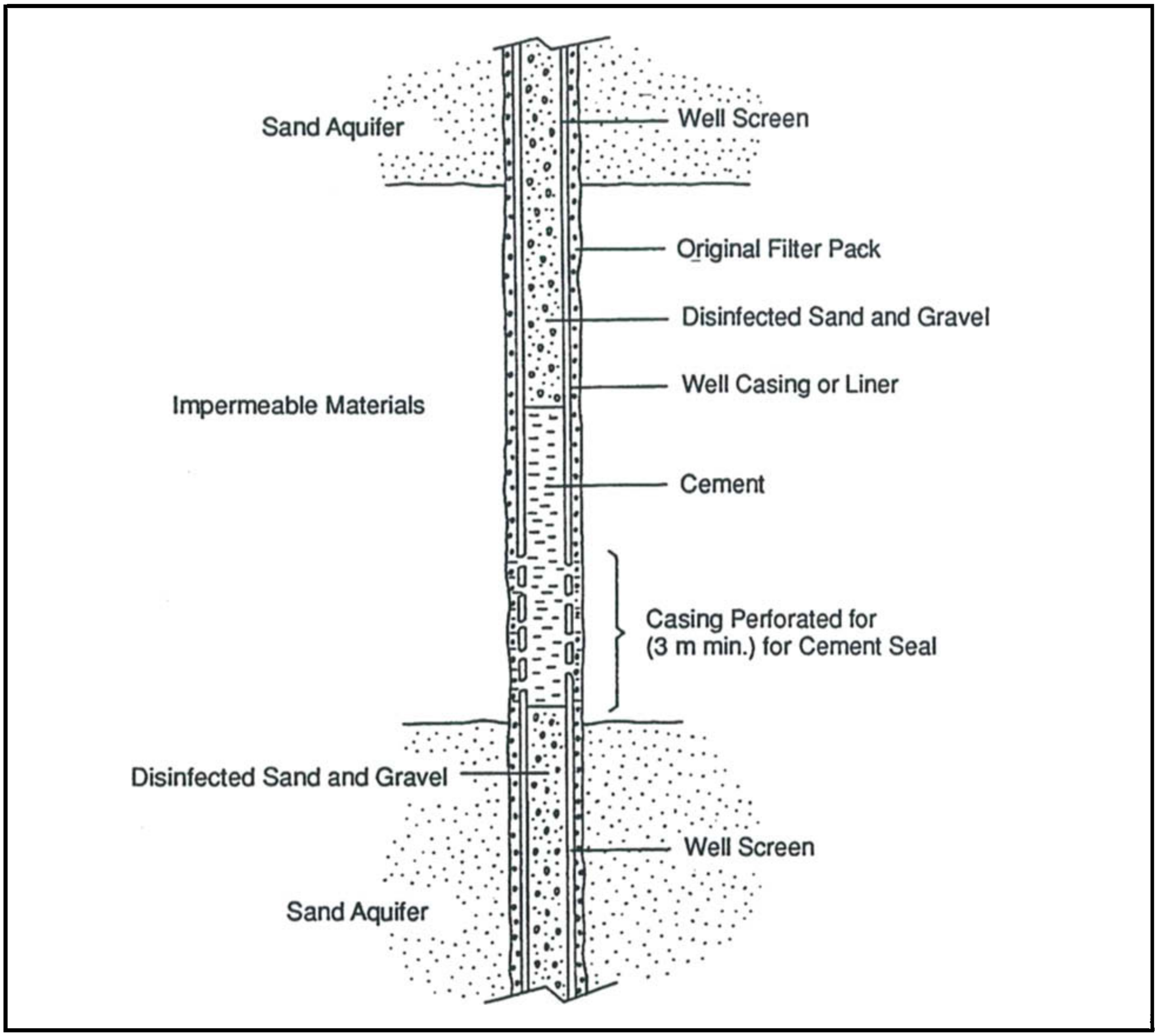


Figure 35. Intermediate Seal.

Figure is from the *Australian Drilling Manual.*

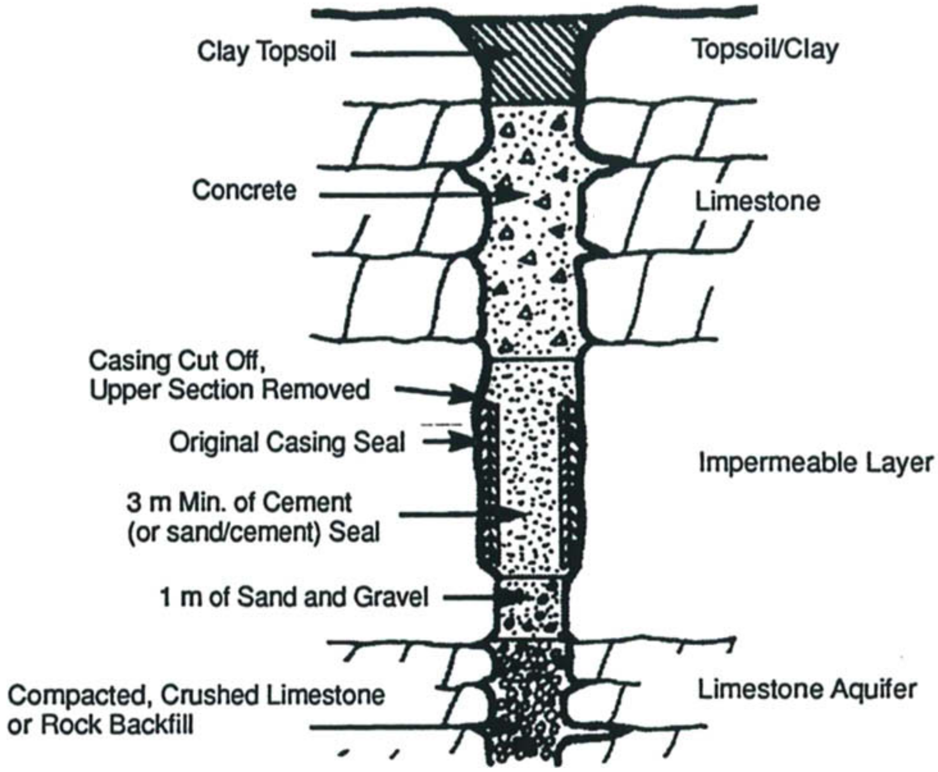


Figure 36. Seal at Uppermost Aquifer.

Figure is from *Well and Borehole Sealing*.

Bridges should not be set above known potable aquifer intervals except for aggregate-filled cavernous zones.

In tectonically stable regions, permanent bridges may be composed of cement or cement-bearing materials with other noncorrodible mechanical components. The cement must be allowed to harden for at least 24 hours, if Type I cement is used, or for at least 12 hours if Type III (high early strength) cement is used, before grouting or backfilling is continued. In earthquake-prone regions, more plastic (flexible) bridge seals should be used.

Mechanical bridges used to provide a base for the permanent bridge must consist only of inorganic materials (typically cement) -- except for nondegradable expandable neoprene, plastic, and other elastomer, and specifically designed for use in well construction. Open boreholes below bridges and caverns should be aggregate-filled to provide dimensional stability below the bridge.

12.2.3 Placement of Grout

General: The engineered grout mixture used as a sealing material in abandonment operations is introduced at the bottom of the well or interval to be sealed (or filled) and placed progressively upward from the bottom to the top of the borehole or well. All such sealing materials are placed by the use of grout pipe, tremie, cement bucket or dump bailer, in such a way as to avoid segregation or dilution of the sealing materials (**Figures 37A,B**).

Chapter 4 provides a discussion and descriptions of grout-handling equipment and cement and bentonite mixtures. Coarse particulate-sized chips of unprocessed bentonite (not discussed in Chapter 4, since it has limited application in annular grouting) is another alternative for borehole and well sealing. This high-solids, relatively rigid bentonite has the advantages of both filling the space to be sealed, and providing expansion due to swelling of bentonite particles when wet.

Dumping cement-based grout material from the top should not be permitted. Bentonite mixtures may be pumped and chipped high-solids "hole-plug" bentonite may be poured from the surface with proper precautions to avoid bridging.

Seals intended to prevent vertical movement of water in the well or bore hole may be composed of cement-based mixtures (including sand-and-cement, bentonite-amended cement or concrete or neat cement) or high-solids bentonite mixtures intended for use as sealing grout. A minimum cement seal length, wherever dimensions permit, should be at least 10 feet (3 m). A grout seal in place should have a hydraulic conductivity lower than the surrounding earth material (Table 12.1).

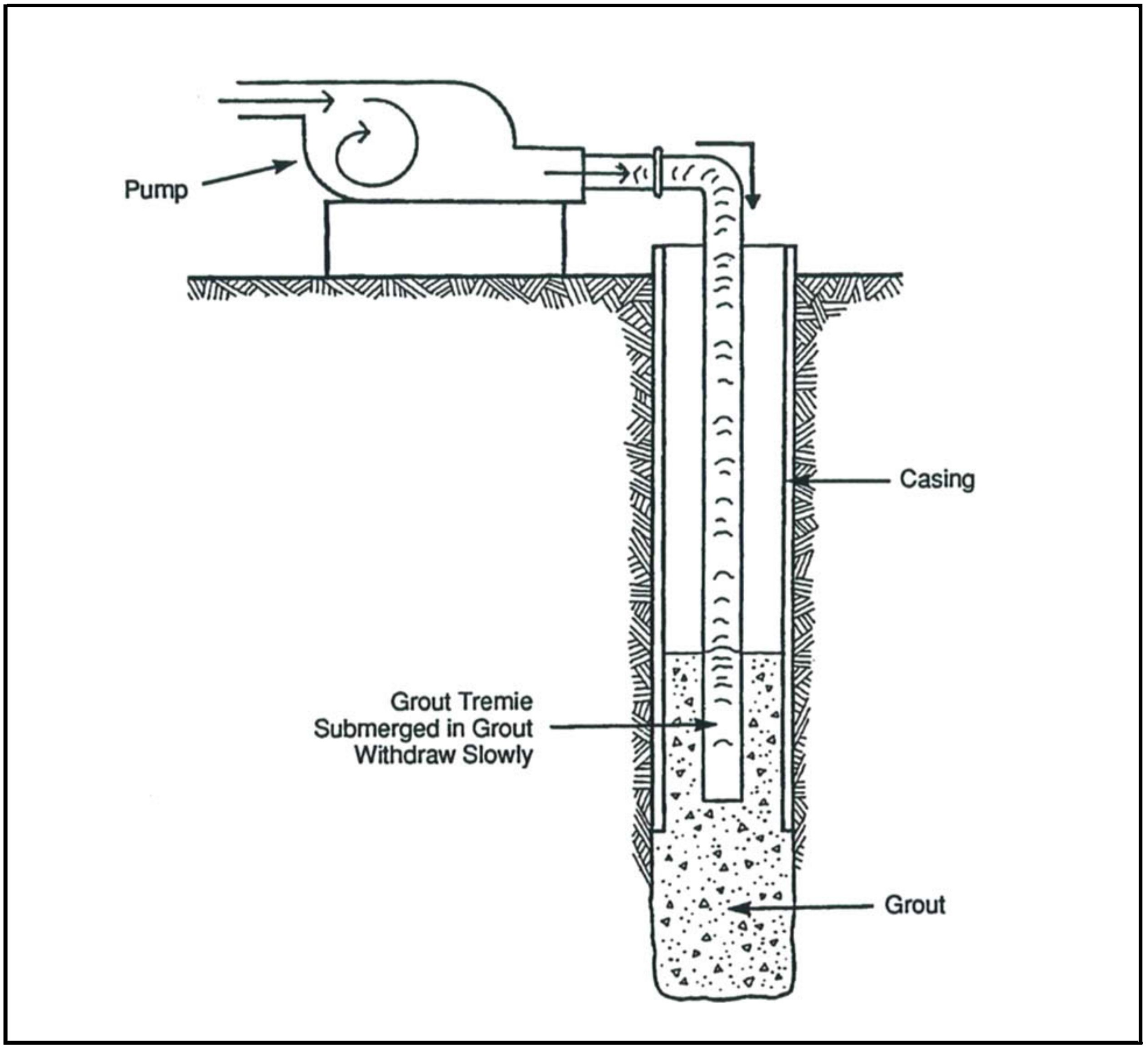


Figure 37A. Pumping Grout Slurry to Seal an Abandoned Borehole Using the Tremie Method.

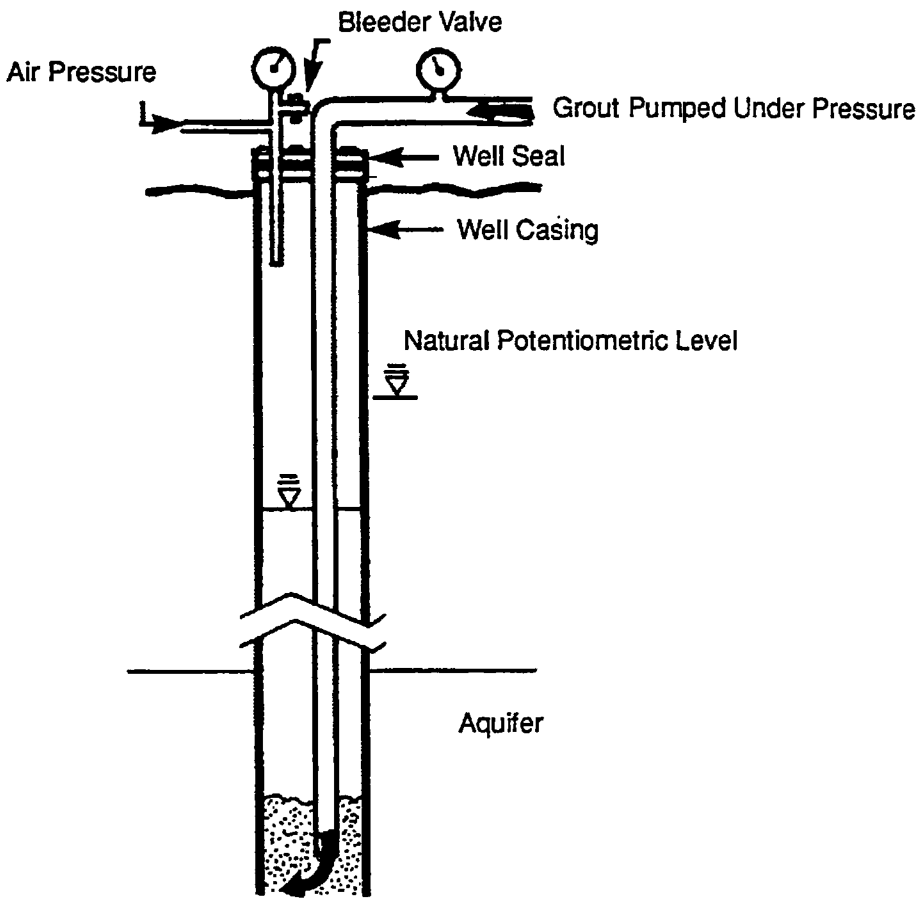


Figure 37B. Grout Pumped Under Pressure.

Figure is from *Well and Borehole Sealing.*

Table 12.1
Permeability of Various Earth and Sealing Materials*

Earth or Sealing Material	Permeability (K) in cm/sec
Silty sand	10^{-1} to 10^{-5}
Glacial till	10^{-7} to 10^{-10}
Compacted soil	10^{-4} to 10^{-9}
Neat cement (6 gal water/94 lb sack)	10^{-5} to 10^{-7}
Bentonite grout (20% bentonite solids)	10^{-8}
Bentonite pellets	10^{-8}
Granular bentonite	10^{-6} to 10^{-7}
Granular bentonite/polymer slurry (15% bentonite)	10^{-8}
Coarse grade (chipped) bentonite	10^{-8}
Cement and bentonite	10^{-5} to 10^{-11}

*Values vary over a range.
Source: Smith (1994) and Well Sealing Workgroup (1996).

Tables 12.2 and 12.3 are provided to assist in calculating the volumes of grout material needed to seal boreholes and wells.

Table 12.2
Volumes of Material to Fill 100 ft of Well or Borehole Length*

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

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

Yield Calculations:

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

Holeplug is a granular bentonite product, 3/8"–3/4" in size that is poured, not pumped, into a well.

Source: Table 6, Well Sealing Workgroup 1996, page 40. (Table based on product information published by NL Baroid, Wyo-Ben Inc., and Chemgrout Inc.)

Table 12.3

Well Casing Volume and Bentonite Needed to Fill a Casing Volume*

Diameter of Opening	Volume: Gallons per Foot of Depth	Volume: Cubic Feet per Foot	Approximate Pounds Graded Bentonite per Foot*	Approximate Linear Feet Filled per 50-Pound Bag of Graded Bentonite
2 inches	0.16	0.02	1.4	35.70
3 inches	0.37	0.05	3.5	14.30
4 inches	0.65	0.09	6.3	7.90
5 inches	1.02	0.14	9.8	5.10
6 inches	1.47	0.20	14.0	3.60
8 inches	2.61	0.35	24.5	2.00
10 inches	4.08	0.55	38.5	1.30
12 inches	5.88	0.79	55.3	0.90
14 inches	8.00	1.07	74.9	0.67
16 inches	10.44	1.40	98.0	0.51
18 inches	13.22	1.77	123.9	0.40
2 feet	23.50	3.14	220.0	0.23
2.5 feet	36.72	4.91	344.0	0.16
3 feet	52.88	7.07	495.0	0.10
4 feet	94.00	12.57	880.0	0.06
5 feet	146.90	19.64	1375.0	0.04
6 feet	211.50	28.27	1979.0	0.03
7 feet	287.90	38.48	2694.0	0.02
8 feet	376.00	50.27	3519.0	0.01
9 feet	475.90	63.62	4453.0	0.01
10 feet	587.50	78.54	5498.0	0.01

Source: Eversoll et al. 1995 (table 2, p. 6).

12.2.4 Methods Of Grout Placement For Specific Seal Types

Intermediate Seals. Intermediate seals may be placed in impermeable strata between aquifers which are identifiable as, or are suspected of being, hydraulically separated under natural, undisturbed conditions. Once the required seal has been installed, the remainder of the impermeable zone or non-producing zone between aquifers shall be filled with fine sand or aggregate, bentonite, or cement-bearing mineral material. Where these intervals are relatively short, it is usually more economical and effective to place a continuous grout seal.

Seal at Uppermost Aquifer. A cement- or bentonite-based seal should be installed in the least-permeable zone in or above the upper aquifer unit. This seal should have a hydraulic conductivity no higher than the last permeable zone immediately above the uppermost water-producing zone. Such seals are only placed only in quiescent (non-flowing) water.

Seals Placed Within Casing, Liners, Filters, etc. Seal which must be placed in casing, liners, or filters require special attention. The material between the well and the face of the bore hole must be thoroughly perforated, ripped, or otherwise disintegrated as the necessary first step. Lineshaft oil or other polymer-containing material (including biofouling) coating the casing or liner surface should be reduced or removed to improve grout adherence. Neat cement only, neat cement with 5-to-6-percent (by weight) bentonite, or high-solids bentonite may be used. Pressure grouting, with injection pressure sufficient to penetrate into the annular space through perforations, should be used as the emplacement method (**Figure 38**).

Example cased well grouting installation procedures:

Case 1. The calculated amount of cement grout required to fill the well interval plus the annular space outside the lining is placed within the space to be cemented, running the cement through a cementing packer manufactured specifically for this purpose and installed immediately above the perforated or ripped zone. The cement shall be injected at a pressure calculated to be at least 50 psi (~3.5 bar) greater than the normal hydrostatic pressure within the well at the point of injection.

Case 2. A calculation is made of the amount of bentonite or cement grout required to fill the casing interval plus the annular space outside the lining, plus sufficient grout to fill an additional 10 feet (3 m) of the lining. The calculated amount is introduced at the bottom of the interval to be sealed.

Sandpoint wells: For a well of this type, it is best to pull it entirely out of the ground if at all possible and permit the hole to collapse if possible. If it does collapse, excavate to 3 to 5 ft and install a 1- to 3-ft moistened grout seal (using granular or 0.25-

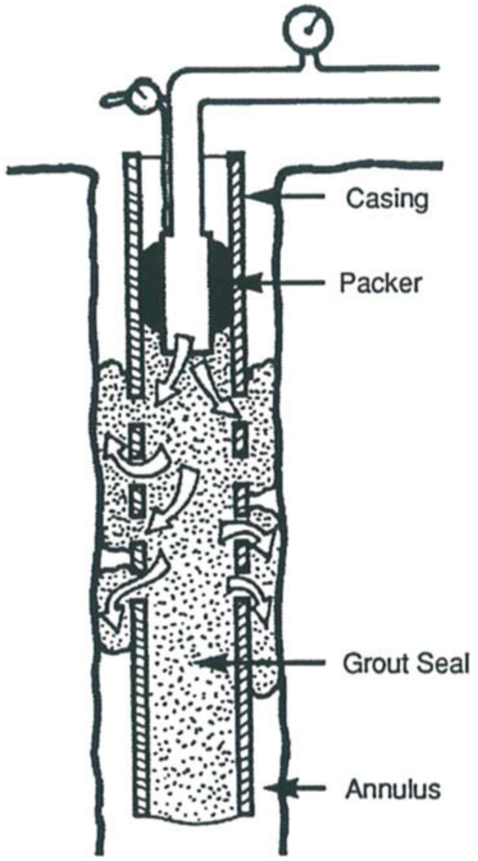


Figure 38. Seals Placed Within Casing.

Figure is from *Well and Borehole Sealing*.

in. chip bentonite). If the hole does not collapse, pump the hole full of cement or bentonite grout to within 3 ft of the surface, then finish with surficial soil.

Sealing dug wells and large shafts: Most dug water wells are relatively shallow (<300 ft or 100 m). Measure the static water level and check the shaft diameter and total measurable depth. Drilling logs from nearby may be used to determine the aquifer and aquitard arrangement. Fill the shaft to within 1 ft (300 mm) of the measured static water level with clean, chlorinated sand, sand-and-gravel, or aggregate. Install a 3-ft (1-m) bentonite seal on top of the fill layer using coarse (0.25- to 0.5-in) "hole plug" bentonite chips. The remainder of the well cavity may then be filled with sand or native (clean fill) earth materials free of contamination, sticks and large objects to within 6 ft (2 m) of the ground surface or final graded surface. Finish with (1) a 3-ft layer of bentonite (moistened thoroughly), then (2) a 3-ft layer of surficial soil and mound up to allow for settling.

Contaminated wells: These should be entirely filled with low-permeability grout according to the procedure specified by the local jurisdiction. The uppermost 3-6 feet (2 m) of the bore hole (at land surface) may be filled with a material appropriate to the intended use of the land.

12.3 Well Decommissioning Records

Before equipment is removed from the site, the exact location of the sealed well or hole should be determined and recorded, referencing the location with permanent reference points, by global positioning system, or otherwise as prescribed by the state or local regulatory agency. All information relative to the abandonment procedures and the location of the abandoned well should be recorded as prescribed by the state or local regulatory agency, with copies supplied to the respective agency and the owner of the land. Where required by local ordinance, copies may also need to be sent to other interested parties such as the managers of a wellhead protection area encompassing the property where the decommissioned well was located.

References

ASTM. Guide for Decommissioning of Ground Water Wells, Vadose Zone Monitoring Devices, Boreholes and Other Devices for Environmental Activities, *1996 Annual Book of ASTM Standards, Vol. 4.09, ASTM, West Conshohocken, PA, pp. 160-175.*

Australian Drilling Industry Training Committee, 1997. *Drilling: The Manual of Methods, Applications and Management. Lewis Publishers, Boca Raton, FL.*

Eversoll, D.A., D.R. Hay and R.J. Tremblay, 1995. *Guidelines for Decommissioning Water Wells: How to Plug Water Wells, Miscellaneous Publication No. 37, Conservation and Survey Division, Institute of Agriculture and Natural Resources, University of Nebraska-Lincoln, Lincoln, NE.*

Gaber, M.S. and B.O. Fisher, 1988. *Michigan Water Well Grouting Manual, Michigan Department of Public Health, Lansing, MI.*

Harth, G. 1994. Bore cementing, part B. Drillers Seminar Handbook, 1994, Dalby 2 & 3 March 1994, Queensland Department of Natural Resources, Toowoomba, pp. 7.16-7.30.

NWWA Committee on Water Well Standards. 1975. *Manual of Water Well Construction Standards, EPA - 570/9-75-001. Office of Water Supply, Washington, DC.*

Smith, S.A. 1994. *Well and Borehole Sealing: Importance, Materials, Methods and Recommendations for Decommissioning. Ground Water Publishing Co., Dublin, OH.*

Well Sealing Workgroup, 1996. *Technical Guidance for Sealing Unused Wells, State Coordinating Committee on Ground Water, State of Ohio, Columbus, OH.*

Chapter 13
Standards and Quality Control

13 Standards and Quality Control

An important aspect of ground-water supply exploration, well construction and development, and eventual decommissioning of wells is the existence of standards for practice and conduct. In the United States, Canada, and numerous other nations, federal, state or provincial, and sometimes local agencies have long maintained standards for essential well construction elements. These typically address well location, type of construction, casing, grout, yields, and water quality. In addition, national state and provincial governments also regulate the qualifications of personnel involved in well siting, drilling, construction, testing, and inspection.

States and provinces may also issue guidelines, which do not have the force of regulation or legal standards, but may have the same influence (e.g., the need to follow a guideline in order to obtain a well permit). Readers involved in any of these activities should be familiar with the standards and guidelines of the jurisdictions in which they are working. Readers are referred to the appropriate agencies, but should also consult the National Ground Water Association, which maintains information on well and well construction law, regulations, standards, and guidelines in the United States: 601 Dempsey Rd., Westerville, OH 43081, tel. 800-551-7379, e-mail: ngwa@h2o-ngwa.org or URL: www.ngwa.org. Because of its status as an association that spans the ground water industry, NGWA is the central source of well construction information.

Some general definitions of the differences among these categories:

Regulations:	Requirements defined by law ("must do")
Standards:	Normal expected professional practice as defined by an organization, agency or industry.
Consensus standards:	are set by mutual agreement by persons involved in the use of standards.
Guidelines:	Recommended practice, normally without the formal authority of a regulation or standard. However, they may have the same effect in practice.

13.1 Consensus and Quasi-Official Standards for Practice

Various organizations maintain standards pertinent to drilling, ground-water testing, and well construction. While not specifically legally binding in themselves, they are often cited in regulations, or may be used informally by regulatory personnel to evaluate well-related activities.

Table 13.1
Active Standard-Setting Organizations

Organization	References	Standards Activity
ASTM	100 Barr Harbor Dr. West Conshohocken, PA 19428 tel: 1-610-832-9585 fax: 610-832-9555 e-mail: service@local.astm.org URL: www.astm.org	A wide variety of aspects of drilling, testing, and well construction
AWWA	6666 W. Quincy Ave. Denver, CO 80235 tel: 303-794-7711 fax: 303-730-0851 URL: www.awwa.org	Well construction, pumps, disinfection, chemicals used in these activities
NGWA	601 Dempsey Rd. Westerville, OH 43081 tel: 800-551-7379 or 614-898-7791 fax: 614-898-7786 e-mail: ngwa@ngwa.org URL: www.ngwa.org	Certification of personnel and central clearinghouse of well construction and testing information
NSF International	3475 Plymouth Rd. Ann Arbor, MI 48105 tel: 800-673-6275 or 313-769-8010 fax: 313-769-0109 e-mail: info@nsf.org URL: www.nsf.org	Materials and chemicals used in well and water supply work
Water Systems Council	800 Roosevelt Rd., Bldg. C, #20 Glen Ellyn, IL 60137 tel: 630-545-1762 fax: 630-790-3095	Well caps and pitless units and adapters

Tables 13.2 and 13.3 list relevant standards in water well construction.

Table 13.2
Various U.S.-Based Standards Addressing Well Construction

ANSI/AWWA A100	AWWA Standard for Water Wells
ANSI/AWWA C654	AWWA Standard for Disinfection of Wells
Committee of the Great Lakes–Upper Mississippi River Board of State Public Health and Environmental Managers	"Ten State" Standard for Water and Wastewater Facilities
WSC	Performance Standards (PAS-97) and Installation Procedures for Sanitary Water Well (Pitless Adapters, Pitless Units and Water Tight Caps)
NSF International	NSF-60 and NSF-61 (NSF-pw) Chemicals and materials for potable water use and materials for potable water use (health effects), and NSF-14 for plastic plumbing system components

Table 13.3
Selected ASTM Standards Relevant to Drilling, Well Construction, Completion, Testing, and Decommissioning

D 1452	Practice for soil investigation and sampling by auger borings
D 1587	Practice for thin-walled tube geotechnical sampling of soils
D 2113	Practice for diamond core drilling for site investigation
D 2488	Practice for description and identification of soils (visual-manual procedure)
D 4043	Standard guide for selection of aquifer-test method in determining hydraulic properties by well techniques
D 4044	Standard method (field procedure) for instantaneous changes in head (slug tests) for determining hydraulic properties of aquifers
D 4050	Standard test method (field procedure) for withdrawal and injection well tests for determining hydraulic properties of aquifer systems
D 5088	Practice for decontamination of field equipment used at nonradioactive waste sites
D 5092	Practice for design and installation of ground water monitoring wells in aquifers
D 5254	Practice for minimum set of data elements to identify a ground water site
D 5255	Practice for certification of personnel engaged in testing soil and rock
D 5299	Guide for decommissioning ground water wells, vadose zone monitoring devices, boreholes and other devices for environmental activities
D 5434	Guide for field logging of subsurface explorations of soil and rock
D 5521	Guide for development of ground water monitoring wells in granular aquifers
D 5608	Practice for decontamination of field equipment used at low level radioactive waste sites
D 5716	Test method to measure rate of well discharge by circular orifice weir
D 5737	Guide to methods for measuring well discharge
D 5753	Guide for planning and conducting borehole geophysical logging
D 5781	Guide for use of dual-wall reverse circulation drilling for geoenvironmental exploration and installation of subsurface water-quality monitoring devices
D 5782	Guide for use of direct air rotary drilling for geoenvironmental exploration and installation of subsurface water-quality monitoring devices
D 5783	Guide for use of direct rotary drilling with water-based drilling fluid for geoenvironmental exploration and installation of subsurface water-quality monitoring devices
D 5784	Guide for use of hollow-stem augers for geoenvironmental exploration and installation of subsurface water-quality monitoring devices
D 5785	Guide for use of cable-tool drilling and sampling methods for geoenvironmental exploration and installation of subsurface water-quality monitoring devices
D 5786	Practice (field procedure) for constant drawdown tests in flowing wells for determining hydraulic properties of aquifer systems
D 5787	Practice for monitoring well protection
D 5872	Guide for use of casing advancement drilling methods for geoenvironmental exploration and installation of subsurface water-quality monitoring devices
D 5875	Guide for use of cable-tool drilling and sampling methods for geoenvironmental exploration and installation of subsurface water-quality monitoring devices
D 5876	Guide for use of direct rotary wireline casing advancement drilling methods for geoenvironmental exploration and installation of subsurface water-quality monitoring devices
D 5903	Guide for planning and preparing for a ground water sampling event
E 380	Standard practice for Use of the International System of Units (SI) (the modernized metric system)

In general, ASTM documents may be divided into "guides", "test methods" and "standard practices." Guides are an overview of practices recommended for completeness or quality in an investigation, and do not specify exact procedures. Test methods are specific step-by-step test procedures. Standard practices are more exact delineations than guides of fairly mature procedures. In addition, ASTM publishes "provisional standards" in areas where it is perceived that some guidance is helpful, but these provisional standards are not finalized.

Standards in the following topic areas are anticipated:

Maintenance and rehabilitation of ground water monitoring wells.

Designing and constructing production wells.

Locating abandoned wells.

Selection and documentation of existing wells for use in environmental site characterization and monitoring (would pertain to observation wells for tests).

Permanent closure of geotechnical exploration boreholes.

Diamond-core drilling, coring, and sampling for site investigation.

Design and installation of flush-to-ground-surface protection for monitoring wells.

13.2 Certification and Licensing of Personnel

Since 1968, the NGWA has maintained a certification program for water well and monitoring well contractors and pump installers, organized by technical category. NGWA certification exists as a long-standing and well-developed standard of professional well construction personnel qualifications. To qualify, a person must have two years experience (or an equivalent in formal training), and then pass a test on the specific method (e.g., mud rotary drilling). The NGWA certification program also has provision for granting Master Ground Water Contractor to persons who pass all the topical tests, and complete an essay exam. Current specific information on the NGWA certification program should be obtained from the association. NGWA also offers a process for certified gound water professional designation for hydrogeologists and engineers, based on experience and qualifications. Where “professional” oversight is required in a ground water project “CGWP” is a valid standard of professionalism.

ACKNOWLEDGEMENTS

This manual's first (1975) edition was prepared for the U.S. Environmental Protection Agency (EPA) under the auspices of the National Water Well Association Committee (NWWA) on Water Well Standards (WWS), comprised of thirty-four prominent scientists, engineers, and well contractor members of the ground water industry, including representatives from state regulatory agencies. This was the first recorded attempt in the industry to assemble a description of standard methods of practice in water well construction. This was an extraordinary effort by industry professionals from all areas of the Lower 48 U.S. states.

The original technical research, compilation and editing was performed under the general direction of Jay H. Lehr, then NWWA Executive Director, and the immediate supervision of Michael D. Campbell, then NWWA Director of Research. Many people in industry and state and federal agencies also provided input, which is gratefully acknowledged.

The EPA Office of Water Supply project officer was Edwin L. Hockman. Wilbur J. Whitsell and William E. Thompson of the Office of Water Supply undertook the major tasks of review, editing, and project coordination

The current edition was developed as an update to the 1975 *Manual*, which had extensive and worldwide distribution and use, but had become dated. The National Ground Water Association assembled a Manual of Well Construction Practices Task Force, consisting of members from many regions of the U.S. and each of the industry sectors. The names of those who served on the Task Force in addition to contributing revised text material are as follows:

Tom Downey – Nebraska
Charlie Riggs – Missouri
Fletcher Driscoll – Minnesota
Sam Geffen – Texas
Rod Tremblay – Nebraska
Joe Goebel – Indiana
Gary Hix – Arizona
Arnie Schiffman - New Jersey
Scott Golden –Ohio
Todd Reichart – Pennsylvania

Further review was provided by Sue Bohenstengel – Illinois, George Goffke – Illinois, Jarrell Greene – Georgia, Steve Gross – Pennsylvania, Bob Lyon – Maryland, Bruce Macler – California, Mike Mortensson – California, Pitz – Illinois, Roger Renner –

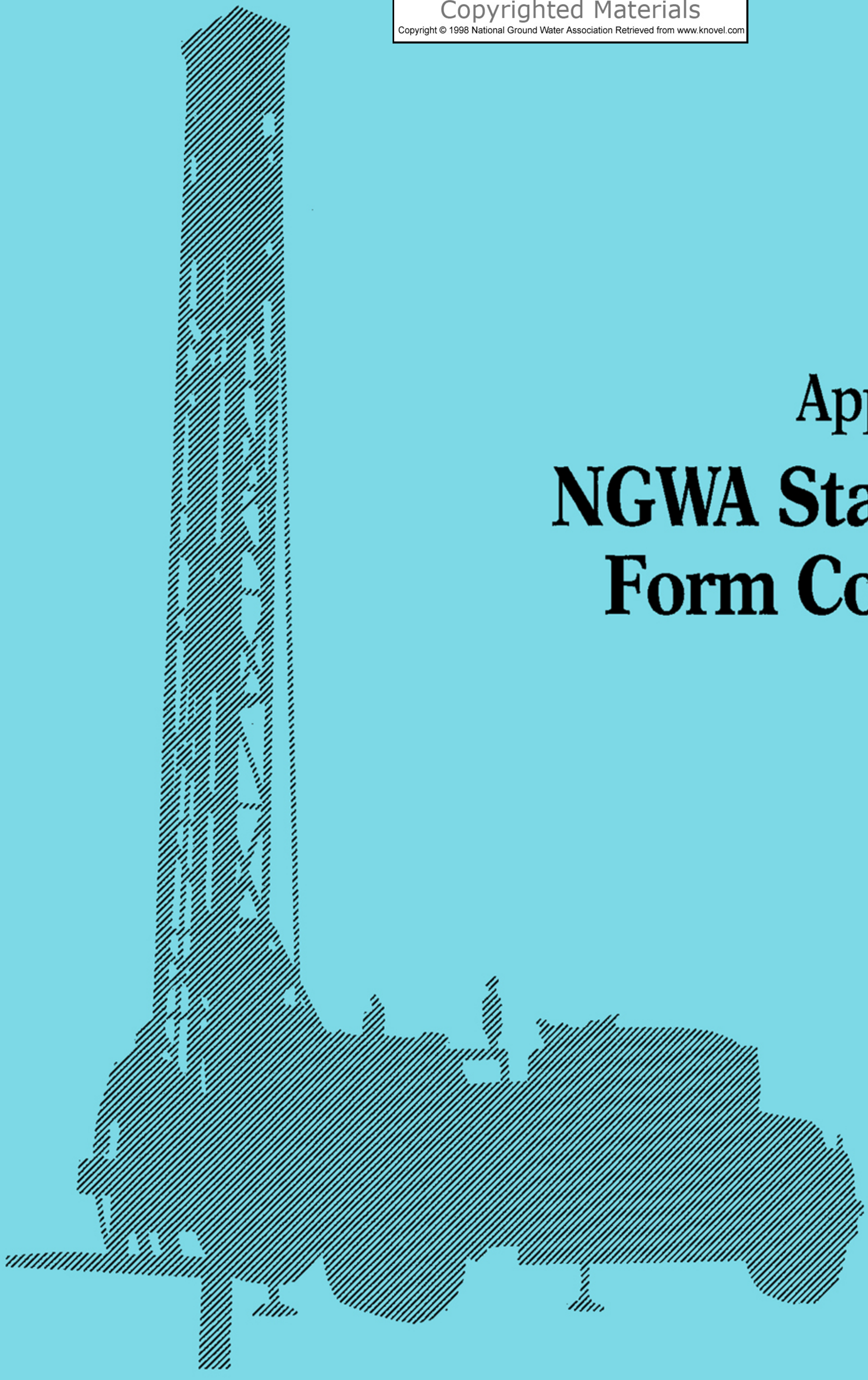
Minnesota, Eric Neubecker – Michigan, Elly K. Triegel – Pennsylvania, K. Michael Garman – Florida, K. C. McCabe – California, Jim Weston – Missouri, Carol Apgar – Delaware, Andre Fiedler – Colorado, and George Gillespie – Minnesota. NGWA staff included Kathy Butcher (project manager), Rosemary Purtee, Katherine Kelley, Susan Colley, Barbara Deitch, and the late Dr. Robert N. Farvolden (former NGWA Senior Scientist). Final technical writing and editing was performed by Stuart Smith, CGWP, Smith-Comeskey Ground Water Science, Ada, Ohio.

The National Ground Water Association also wishes to thank the publishers of the following publications for their permission to reprint charts, graphs, and illustrations: the Australian Drilling Manual, the *AWWA Standard for Water Wells*, the Basic Ground-water Hydrology, Groundwater and Wells, the Guidelines for Decommissioning Water Wells, the Handbook of Ground Water Development, and the Well and Borehole Sealing.

REVISED MANUAL OF WATER WELL CONSTRUCTION PRACTICES

19C	Gravel Pack Selection	Handbook of Ground Water Development
20	Azimuth Compass Card Dip Pendulum Card	Australian Drilling Manual
21	Pipe or Dummy Test	Australian Drilling Manual
22	Plummet Test	AWWA Standard for Water Wells
23	Pendulum Indicator	Australian Drilling Manual
24	Azimuth and Drift Indicated by Photograph Direction Instrument	Australian Drilling Manual
25	Terms and Equipment Used in Air Lift Pump	Groundwater and Wells
26	Installation of Pressure Gauge in Casing Seal	
27	Rossum Sand Tester	Handbook of Ground Water Development
28	Air Lift Test Method Installation	Australian Drilling Manual
29A	V-Notch Weir	Australian Drilling Manual
29B	Orifice Weir	Australian Drilling Manual
29C	Orifice Bucket	Australian Drilling Manual
29D	Methods of Drawdown Measurement	Handbook of Ground Water Development
30A	Pulling the Screen with a Sand Hitch	
30B	Casing Spear	
31A	Using the Jacking Method to Pull Casing	Well and Borehole Sealing
31B	Using A Combination of Hydraulic Jacking and Percussion With Cable Stem to Remove Casing	Well and Borehole Sealing
32	Borehole Overdrilling	Well and Borehole Sealing
33A	Borehole Bridging	Well and Borehole Sealing
33B	Cement Plugging Tools	Well and Borehole Sealing
34	Well Plugging Procedures in Artesian Wells	Well and Borehole Sealing
35	Intermediate Seal	Australian Drilling Manual
36	Seal at Uppermost Aquifer	Well and Borehole Sealing
37A	Pumping Grout Slurry to Seal an Abandoned Borehole Using the Tremie Method	
37B	Grout Pump Under Pressure	Well and Borehole Sealing
38	Seals Placed Within Casing	Well and Borehole Sealing

LIST OF TABLES



Appendix A
NGWA Standard Form Contract

Water Well Drilling Agreement

and

Instructions for Use

National Ground Water Association
601 Dempsey Road
Westerville, Ohio 43081-8978
Phone: 800 551.7379 or 614 898.7791
Fax: 614 898.7786

NGWA Press

Table of Contents

Instructions for Use

WATER WELL DRILLING AGREEMENT

Overview: What Terms are Necessary to Create a Contract?

If two parties agree to a price and a product, they create a contract. An oral agreement is a contract, and many disputes end up in court because persons do not realize that courts applying contract law might enforce any such agreement.

Thus, the purpose of drafting a written agreement is to make sure that all parties understand exactly to what they are agreeing. All changes to the Agreement should be in writing, and the parties should agree that any oral agreements simply shall not be enforced.

Terms of the Agreement attempt to reflect the parties' mutual understanding on all issues which typically lead to disputes in construction contracting. If construction proceeds as planned, the Agreement terms need not be enforced or even reviewed. The written agreement is re-read only after a dispute arises, and therefore any contract should contain all necessary provisions to avoid foreseeable disputes. For instance, in addition to a precise description of the parties, the work, and the price, the Agreement should address the schedule for completion, responsibility for safety and injuries, how changes to the work or Agreement can be agreed upon, and how the parties will resolve disputes.

Many contractors use a one-page "purchase order" with no terms addressing areas of common misunderstanding. This does not serve either the customer or the contractor, avoiding discussion of issues which may be agreeable before a dispute, but cannot be agreed upon after a problem arises. Therefore, the goals of this standard Water Well Drilling Agreement are:

1) To provide a simple, complete contract primarily for use with individual homeowners or short-term commercial subcontractors;

2) To allow for flexibility in the work and state or local law, through use of customized attachments; and

3) To include basic terms to raise issues oriented language as a sales tool, not leverage to significant advantage.

This Agreement may be used as a complete document, or either party may select only individual provisions from the Agreement to develop their own form. If the owner has a contract for review, this document is intended to help the contractor consider the issues, and offer individual alternative provisions as appropriate.

Construction Contract Review and Negotiation

Several general areas of dispute require routine consideration when negotiating any construction contract, whether the contractor or owner writes the first draft. A contractor must make practical business judgments about these issues, as precise legal language always is subject to interpretation. Depending upon the parties' relationship and experiences, in a positive environment the contractor might overlook unfavorable contract terms, or alternatively in a negative environment the contractor might walk away from a job no matter how favorable the contract terms.

THE PARTIES: A contractor must consider the other party carefully. If the Agreement is directly with the owner, the contractor should expect the job description to be reliable, as no third parties' intervene to misinterpret the buyer's intent. The contractor can assess financial responsibility for payment based on the property value. However, an owner may not understand even the most basic principles of construction contracting, and misunderstandings arise when a contractor relies upon "industry standards" which the owner does not know. Scheduling conflicts and numerous change orders typically result because an Owner does not plan the project based upon construction experience.

In contrast, if the Agreement is with another contractor or owner's representative, the drilling contractor may assume that the other party has some experience in construction procedures. However, care must be given to the work description detail, and determine whether the other party is reputable, is authorized to allow the contractor onto the property, and is financially responsible for payment. In addition, the other party may insist on unfavorable contract terms based on construction experience and leverage.

PAYMENT: Unlike public works projects, private projects seldom offer payment bonds or other evidence of financial responsibility. Therefore, the contractor must review the local **Mechanics' Lien Law,** to determine whether a statutory notice must be filed, and whether specific notices must be included in the contract language. Most states also have **Home Solicitation** statutes, requiring that consumers be given specific notices with a right to cancel any contract in certain circumstances, even if the work has been performed. Finally, **credit terms** require compliance with federal and state laws, with necessary disclosures. Consult a local attorney to determine necessary provisions in particular states.

The contract should specify enough information for the contractor to provide all **notices,** both for payment applications and for any change orders or claims. The contractor must follow any specific procedures in the agreement, or risk loss of payment.

SCHEDULE: Owners look for a date certain in completion, where contractors look to avoid this commitment. As a business policy to avoid disputes, it is better to have a date certain, negotiated well-beyond the likely date of completion. This avoids any misunderstanding arising from the owner taking other actions which depend upon completion, such as moving into that new home only to find no running water. The owner may expect the contractor to pay any costs.

For construction, the contractor must review whether the owner will pay for **owner-caused delays**, which cost the contractor more in rental equipment, labor, increased material prices, and lost opportunities on other jobs. Some owner documents will include a "no. damage for delay" clause if legal in the state, allowing only an extension of the completion deadline, but no money. Contractors should look for these provisions, as the owner has no liability if the contractor agreed to the term knowingly.

The contractor also should insist that the owner is liable for **unknown conditions**, particularly underground. While most courts will allow additional compensation to a contractor for latent conditions even without express contract language, as the building site is the owner's responsibility, some contracts require the contractor to warrant that the Contractor inspected and tested the site and agrees that there are no such conditions, thus waiving any additional compensation.

The parties should have a clear understanding of when the project is "complete". Is the well complete when it pumps water, or does the well require testing, and site restoration? This understanding cannot be left to chance.

DAMAGES: Case law in each state will determine the extent to which a contractor can claim money damages if the other party breaches the agreement. Many contracts contain a **liquidated damages clause**, stating that damages are difficult to determine and thus limiting the parties to a set amount. Such amount must bear some relation to potential losses, or the courts will not enforce the clause if it appears to be a penalty. These provisions can be favorable to contractors, limiting potentially large liability to a fixed amount. However, some provisions will apply only to certain losses, such as liquidated damages for delay in completion. A contractor must consider carefully any limitation to damages in a contract.

DOCUMENTATION: Just as a written contract avoids disputes, usually requiring written notices of any changes to insure accuracy, the contractor must develop a consistent practice of internal documentation on each project. **Daily job logs** provide an invaluable source of information when alleging cumulative weather delays, or owner or other contractor interference.

As well drilling typically requires that the contractor undertake **design** of the work, the contractor should document the precise well site in a diagram approved by the owner, with any other system architecture if it could be subject to disagreement. The owner should initial the final design so there is no doubt of approval.

When incidents occur which may lead to later liability, the contractor should send a **written notice** immediately to the owner if the contractor will claim that the owner should bear the cost. The owner has a right to "mitigate the damages", and can avoid payment if the contractor allowed an incident to continue causing greater damage by failing to give the notice.

Review of NGWA Water Well Drilling Agreement Terms

The enclosed standard Agreement should be reviewed by the Drilling Contractor's local attorney for compliance with state laws. Additional provisions can be incorporated by attachment, or the Drilling Contractor can prepare a customized contract by selecting only those provisions desired. All blanks should be filled in and attachments completed before submitting the Agreement to the Owner for consideration.

PROPERTY OWNER'S NAME: Make sure that the customer has proper authority to contract for the work. Identify on the document whether the customer owns the property, rents the property, is a prime contractor with the owner, or has another interest that provides the authority to contract. What happens if the owner does not like the location or specifications of the well once finished?, Will the "authorized representative" pay" to re-drill the well? If in doubt, get the owner's direct approval on any key documents.

PROPERTY DESCRIPTION: Be as specific as possible in filling in the legal description of the property where the well will be located. This is necessary to aid in filing for any lien, judgment, or other statutory notices such as a notice of commencement. Identify the actual property owner if the owner is not signing the Agreement.

DESCRIPTION OF THE WORK: For a standard contract form agreement to be used successfully while providing flexibility, a "Job Proposal" and a "Site Location Diagram" should be attached. As the Drilling Contractor will be responsible for some design, any variables should be submitted to the Owner and initialed to show the Owner's express approval. Then the Drilling Contractor can rely precisely on the work described and the prices quoted. Neither document requires any specific form; a letter, purchase order, and hand-drawing are acceptable, as long as they accurately reflect the final deal.

Government approvals must be considered before signing the Agreement. Which agencies must approve, and who will be responsible to get the approval (and liable if not approved) should be listed in writing. Consider the building permit, zoning restrictions, water and sewer tie-in requirements, septic or drainage restrictions, testing and health approvals. Any single failure will land the Drilling Contractor in court if not expressly stated to be the owner's responsibility and risk.

DRILLING CONTRACTOR'S STATUS AND DUTIES: The standard of care under "Control" requires the Drilling Contractors' "best skill and attention". This standard is lower than requiring the Drilling Contractor to follow industry standards, or the standard of care available".

The Agreement includes an express reservation under "Debris, Restoration" that the Owner will be responsible for site restoration. This should be called to the Owner's attention, so there are no surprises. If the Owner disagrees, add a specific item to the Job Proposal.

Liability for job site injuries is limited in "Responsibility" to only the work of the Drilling Contractor, its employees and subcontractors. Typical construction contracts vary this clause in many ways, and a contractor should review any alternative provisions carefully. Some states prohibit over-reaching shifting of liability.

Under "Safety", the Drilling Contractor agrees to "take all reasonable precautions" to protect even the Owner's and neighbors property. This is a selling point to Owners, but requires the Drilling Contractor to make an affirmative effort in protecting even the adjoining property. If an injury occurs the Drilling Contractor can point to the "reasonable precautions" taken. This provision does not say that the Drilling Contractor will be liable to pay for those damages, unless the Owner can demonstrate that the Drilling Contractor failed to take reasonable precautions. In essence, the Owner must allege Drilling Contractor negligence, for which the Drilling Contractor would be liable anyway.

CONTRACT PRICE: The Contract Price must equate to the prices listed on the Job Proposal. Often a contractor will propose one set of services, but fail to amend the proposal in writing before performing the work - a sure formula for litigation.

This Agreement establishes a unit Drilling Price with maximum depth, which cannot be exceeded without written authorization. If the Owner wants to continue beyond the maximum depth, the Drilling Contractor may change the per foot price and need not agree to the same unit prices in the Job Proposal.

The Materials, Costs price should be identical to the same price on the Job Proposal, and the Total Price should be included to give the Owner an express understanding as to the total cost, sales tax included, if the maximum depth is reached and all services are performed. Contracts which do not specify a maximum depth or total price leave to chance the possibility that a court will find that the Owner did not agree to that total; what is the point of a contract if such variables are possible?

Included as an option is the "Dry Hole Discount", as a sales tool. If the Drilling Contractor does not wish to offer this, the paragraph should be crossed out. Likewise, the Initial Payment is an option, which sophisticated Owners and prime contractors may refuse.

The Payments schedule allows to the Owner a specific number of days to pay after the Drilling Contractor sends the invoice. No interest is charged in this Agreement, as credit terms generally are regulated by federal and state laws; if incorrectly done, the contract can be voided. While most wells will not take a month for completion, the Agreement contemplates use for multiple drillings for one Owner, or a commercial use which might extend more than thirty days. In that event, an Owner may expect to pay only when the entire project is complete; the Drilling Contractor cannot claim interim funds without an express provision for periodic payments.

OWNER'S CHANGES: Typical to any construction project are changes. This provision requires that all changes be in writing and that the Drilling Contractor need not accept them on the face of the order but has the chance to re-price the contract in consideration of the change. The Agreement also disclaims any Drilling Contractor liability for delay due to a change order.

Unlike many Owner-drafted contracts, once this Agreement is signed the Owner is liable under this Agreement for the entire Job Proposal, and may not stop the project to cut costs. Such stop action would be a change order, and the Drilling Contractor is entitled to the profit under the Agreement just as if the well is completed.

SCHEDULE OF WORK: Some contractors prefer not to give a firm completion date. But owners plan on a date whether the contractor intends it or not. This term should not be excluded, so that both parties have a mutual understanding. Not included is the phrase "time is of the essence", so that the Drilling Contractor may argue that any delay does not breach the contract.

The Agreement defines "Complete" for the well as merely operational by the Owner. Thus, the Drilling Contractor may request payment even if some government approvals or testing still might be required for full use. The parties should discuss what they believe is "complete" when drafting the Job Proposal, so that the Owner does not dispute payment even if the Drilling Contractor technically finished.

DISPUTE, RESOLUTION, TERMINATION: This provision could include a number of foreseeable events upon which the parties might want to declare the Agreement in breach or simply no longer in force. As a standard form, included only are non-payment by the Owner and non-conforming work by the Drilling Contractor.

The Drilling Contractor must give the Owner a written notice if not paid on time, with a grace period of seven days. Likewise, the Owner must give the Drilling Contractor "a reasonable opportunity" as a grace period to correct any work problems.

Disputes must be resolved by binding arbitration, which in most states bars any action in court. The provision favors the Drilling Contractor, as arbitrators tend to represent members of the construction industry and not owner's interests. The process is faster than court, and less formal.

WARRANTIES: Local counsel must review this provision to include any requirements of state law. Most states imply into the contract the warranties of fitness for purpose and merchantability, which can be waived with express terms. The Drilling Contractor should review exactly what is warranted, and for how long, attaching a specific description so as to avoid any doubt. A year or more after the well was drilled will be the test of whether the Owner is satisfied based upon the mutual understanding from the written warranty provisions.

The law regarding warranties on the materials and equipment constantly changes. Generally, the trend is to hold the Drilling Contractor responsible for any merchandise, regardless of the fact that the Drilling Contractor did not manufacture it. The Drilling Contractor should discuss "products liability" insurance and other proper insurance coverage with an insurance agent and discuss warranties with an attorney. For example, the Magnuson-Moss Warranty Federal Trade Commission Improvement Act governs the labeling of warranties of consumer goods. Unless the warranty meets the minimum standards for full warranties provided in the Act, it must be designated a "limited warranty".

The Drilling Contractor must expressly disclaim any guarantee of water quantity or quality. If the Drilling Contractor wants to assure the Owner of specific quantity as a condition of drilling, or quality after testing, put the exact understanding in writing, along with the impact to price or cost. For instance, under the "Dry Hole Discount", the Owner gets a price break, but no more.

In a specific geographic area that is known to be prone to natural contamination of a certain character, (e.g., the western part of the United States where arsenic levels are potentially higher than those deemed safe pursuant to governmentally-imposed standards), it may be advisable to also use a more specific addendum page that more explicitly warns of the type of potential contamination, as well as the potential effect on human health from the use of such water for human consumption.

ENTIRE AGREEMENT: This provision makes clear that all understandings must be in writing and any oral agreement before or after this Agreement is signed is irrelevant and unenforceable. If a handshake is good enough, there is no purpose for a written Agreement which is not to be followed.

SEVERABILITY: Some court precedent holds that if any single provision in the Agreement is declared void, the entire Agreement is void as the document must be enforced as a whole to give full effect to the parties' understanding. Unfortunately, this may prevent the Drilling Contractor from payment on the undisputed work due to a dispute on one provision. Therefore, this clause should appear in any contract, unless the parties feel all clauses are necessary as a whole.

SIGNATURES: Both parties each should sign two copies of the Agreement, so that each has a signed original copy in the event of a dispute.

LOCAL, STATE LAWS: This Agreement is a form designed to apply to typical well drilling and repair sales. However, it cannot apply to all situations and comply with all laws of the 50 states. As a consequence, before using this Agreement, consult your attorney for specific legal requirements applicable to consumer and/or home solicitation sales, among other specific state law requirements.

Many states require notices and statutory language included in the contracts. Two examples are provided; the Texas statute requiring the contractor to give notice of an existing well which requires plugging, and the Minnesota statute requiring notice of mechanics' lien rights. In addition, other specific contract variations may be necessary for particular terms agreed to by the parties. This form Agreement and Instructions are provided as a service, and are not intended to offer legal advice whatsoever. **The National Ground Water Association and its agents disclaim any and all liability for damages attributable to the use of this standard form Agreement.**

LIENS: Specific steps must be taken within specific time limits to obtain certain liens. The Drilling Contractor always should consult a local attorney prior to contract as to the proper way to meet the lien requirements, attaching such language in the Agreement if required. Time limitations are critical under all state lien laws. In some states, a notice of commencement must be filed before construction begins for purposes of mechanic's lien laws. Be aware of the specific requirements in the project state.

NO CREDIT TERMS: This Agreement should not be used in installment payment transactions where credit has been extended to your customer. Use it only where the customer's obligation is to pay cash upon termination of your work. If used for a credit transaction, the parties will violate numerous state and federal laws, which carry severe penalties.

JOB PROPOSAL: This attachment is necessary, as referred to in the "Description of the Work" in the Agreement. In a larger construction contract, this would contain the plans and specifications describing the scope of work. The Drilling Contractor may use any similar proposal form, but must list all work to be performed in detail. If work is left to verbal agreement or is unclear, a court may not enforce the Agreement for payment of that work, as the parties did not have a "meeting of the minds". Thus, be sure to get the Owner's initials at the bottom of this page, just so there is no doubt that the Owner intends to pay for these items.

WELL MAINTENANCE, TESTING SERVICE ADDENDUM: This form is optional. Drilling Contractors may not consider either an ongoing maintenance contract or testing until an owner initiates a request later. As this is different than the scope of work contained in the primary Agreement, an additional form and signature is required.

The Addendum must contain a description of the work, a price, and a schedule. An express warranty also protects the Drilling Contractor from any Owner mistake. If prepared separately from the primary Agreement, other terms (such as dispute resolution) should be added. Here, by attaching it as an addendum, not only is the agreement made as early as possible, prior to problems arising, but the Addendum can refer to the other terms of the Agreement.

Summary

The National Ground Water Association hopes that this standard "Water Well Drilling Agreement" serves its membership as a form useful in most individual or commercial sales opportunities. With a careful review and understanding of the terms, including all understandings in writing, the Drilling Contractor will anticipate typical issues addressed in construction contracts while offering a flexible Agreement to foster a positive relationship with the customer.

Please contact us to offer comments or feedback for consideration in future additions.

WATER WELL DRILLING AGREEMENT

This Water Well Drilling Agreement (the "Agreement") is made and entered into effective this

______ day of ______________________, 200____ between:

______________________________________("Owner" or Owner's Authorized Representative) and

______________________________________("Drilling Contractor"), for the construction of a Water

Well on the real property at the following location ("Premises"):

____[STREET ADDRESS],

_______________________ [CITY], _________________ [COUNTY], ________________ [STATE],

and for which Premises the Owner has the authority to undertake the improvements contemplated by this

Agreement, upon the following terms and conditions.

1. *DESCRIPTION OF THE WORK*.

1.1 *Work:* Drilling Contractor agrees to furnish all labor, services, materials, equipment, and all other things necessary for the timely and proper completion of the Water Well in accordance with the Job Proposal and to be located as identified on the Site Location Diagram, each attached hereto and made a part of this Agreement (the "Work").

1.2 *Restrictions:* Drilling Contractor agrees to cause construction of the Water Well in accordance with all applicable zoning and building regulations, laws, ordinances, and orders of any public authority bearing on the construction and all restrictions and covenants of record concerning the subdivision in which the Premises are located, if applicable.

2. *DRILLING CONTRACTOR'S STATUS AND DUTIES*.

2.1 *Control:* Drilling Contractor will supervise and direct the Work, using its best skill and attention, and shall be solely responsible for and have control over construction means, methods, techniques, sequences, and procedures and for coordinating all portions of the Work under this Agreement. Construction of the Water Well shall conform to the Job Proposal, with such changes only as may be agreed to by the parties in writing. Neither party will unreasonably withhold its agreement.

2.2 *Debris, Restoration:* During construction, Drilling Contractor shall keep the work site and surrounding area free from any unreasonable accumulation of debris and waste materials. Unless expressly agreed to in writing in the Job Proposal, upon completion of the Work the Owner shall be responsible to remove all debris, waste and surplus materials or rubbish remaining on the work site, and to restore the site to its required condition. The Drilling Contractor shall not be responsible for any site restoration.

2.3 *Responsibility:* Drilling Contractor shall be responsible to Owner for the acts and omissions of Drilling Contractor's employees, subcontractors, and their agents and employees, and other persons performing portions of the Work under a contract with Drilling Contractor.

2.4 *Safety:* Drilling Contractor shall be responsible for initiating, maintaining, and supervising all safety precautions and programs in connection with the performance of the Work and shall comply with all applicable laws, ordinances, rules, regulations, and orders. Drilling Contractor shall take all reasonable precautions for safety of, and shall provide protection to prevent damage, injury, or loss to a) persons who may be directly injured during the Work, b) the Water Well and materials and equipment to be incorporated therein, and c) any other property and improvements at the site or adjacent thereto.

3. *CONTRACT PRICE*. Owner shall pay Drilling Contractor as follows:

3.1 *Drilling Price*: $___________.00 total drilling price at the rate of $___________.00 per lineal foot drilled, to a maximum depth of _________ feet. Drilling Contractor shall not exceed this depth without written authorization of Owner agreed to by Drilling Contractor not to exceed an additional lineal foot price and depth.

3.2 *Materials, Costs:* $___________.00 total materials and costs, as itemized in the Job Proposal. No additional Work shall be performed other than as itemized in the Job Proposal without written authorization of Owner agreed to by Drilling Contractor.

3.3 *Total Price:* $___________.00 total contract price including maximum depth drilling and all other costs as itemized in the Job Proposal. This price shall not be changed without written authorization of Owner agreed to by Drilling Contractor.

3.4 *Dry Hole Discount:* If the Drilling Contractor reaches the maximum depth without producing ______gallons of water per day, and the Owner decides not to authorize additional drilling, the total drilling price shall be discounted by $___________.00, and the Owner shall pay only for the drilling, those materials and other costs in the Job Proposal actually used to that date.

3.3 *Initial Payment:* Owner agrees to prepay $___________.00 of the total price to Drilling Contractor upon signing of this Agreement to provide Drilling Contractor with funds in advance for expenses relating to the Work.

3.4 *Payments:* Upon receipt of each payment made by Owner to Drilling Contractor, Drilling Contractor will provide the Owner with a lien waiver in the amount of the payment received. If the duration of the Work continues for more than one month, Drilling Contractor shall be entitled to payment of the Work completed monthly, by submitting a Payment Application accompanied by properly executed releases of liens by subcontractors and substantial material suppliers for the prior payment. The Owner shall pay Drilling Contractor not later than ______ days after receipt of a Payment Application.

4. *OWNER'S CHANGES*. Owner, without invalidating this Agreement, may order changes in the Work. Such changes shall be authorized by written modification of this Agreement. An appropriate adjustment to the price will be made with the consent of both Owner and Drilling Contractor in writing, which consent shall not be unreasonably withheld. Owner acknowledges and agrees that Drilling Contractor's ability to complete the Work in a timely manner will be directly affected by any change order requested by Owner.

5. *SCHEDULE OF WORK*.Construction shall begin by _______________[date] and shall be complete by _______________[date] excepting delays beyond Drilling Contractor's control. "Complete" shall mean that the Water Well is operational by Owner.

6. *DISPUTE RESOLUTION, TERMINATION*.

6.1 *Non-Payment:* If Owner fails to make payment due to Drilling Contractor for a period of ______ days after the submission of a Payment Application for Work that is not disputed by Owner, Drilling Contractor may terminate this Agreement seven (7) additional days after written notice to Owner, and recover from Owner payment for all Work executed and for loss of materials, equipment, tools, and machinery, including reasonable overhead, profit and other consequential damages.

6.2 *Corrections:* Owner shall provide Drilling Contractor with a reasonable opportunity to cure any claimed non-conformity and agrees not to remove Drilling Contractor from the Premises or order Drilling Contractor to stop work so long as Drilling Contractor diligently undertakes to cure the claimed non-conformity.

6.3 *Mediation, Arbitration:* All claims or disputes between Owner and Drilling Contractor arising out of or relating to this Agreement shall be submitted to non-binding mediation pursuant to the Construction Industry Mediation Rules of the American Arbitration Association. Owner and Drilling Contractor shall mutually select and equally share in the cost of the services of a mediator. The chosen mediator must have reasonable knowledge of the water well drilling industry. In the event that the dispute is not resolved following mediation, the matter shall be resolved by binding arbitration pursuant to the Construction Industry Arbitration Rules of the American Arbitration Association.

7. *WARRANTIES.*

7.1 *Workmanship, Materials:* Drilling Contractor warrants that (i) all Work performed hereunder will be performed in accordance with this Agreement and in a proper workmanlike manner, free from all defects; (ii) all materials used will be new; and (iii) all materials, the Work, and the Premises will at all times be free and clear of liens and encumbrances. In addition to the foregoing warranty, Drilling Contractor will assign to Owner all warranties received by Drilling Contractor in connection with the Work, including, specifically, manufacturer's warranties and guarantees on appliances and equipment incorporated into the Water Well.

7.2 *Express Warranties, Only:* No representations or warranties, expressed or implied, are made or agreed to be made by any party hereto, except those specifically provided herein. Drilling Contractor provides no other warranty or guarantee, unless expressly in writing attached to this Agreement and signed by both Owner and Drilling Contractor.

7.3 *No Quantity of Water Guaranteed:* Drilling Contractor specifically does not warrant that the water well being constructed will produce water in any specific quantity, or that it will produce any water at all. All risk of failure to produce water shall be borne by the Owner, and failure to produce water shall not release Owner from payment other than in accord with this Agreement.

7.4 *No Quality of Water Guaranteed:* Drilling Contractor specifically does not warrant that the water well being constructed will produce water of any specific quality, or that it will be fit for human consumption, except as otherwise specifically required by state law. All risk of failure to produce water fit for human consumption shall be borne by the Owner, and failure to produce water fit for human consumption shall not release Owner from payment other than in accord with this Agreement.

8. *NOTICE OF POSSIBLE CONTAMINATION.*

8.1 *Notice of Potential Natural Contamination:* Drilling Contractor hereby gives notice to Owner that certain natually occurring contaminants may be present in the ground water that will supply the water well being constructed. Such naturally occurring contaminants may include, but are not limited to, certain minerals, bacteria and toxics such as arsenic, and may render the water produced by the well unfit for human consumption unless the water is treated on an ongoing basis. Drilling Contractor specifically disclaims any guarantee that the water produced by the well will be free from any such contamination, and Owner acknowledges being notified of such potential natural contamination by signing this Agreement and initialing here: ________

8.2 *Notice of Importance of Testing:* Drilling Contractor hereby gives notice to Owner that prior to using the water in the well for any purpose, and in particular for human consumption, Owner is advised to have the water tested for naturally occurring contamination. Owner is responsible for arranging, ensuring completion of, and payment for such testing, unless otherwise provided in this Agreement. All risk of the presence of naturally occurring contaminants in the water shall be borne by the Owner, and the presence of naturally occurring contaminants in the water shall not release Owner from payment other than in accord with this Agreement. Owner acknowledges being notified of the importance of testing for naturally occurring contaminants by signing this Agreement and initialing here: ________

9. *ENTIRE AGREEMENT*. This Agreement contains the entire understanding of the parties hereto and all prior agreements, which fully and completely constitutes the entire Agreement between the parties regarding the construction of the Water Well.

10. *SEVERABILITY*. Each provision of this Agreement shall be interpreted in such manner as to be effective and valid under law. If any term, condition, covenant, agreement or provision of this Agreement shall be deemed invalid or unenforceable under applicable law, such provision shall be ineffective to the extent of such prohibition or invalidity without invalidating, impairing or otherwise effecting any other provision of this Agreement, which shall remain in full force and effect.

Signed and agreed to effective the day and year first above stated.

OWNER:	DRILLING CONTRACTOR:
______________________________	______________________________
By: ___________________________	By: ___________________________
Address: _______________________	Address: _______________________
______________________________	______________________________

ATTACHMENTS AND ADDENDA:

______ Job Proposal

______ Site Location Diagram

______ Well Maintenance, Testing Service Addendum

______ Notification of Potential Contamination Addendum

LEGAL NOTICES ATTACHED:

______ Express Warranties, Waivers

______ Notice of Abandoned or Deteriorated Well[1]

---

1 For example, excerpts from Texas Rev. Civ. Statutes, Water Code, Title 2, Sub. D, Sec. 32.017: "(b) A licensed driller shall notify the commission and the landowner or person having a well drilled when the driller encounters water injurious to vegetation, land, or other water, and the well must be plugged, repaired, or properly completed in order to avoid injury or pollution. The driller shall assure that the well is plugged, repaired, or properly completed under standards and procedures adopted by the commission."

______ Mechanics' Lien Notice[2]

Other Legally Required Notices:

______ A ____

______ B ____

______ C ____

"(c) A licensed driller who knows of an abandoned or deteriorated well shall notify the landowner or person possessing the well that the well must be plugged or capped in order to avoid injury or pollution."

2 For example, Minnesota Statutes, Sec. 514.011 requiring in contract notice to owner of lien rights.

<u>WATER WELL DRILLING AGREEMENT</u>

JOB PROPOSAL

Drilling

1. Test drilling, estimated depth ___feet at $ __________per foot $__________
2. Well drilling, estimated depth ___feet at $ __________per foot $__________

Maximum Drilling Depth, Total Drilling Price: $__________

Materials, Costs

1. Well casing, maximum depth ___feet at $__________per foot $__________
   Casing size: __________________
2. Well and pump permit $__________
3. Well screen and installation $__________
4. Well developing and surging $__________
5. Well acidization $__________
6. Well disinfection $__________
7. Chemical and bacteriological laboratory tests $__________
8. Pump and installation, Repairs $__________
9. Other Materials, concrete, gravel $__________
10. Labor (Non-supervisory base rate $__________ per hour). $__________
11. Other skilled trades (electrical) $__________
12. Trencher or backhoe work $__________
13. Crane, truck or service rig $__________
14. Mobilization and demobilization $__________
15. Other water-supply equipment and installation $__________
16. Area cleanup $__________
17. Other:____ $__________

Sub-Total Material and Costs: $__________

Total Drilling, Material and Costs: $__________

Sales tax: $__________

Total Proposal Price: $__________

APPROVED BY OWNER: ____________

WATER WELL DRILLING AGREEMENT
WELL MAINTENANCE, TESTING SERVICE ADDENDUM

This Well Maintenance, Testing Service Addendum ("Addendum") to the Water Well Drilling Agreement (the "Agreement") originally dated ______________________, 200____ between the parties signed below, is made and entered into this ______ day of ______________________, 200____ upon the following terms and conditions:

1. *DESCRIPTION OF THE WORK.*

1.1 *Maintenance*: The Drilling Contractor shall perform periodic labor for maintenance of the Well upon request of the Owner, furnishing and installing replacement materials as required and directed by Owner. Maintenance visits shall not be less than once per ____________ (time period), nor more than _____________ per year.

1.2 *Testing:* The Drilling Contractor shall perform periodic tests of the Well upon request of the Owner. Tests shall be conducted not less than once per ____________ (time period), nor more than _____________ per year, including the specific tests listed below.

2. *CONTRACT PRICE.* Owner shall pay Drilling Contractor as follows:

2.1 *Maintenance*: Maintenance work shall be charged at the rate of $________.00 per ________ (insert "visit", "hour" or other basis), plus Drilling Contractor's actual cost of replacement materials, with a markup of ________% (percent), plus tax.

2.2 *Testing:* Testing shall be charged at the rate of $________.00 per ________ (insert "test", "hour" or other basis), plus Drilling Contractor's actual cost of testing supplies, with a markup of ________% (percent), plus tax. Specific tests shall be performed at an inclusive price:

a. ______________________ $________.00 b. ______________________ $________.00

c. ______________________ $________.00 d. ______________________ $________.00

2.3 *Maximum Price:* In no event shall the total cost pursuant to this Addendum exceed $____________________.00 without additional agreement between the parties.

3. *SCHEDULE OF WORK:* The Work shall begin on ______________________, 200____ and continue as required by the Owner, in effect until ______________________, 200____.

4. *OTHER TERMS:* Drilling Contractor specifically does not warrant and shall not be held liable for the quantity or quality of the water produced during or after maintenance or testing, or to determine whether any maintenance or tests are required, but shall serve only as the Owner directs. The parties hereby incorporate all other terms of the prior Agreement, not in direct conflict with the terms of this Addendum, as though fully restated herein.

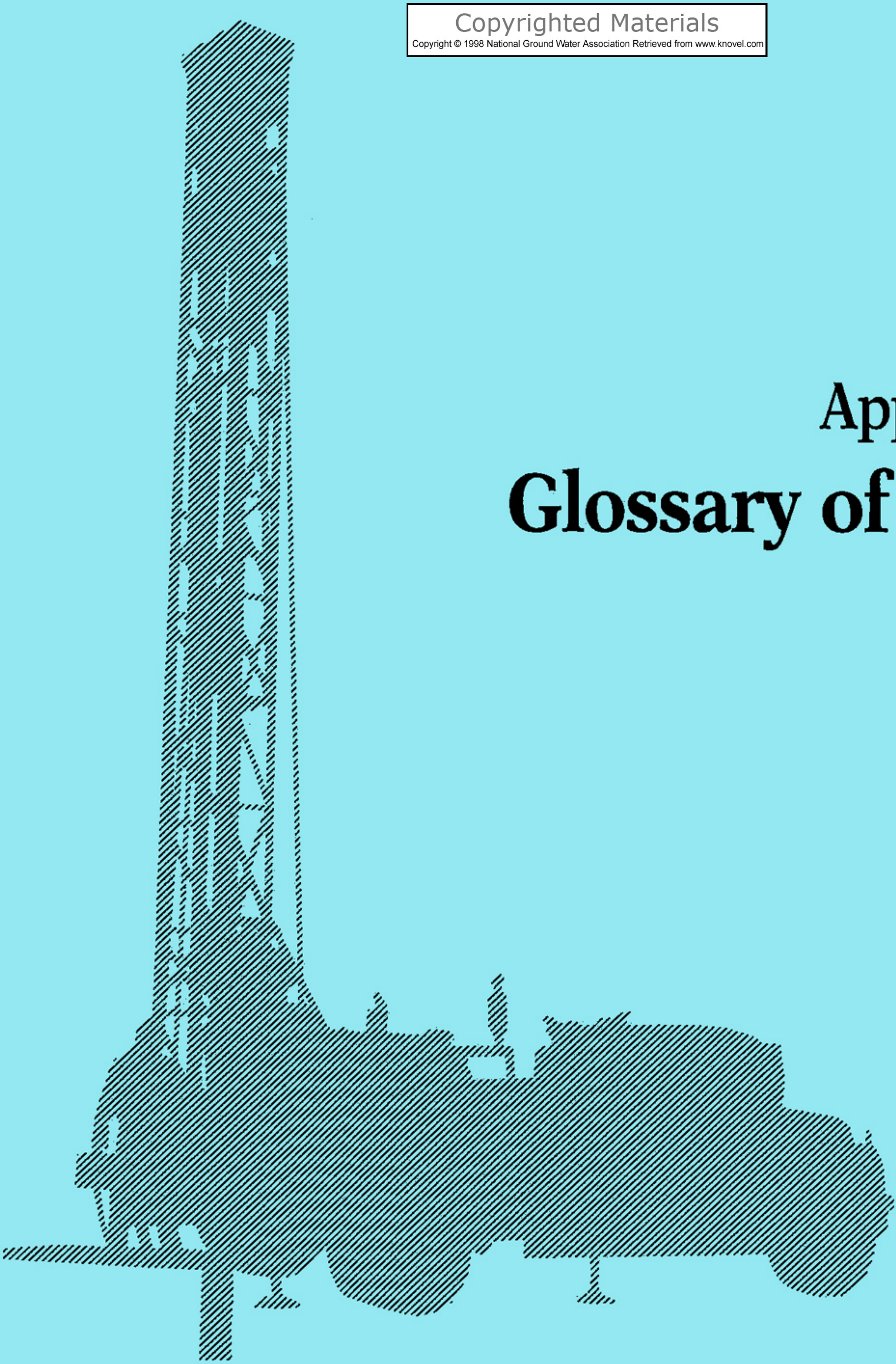
Signed and agreed to effective the day and year first above stated.

OWNER:	DRILLING CONTRACTOR:
______________________________	______________________________
By: ___________________________	By: ___________________________
Address: _______________________	Address: _______________________
______________________________	______________________________

Addendum of Notification
of
Potential Contamination

By this addendum, Drilling Contractor hereby notifies Owner that because Owner's well will be located in ____________________________ [insert general geographic area here; e.g. "the western portion of the United States"), it is possible that ground water that will supply the well will be contaminated with higher levels of ________________________________ [insert specific contaminant here; e.g. arsenic] than are considered safe for human consumption. Over time, the consumption of water containing higher levels of ________________________________ [insert specific contaminant here; e.g. arsenic] than are considered safe for human consumption may lead to ____ [insert specific health risk here; e.g. arsenic poisoning].

Drilling Contractor hereby gives notice to Owner that prior to using the water in the well for any purpose, and in particular for human consumption, Owner is advised to have the water tested for all naturally occurring contamination, and specifically for __________________________________ [insert specific contaminant here; e.g. arsenic]. Owner is responsible for arranging, ensuring completion of, and payment for such testing, unless otherwise provided in this Agreement. All risk of the presence of naturally occurring contaminants, including but not limited to _________________________________ [insert specific contaminant here; e.g. arsenic], in the water shall be borne by the Owner, and the presence of naturally occurring contaminants in the water shall not release Owner from payment other than in accord with this Agreement. Owner acknowledges being notified of the importance of testing for naturally occurring contaminants, including but not limited to __________________________________ [insert specific contaminant here; e.g. arsenic], by signing this Agreement and initialing here: ________



Appendix B
Glossary of Terms

APPENDIX B
Glossary of Terms[1]

A

ABANDONED WELL-To cease efforts to produce fluids from a well in depleted formation and to plug the well without adversely affecting the environment.

ACCELERATOR-A material that accelerates or speeds up the normal rate of reaction between cement and water, resulting in an increase in the development of early strength, and, in some cases, a decrease in the setting time or thickening time.

ACID-Any chemical compound containing hydrogen capable of being replaced by positive elements or radicals to form salts. In terms of the dissociation theory, it is a compound which, on dissociation in solution, yields excess hydrogen ions. Acids lower the pH. Examples of acids or acidic substances are: hydrochloric acid, tannic acid, and sodium acid pyrophosphate.

ACID RESISTANCE-The ability of a hardened cement slurry to withstand the softening and corrosive effects of organic or mineral acids, or water solutions of these acids and their salts having a pH lower than 7.0.

ACTIVE STATUS-A water well which is in use.

ADDITIVE-A material other than cement or water that is added to a cement subsequent to its manufacture to modify properties. Equivalent of admixture in ASTM usage.

AGGREGATE-An essentially inert material of mineral origin having a particle size predominantly greater than 10 mesh. Also a group of two or more individual particles held together by strong forces which are not subject to dispersion by normal mixing or handling.

ALKALINITY-The combining power of a base measured by the maximum number of equivalents of an acid with which it can react to form a salt. In water analysis, it represents the carbonates, bicarbonates, hydroxides, and occasionally the borates, silicates, and phosphates in the water. It is determined by titration with standard acid to certain datum points.

ANNULAR FLOW-Formation fluids are produced up through the tubing-casing annulus and recovered at the surface.

ANNULAR SPACE-The space between the well bore and the outside of the well casing.

ANNULUS (ANNULAR SPACE)-The space surrounding pipe suspended in the wellbore. The outer wall of the annulus may be the wall of the borehole or it may be larger pipe.

API-American Petroleum Institute. Founded in 1920, this national oil industry trade association maintains a headquarters office in Washington, D.C., and a Production Department office in Dallas, Texas. It is also used as a slang expression for a job well done (that work is strictly API), or for utter confusion (it's API today, two engines are down). Standards for many items of drilling and producing equipment are produced by industry committees of the Production Department, including specifications for wire rope and solid wire line.

API CEMENT CLASSES-A classification system for well cements defined in API Spec 10.

AQUICLUDE-A body of relatively impermeable soil or rock materials that is capable of absorbing water but will not transmit it fast enough to supply a well.

AQUIFER-A reservoir which bears water in recoverable quantity.

AQUIFER-A formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield economical quantities of water to wells and springs.

AQUITARD-A geologic formation, group of formations, or part of a formation through which virtually no water moves.

ARTESIAN WELL-A well deriving its water from a confined aquifer in which the water level stands above the ground surface; synonymous with flowing artesian well.

ASTM-American Society for Testing and Materials

AUGERED WELL-A well that is constructed by using an auger to bore the hole and extract materials.

B

BALANCE, MUD-A beam-type balance used in determining drilling fluid density. It consists primarily of a base, graduated beam with constant-volume cup, lid, rider, knife edge, and counterweight

BALANCED CEMENT PLUG-The result of pumping cement through drill pipe, workstring, or tubing until the level of cement outside is equal to that inside the drill pipe/workstring/tubing. The pipe is then pulled slowly from the cement slurry, leaving the plug in place. The technique is used in both open-hole and cased hole applications when the wellbore fluids are in static equilibrium.

BARREL - (BBL OR bbl)-A common unit of liquid volume measurement in the petroleum industry. One barrel (1 bbl) is equivalent to 4 2 gallons (158.97 liters).

BENTONITE-A plastic, colloidal clay largely made up of the mineral sodium montmorillonite; a hydrated aluminum silicate. For use in drilling fluids, bentonite has a yield in excess of 85 bbl/ton. The generic term "bentonite" is neither an exact mineralogical name nor is the clay of definite mineralogical composition.

BENTONITE GROUT-Bentonite grout consists of powdered sodium bentonite clay and clean water in the proportion of not less than 1 pound of powdered bentonite to 1 gallon of water. Bentonite grout may be used in all geologic formations. Bentonite pellets and granular bentonite may also be used as a seal material without forming a slurry.

BENTONITE SLURRY-A mixture of bentonite and water, weighing not less than 9 pounds per gallon.

BHP-Bottom Hole Pressure

BHT-Bottom Hole Temperature (°F)

BOND-Adhering, binding, or jointing of two materials (e.g., cement to casing).

BONDING-The state of bond between cement and casing and/or formation.

BORED WELL-Synonymous with an augered well or a well dug with a bucket-drill.

BOREHOLE-The wellbore; the hole made by drilling or boring a well.

BOTTOM HOLE PRESSURE-The pressure at the bottom of a well generally associated with the pore pressure of the formation open to the well.

BRIDGE-An obstruction in the drill hole or annulus. A bridge is usually formed by caving of the wall of the wellbore, by the intrusion of a large boulder, or by filter pack materials during well completion. Bridging can also occur in the formation during well development.

BRIDGE PLUG-A downhole tool (composed primarily of slips, a plug mandrel, and a rubber sealing element) that is run and set in casing to isolate a lower zone while an upper section is tested, cemented, stimulated, produced, or injected into.

BRIDGING MATERIAL-Fibrous, flaky, or granular material added to a cement slurry or drilling fluid to aid in sealing formations in which lost circulation has occurred.

BRINE-Water containing relatively high to saturation concentrations of common salt (NaCl) and relatively low concentration of other salts of calcium, magnesium, zinc, etc.

BULLHEAD SQUEEZE-The process by which hydraulic pressure is applied to a well to force fluid such as cement outside the wellbore. Annular flow (returns) is prevented by a packer set in the casing above the perforations and/or in open-hole.

BULLHEAD SQUEEZE-The process by which hydraulic pressure is applied to a workstring or tubing to force fluids, such as cement, outside the wellbore. Annular flow (returns) is prevented by a packer set in the casing above the perforated and/or open-hole interval. The packer shields the inner string wall from exposure to the pumping pressures.

C

CABLE-TOOL DRILLING-A method of drilling a well by allowing a weighted bit at the bottom of a cable to fall against the formation being penetrated.

CALCIUM-One of the alkaline earth elements with a valence of 2 and an atomic weight of about 40. Calcium compounds are a common cause of the hardness of water. It is also a component of lime, gypsum, limestone, etc.

CALCIUM CARBONATE ($CaCO_3$)-A slightly soluble calcium salt (limestone, oyster shells, etc.) sometimes used as a weighting material, and also as a standard unit for expressing hardness of water.

CALCIUM CHLORIDE (CaC_2)-A highly soluble salt which imparts special properties to drilling fluids, but primarily to increase the density of the fluids and to accelerate the hydration reaction of cement and water.

CALCIUM HYDROXIDE ($CA(OH)_2$]-The active ingredient of slaked lime and also a hydrolytic constituent of Portland cement. In field technology it is called "lime."

CALCIUM SULFATE-Anhydrite ($CaSO_4$), gypsum ($CaSO_4 \bullet 2H_2O$), hemihydrate ($CaSO_4 \bullet \frac{1}{2}H_2O$), or combinations of these.

CASING-A tubular retaining structure installed in the excavated hole to maintain the well opening.

CASING CEMENTING-The practice of filling an annulus with cement slurry.

CASING STRING-The pipe run in a well, for example: surface string, intermediate string, production string, etc.

CATHODE-The portion of a corrosion cell which does not corrode. Reduction always occurs at cathode.

CATHODIC PROTECTION-A technique to prevent the corrosion of a metal surface by making that surface the cathode of an electrochemical cell.

CEMENT

API Classes-Cement (Classes A through J) meeting the applicable requirements of API Spec 10. ASTM Types-Cement (Types I through V) meeting the applicable requirements of Standard Specifications for Portland Cement ASTM C 150.

Common, Regular or Ordinary-A cement intended for use under conditions not requiring moderate to high sulfate resistance. Corresponds to API Class A or Class C which are similar to ASTM Type I or Type III cements, respectively.
Construction-See Common, Regular or Ordinary.

Gel Cement-A cement or cement slurry that has been modified by the addition of bentonite.

CEMENT-A mixture of calcium aluminates and silicates made by combining lime and clay while heating. Slaked cement contains about 62.5 percent calcium hydroxide, which is the major source of trouble when cement contaminates drilling fluid.

CEMENT DENSITY-The specific gravity of a well cement as determined by a method similar to ASTM C 188: Test for Density of Hydraulic Cement. Most Portland cements have a specific gravity of about 3.15 when tested by this method. Cement density should not be confused with slurry density.

CEMENTING-The process of pumping a cementitious slurry into a well through steel pipe to critical points in the annulus or open-hole. Cementing is performed to isolate different zones in the well, protect the pipe from corrosive fluids, support the pipe in the hole, or repair previous cement jobs.

CEMENTING TIME-The total elapsed time for a cementing operation from the beginning of mixing until the completion of displacement to final depth and complete circulation of any excess slurry to the surface.

CENTRALIZERS-Guides which are attached to casing and which serve to keep it centered in the hole. See API Spec 10D.

CIRCULATE-To cycle fluid through pipe and wellbore while drilling operations are temporarily suspended. This is done to condition the drilling fluid and the wellbore before hoisting the drill pipe and to obtain cuttings from the bottom of the well before drilling proceeds. Circulation of the drilling fluid while drilling is suspended is usually necessary to prevent drill pipe from becoming stuck.

CIRCULATION-The movement of drilling fluid from the suction pit through pump, drill pipe, bit, annular space in the hole, and back again to the suction pit. The time involved is usually referred to as circulation time.

CLAY-A plastic, soft, variously colored earth, commonly a hydrous silicate of alumina, formed by the decomposition of feldspar and other aluminum silicates. In a true clay, 30% by weight of the solid particles are of diameter less than 0.002 micrometer.

COILED TUBING-A continuous length of small diameter (i.e., usually 1" to 1 3/4") ductile steel tubing which is coiled onto a reel. The tubing is fed into the well by an injector head through a coiled tubing blow-out preventer or stuffing box. The coiled tubing may be used for pumping fluids, including cement, into the wellbore.

CONCRETE GROUT-A mixture of one sack (94 pounds) of Portland cement, an equal amount by volume of sand and gravel or crushed stone, and not more than 7 gallons of clean water.

CONDUCTOR PIPE-A relatively short string of large-diameter pipe which is set to keep the top of the hole open and provide a means of returning the upflowing drilling fluid from the wellbore to the surface drilling fluid system until the first casing string is set in the well. Conductor pipe may also be used in well control. Conductor pipe is usually cemented.

CONFINED AQUIFER-A formation in which the groundwater is isolated from the atmosphere at the point of discharge by impermeable geologic formations; confined groundwater is generally subject to pressure greater than atmospheric.

CONFINING LAYER-A body of impermeable or distinctly less permeable material that lies above and/or below one or more water-bearing zones.

CONNATE WATER-Water that probably was laid down and entrapped with sedimentary deposits, as distinguished from migratory waters that have flowed into deposits after they were laid down.

CORROSIVE GAS-A gas which when dissolved in water or other liquid causes metal attack. Usually included are hydrogen sulfide (H_2S), carbon dioxide (CO_2) and oxygen (O_2)

CROOKED HOLE-Wellbore which has been inadvertently deviated from a straight hole.

CURING TIME-Minimum time required for particular types of cementing or grouting materials to harden.

D

DARCY-A unit of permeability. A porous medium has a permeability of 1 Darcy when a pressure of 1 atmosphere on a sample 1 cm long and 1 sq cm in cross section will force a liquid of 1-cp viscosity through the sample at the rate of 1 cc per sec.

DECOMMISSIONED WELLS-When used in relation to a water well shall mean the act of filling, sealing, and plugging water well in accordance with the rules and regulations of the state Department of Health.

DENSITY-Matter measured as mass per unit volume expressed in pounds per gallon (ppg), pounds per square inch per 1,000 ft of depth (psi/1,000 ft), and pounds per cubic ft (lb/cu ft). Density is commonly referred to as "weight."

DISPERSANT-A cement additive which reduces the initial consistency of cement slurries.

DISPLACEMENT-The lateral distance from the surface location to the primary target.

DISPLACEMENT RATE-The volumetric flow rate at which cement slurry is pumped down the hole.

DISPOSAL WELL-A well through which fluid (usually brine) is returned to subsurface formations.

DOMESTIC WATER-A water well providing water to any water supply system furnishing water for human consumption other than a public water system, or for the watering of livestock, poultry, farm and domestic animals used in operating a farm, and for the irrigation of lands not exceeding a total of two acres in area.
DOWNHOLE-A term to describe tools, equipment, and instruments used in the wellbore. For example, a downhole tool is used in the wellbore. Also, conditions or techniques applying to the wellbore.

DRILL STRING-A combination of drill pipe, drill collars, and accessory components.

DRILLED WELL-A well that is constructed with a rotary drilling machine that incorporates the use of circulating drilling fluid or compressed air to remove drill cuttings from the well hole.

DRILLING FLUID-A fluid circulated through the bit; an integral part of rotary drilling. It serves to carry cuttings from the bit. Hole conditions may dictate other necessary functions for the fluid. The fluid phase may be air (or other gas), water, oil or any combination thereof.

DRILLING FLUID OR MUD-A circulating fluid used in rotary drilling to perform any or all of a variety of functions required in the drilling operation.

DRILLING MUD-A drilling fluid where the fluid phase is oil, water, or a combination thereof (synonym MUD).

DRILLING MUD-A fluid composed of water and clay (either native clay or a combination of native and commercial clays) used in drilling operations to remove cuttings from the hole, to clean and cool the bit, to reduce friction between the drill stem and the sides of the hole, to seal the sides of the hole, to prevent caving, bridging or loss of circulation, and to prevent the interchange of water between aquifers. When permitted, drilling mud maybe used as filler or plugging material, provided it weighs not less than nine pounds per gallon.

DRILLING OUT-The operation during the drilling procedure when the cement is drilled out of the casing before further hole is made or completion attempted.

DRILLING RIG-Equipment and machinery assembled primarily for the purpose of drilling or boring a hole in the ground.

DUG WELL-A hand-dug well sometimes lined with brick or stone but in many locations unlined.

DUMP BAILER-A cylindrical container with a shear device that is used to release small batches of cement downhole on impact or by electrical activation. Used primarily to install cement on downhole tools such as bridge plugs or cement retainers.

E

EFFECTIVE PERMEABILITY-The permeability of a rock to a fluid when the rock is not 100% saturated with the fluid. See Permeability.

EFFLUENT-A discharge of liquids and/or solids into the environment, partially or completely treated or in their natural state. Generally used in regard to discharges into waters.

ELECTROLYTE-A chemical substance or mixture, usually liquid, containing ions that migrate in an electric field. The term electrolyte refers to the soil or liquid adjacent to, and in contact with a buried or submerged metallic structure including the moisture and other chemicals contained therein

F

FALSE SET-An abnormal early thickening of cement slurry wherein the slurry remains pumpable for the usual thickening time. The thickening may be reversible during the pumping history of the slurry.

FILLING MATERIALS-Well-plugging materials that are used to take up space in a well.

FILTER CAKE-The suspended solids that are deposited on a porous medium during the process of filtration. See also Cake Thickness.

FILTER-CAKE THICKNESS-A measurement of the solids deposited on filter paper in 32nd of an inch during the standard 30-min. API filter test. See Cake Thickness. In certain areas the filter-cake thickness is a measurement of the solids deposited on filter paper for a 7 1/2-min. duration.

FILTRATE-The liquid that is forced through a porous medium during the filtration process.

FILTRATION-The process of separating suspended solids from their liquid by forcing the latter through a porous medium. Two types of fluid filtration occur in a well: dynamic filtration while circulating and static filtration while at rest.

FINAL SET-Cement shall be considered to have acquired its final set when it will bear, without appreciable indentation, the final Gillmore needle. This is not an API test. See ASTM C 266: Time of Setting of Hydraulic Cement by Gillmore Needles.

FINAL STRENGTH-The strength of a cement at such a time when under the given conditions of temperature and pressure it ceases to change significantly (synonym Ultimate Strength).

FISH-Any object lost in the borehole.

FLASH SET-Flash set is abnormal early thickening or setting of cement slurry wherein the cement slurry becomes unpumpable.

FLUID LOSS-The volume of filtrate lost to the permeable material due to the process of filtration. The API water loss is the volume of filtrate determined according to the Fluid-Loss Test given in API Spec 10.

FLUID LOSS CONTROL-A means by which the volume of filtrate lost to a permeable material is reduced.

FLY ASH-Fly ash is the finely divided residue that results from the combustion of ground or powdered coal in thermal generating plants and is transported from the firebox through the boiler by flue gases. Fly ash is an artificial pozzolan.

FORMATION PRESSURE-The pressure exerted by fluids in a formation, recorded in the hole at the level of the formation with the well shut in. Formation pressure may also be termed "reservoir pressure," or "shut-in bottom-hole pressure."

FRACTURE-Crack and crevice in the formation either inherent or induced.

FUNCTIONS OF DRILLING FLUIDS-The most important function of drilling fluids in rotary drilling is to bring cuttings from the bottom of the hole to the surface. Some other important functions are: control subsurface pressures, cool and lubricate the bit and drill string, deposition of an impermeable wall cake, etc.

G

GEL-Oilfield term for sodium-bentonite clays belonging to the general class of montmorillonites.

GEL-A state of colloidal suspension in which shearing stresses below a certain finite value fail to produce permanent deformation. The minimum shearing stress that will produce permanent deformation is known as the gel strength. See Shear Strength.

GEL CEMENT-Cement having a small to moderate percentage of bentonite added as a filler and/or to reduce the slurry weight.

GELATION-The formation of a gel.

GLACIAL DRIFT-A general term for unconsolidated sediment transported by glaciers and deposited directly on land or in the sea.

GRANULAR BENTONITE-A naturally occurring clay that is crushed and sized for pouring and easy handling. Like processed bentonite, it swells when hydrated by fresh water and will form a plastic, essentially impermeable mass.

GRAVEL-PACKED WELL-A well in which filter material is placed in the annular space to increase the effective diameter of the well and to prevent fine-grained materials from entering the well.

GROUNDWATER-Water present in the saturated zone of an aquifer.

GROUNDWATER TABLE-The surface between the zone of saturation and the zone of aeration; the surface of an unconfined aquifer.

GROUT-A fluid mixture of cement and water (neat cement) of a consistency that can be forced through a pipe and placed as required. Various additives, such as sand, bentonite, and hydrated lime, may be included in the mixture to meet certain requirements. Bentonite and water are sometimes used for grout.

GROUTING-The operation by which grout is placed between the casing and the sides of the wellbore to a predetermined height above the bottom of the well. This secures the casing in place and excludes water and other fluids from the wellbore.

H

HYDRATION-The chemical reaction between hydraulic cement and water forming new compounds most of which have strength-producing properties.

HYDRAULIC FRACTURING-The act of pumping fluid(s) into a wellbore and into a specific formation to induce fractures.

HYDROLOGIC PROPERTIES-The properties of rocks or soil that control the entrance of water and the capacity to transmit water.

HYDROSTATIC HEAD-The pressure exerted by a column of fluid, usually expressed in pounds per square inch (6.9 kPa). To determine the hydrostatic head at a given depth in psi, multiply the depth in feet by the density in pounds per gallon by 0.052.

HYDROSTATIC PRESSURE-Uniform external pressure on the sides and ends of a member.

HYDROSTATIC TEST (HYDROTEST)-Filling a pipe with water, under pressure, and its ability to hold a certain pressure without leaking or rupturing.

I

ILLEGAL WATER-Any water well which meets any of the following: is not in an active, inactive or abandoned status; operating equipment has been removed and it is not in an inactive status; is in such a state of disrepair that continued use is impractical; was not properly decommissioned; was constructed after October 1, 1986, but not constructed by a licensed water well contractor or by an individual on land owned by the individual used for farming, ranching, agricultural purposes or at the individual's place of abode.

INACTIVE STATUS-A water well which is in a good state of repair, which the owner has properly maintained, and which meets the following standards: does not impair the water quality of the groundwater encountered by the well; had a water-tight cover constructed to prevent unauthorized access or removal; is visibly marked and identified as a water well and the area around the well kept clean and clear of wastes and debris.

INDUSTRIAL WELL-A well used to supply water for plants that manufacture, process, or fabricate a product. The water is usually used to cool machinery, to provide sanitary facilities for employees, to air-condition the plant, and water grounds at the plant. Water used for mining or processing ore, such as gravel, is included in the industrial category.

INTERMEDIATE CASING STRING-The casing set in a well after the surface casing. Also called PROTECTION CASING.

INVERT OIL-EMULSION DRILLING FLUID-An invert emulsion is a water-in-oil emulsion where fresh or salt water is the dispersed phase aid diesel, crude, or some other oil is the continuous phase. Water increases the viscosity and oil reduces the viscosity.

IRRIGATION/AGRICULTURAL WELL-A well used for irrigating cultivated plants, for watering stock, fish farming, and for similar agricultural activities. Most irrigation wells supply water for farm crops, but this category also includes wells that are used for watering parks, golf courses, cemeteries and wells which are used exclusively for watering lawns in urban areas.

J

JET-PERFORATING-An operation similar to gun-perforating except that a shaped charge of high explosives is used to bum a hole through the casing instead of the gun which fires a projectile.

JETTING-The action of causing erosion by fluid impingement on the formation.

JUNK-Metal debris lost in a hole. junk may be a lost bit, milled pieces of pipe, wrenches, or any relatively small object that must be fished out of the hole.

K

KILL A WELL-To stop a well from producing so that surface connections may be removed for well servicing or workover. It is usually accomplished by circulating water or mud to load the hole and render it incapable of flowing.

KILLING A WELL-Bringing a well that is blowing out under control. Also, the procedure of circulating water and drilling fluids into a completed well before starting well-servicing operations.

L

LAMINAR FLOW-Water flow in which the stream lines remain distinct and in which the flow direction at every point remains unchanged with time. It is characteristic of the movement of groundwater.

LIGNOSULFONATES-Organic drilling fluid additives derived from by-products of sulfite paper manufacturing process from coniferous woods. Some of the common salts, such as ferrochrome, chrome, calcium, and sodium, are used as universal deflocculants while others are used selectively for calcium-treated systems. In large quantities, the ferro-chrome and chrome salts are sometimes used for fluid-loss control and shale inhibition.

LINER-Partial length pipe string extending between bottom of borehole to an elevation above bottom of the previous casing string. Liner performs same function as productive casing in sealing off productive zones and water-bearing formations. Liner may or may not be cemented in place.

LOST CIRCULATION MATERIAL-A material added to cement slurries or drilling fluids which is designed to prevent the loss of cement or mud to the formation. See Bridging Material.

LOW-YIELD CLAYS-Commercial clays chiefly of the calcium montmorillonite type having a yield in the range of 15 to 30 bbl/ton (2.63 to 5.25 ml/t) usually refers to percent by weight. If percent by volume is meant, it should be so stated.

M

MARGINAL WELL-A low-producing rate well that is approaching depletion to the extent that any profit from its continued production is doubtful.

MARSH FUNNEL-An instrument used in determining the Marsh funnel viscosity. The Marsh funnel is a container with a fixed orifice at the bottom so that, when filled with 1,500 ml fresh water, 1 qt (946 ml) will flow out in 26 ±0.5 sec. For 1,000 ml fresh water outflow, the efflux time is 27.5 ±0.5 sec. See API RP 13B for specifications.

MAXIMUM ALLOWABLE WORKING PRESSURE-The maximum gage pressure permissible at the top of a completed vessel in its operating position for a designated temperature. This pressure is based on calculations for every element of the vessel using nominal thicknesses exclusive of allowances for corrosion and thickness required for loadings other than pressure. It is the basis for the pressure setting of the pressure relieving devices protecting the vessel.

MEASURED DEPTH-Actual length of the wellbore from its surface location to any specified station (refer to Well Depth).

MESH-The number of openings (and fraction thereof) per linear inch in a screen, counting from the center of a wire.

MONITORING-Periodic or continuous determination of the amount of ionizing radiation present in a region.

MONITORING WELLS-A well used to obtain hydrologic and water-quality data, usually installed at or near a known or potential source of groundwater contamination.

MONTMORILLONITE-A clay mineral commonly used as an additive to drilling fluids. Sodium montmorillonite is the main constituent in bentonite. The structure of montmorillonite is characterized by a form which consists of a thin plate-type sheet with the width and breadth indefinite, and thickness that of the molecule. The unit thickness of the molecule consists of three layers. Attached to the surface are ions that are replaceable. Calcium montmorillonite is the main constituent in low yield clays.

MUD-A water- or oil-base drilling fluid whose properties have been altered by solids, commercial and/or native, dissolved and/or suspended. Used for circulating out cuttings and many other functions while drilling a well. Mud is the term most commonly given to drilling fluids. See Drilling Fluid.

N

NATURAL CLAYS-Natural clays, as opposed to commercial clays, are clays that are encountered when drilling various formations. The yield of these clays varies greatly, and they may or may not be purposely incorporated into the drilling fluid system.

NEAT CEMENT-A slurry composed of Portland cement and water.

NEWTONIAN FLUID-The basic and simplest fluids from the standpoint of viscosity consideration in which the shear force is directly proportional to the shear rate. These fluids will immediately begin to move when a pressure or force is applied. Examples of Newtonian fluids are water, diesel oil, and glycerine. The yield point as determined by direct-indicating viscometer is zero.

O

OBSERVATION WELL-A well used by the owner, by governmental agencies, or by an appropriate engineering or research organization to obtain information on the water resources of an area.

OBSERVATION WELL-A well drilled in a selected location for the purpose of observing parameters such as water levels and pressure changes.

OCS ORDERS-Rules and regulations promulgated by the Minerals Management Service that govern oil and gas operations in waters under federal control. OCS is an abbreviation for Outer Continental Shelf.

OIL-BASE DRILLING FLUID-The term "oil-base drilling fluid" is applied to a special type drilling fluid where oil is the continuous phase and water the dispersed phase. Such fluids contain blown asphalt and usually 1 to 5% water emulsified into the system with caustic soda or quick lime and an organic acid. Silicate, salt, and phosphate may also be present. Oil-base drilling fluids are differentiated from invert-emulsion drilling fluids (both water-in-oil emulsions) by the amounts of water used, method of controlling viscosity and thixotropic properties, wall-building materials, and fluid loss.

OPEN-HOLE-Uncased portion of a well.

OVERSHOT-A fishing tool attached to a wireline tool string, tubing, rods, or drill pipe that is lowered over the outside of a "fish" lost or stuck in the wellbore. A friction device in the overshot, usually a basket or a spiral grapple, firmly grips the fish allowing it to be pulled from the hole.

P

PACKER-Downhole equipment consisting essentially of a sealing device, a holding or settling device, and an inside passage for fluids. It is used to block the flow of fluids through the annular space between the tubing and the wall of the wellbore (or between tubing and casing) by sealing off the space between them.

PAY SAND-The producing formation, or that formation which represents the objective of drilling. Also referred to as PAY.

PEPTIZED CLAY-A clay to which an agent has been added to increase its initial yield. For example, soda ash is frequently added to calcium montmorillonite clay,

PERCENT WATER-The water content of a cement slurry expressed as parts of water per 100 parts of dry cement by weight. Percent usually refers to percent by weight. If percent by volume is meant, it should be so stated.

PERFORATING-The act of making holes in pipe, cement, or formation at desired depths (usually formed with an explosive device utilizing bullets or shaped charges).

PERMEABILITY-The capacity of a porous medium to conduct or transmit fluids. Normal permeability is a measure of ability of a rock to transmit a one-phase fluid under conditions of laminar flow. Unit of permeability is the Darcy.

pH (pH VALUE)-A unit to measure the degree of acidity or alkalinity of a substance. A neutral solution (as pure as water) has a pH of 7; acid solutions are less than 7; basic, or alkaline, solutions are above 7.

PIPE-A long tube or hollow body of wood, metal, earthenware, or the like, as to conduct water, oil, steam, etc.

A. Conductor Pipe-A short string of casing of large diameter. Its function is to keep the top of the wellbore open and to provide a means of conveying the upflowing drilling fluid from the wellbore to the slush pit.

B. Surface Pipe-The second string of casing run in the well which may be set from a few hundred ft to a depth of a few thousand ft. Its primary purpose is to seal off fresh water aquifers and to help support subsequent casing strings and wellhead equipment.

PIPELINE PIG-A scraping tool forced through a flow line or pipeline to clean the line or test for obstruction.

PLASTIC VISCOSITY-A measure of the internal resistance to fluid flow attributable to the amount, type, and size of solids present in a given fluid. It is expressed as the number of dynes per sq cm of tangential shearing force in excess of the Bingham yield value that will induce a unit rate of shear. This value, expressed in centipoises, is proportional to the slope of the consistency curve determined In the region of laminar flow for materials obeying Bingham's Law of Plastic Flow. When using the direct-indicating viscometer, the plastic viscosity is found by subtracting the 300 rpm reading from the 600 rpm reading.

PLUG AND ABANDON (P&A)-Placement of a cement plug or plugs in a well, in which no future utility has been identified, to seal the entire wellbore against fluid migration, and protect fresh water aquifers from contamination.

PLUG AND ABANDON (PLUGGED AND ABANDONED)-Expressions, often abbreviated "P&A," referring to the act of placing plugs in a depleted well or DRY HOLE, then abandoning it. See Abandon.

PLUG BACK-To place cement or other material at or near the bottom of a well to exclude bottom water or to perform another operation such as side tracking or producing from another depth. It may also be used to denote the setting of a mechanical plug by wire line, tubing, or drill pipe.

PLUG BACK-To place cement or other material in the well to seal off a completion interval, to exclude bottom water, or to perform another operation such as side tracking or producing from another depth. The term also refers to the setting of a mechanical plug in the casing.

PLUGGING MATERIAL-A material used to block off zones while treating or working on other portions of wells. Blocking may be temporary or permanent.

POROSITY-The amount of void space in a formation rock, usually expressed as percent voids per bulk volume. Absolute porosity refers to the total amount of pore space in a rock, regardless of whether or not that space is accessible to fluid penetration. Effective porosity refers to the amount of connected pore spaces (i.e., the space available to fluid penetration). See Permeability.

PORTLAND CEMENT CLINKER-Hard granular nodules composed essentially of hydraulic calcium silicates, with small quantities of calcium aluminates and ferrites, produced by the heat treatment of cement raw materials in a kiln. Clinker is pulverized with the proper quantity of calcium sultate in the manufacture of Portland cements.

POTABLE WATER-Water suitable for drinking or cooking purposes from both health and aesthetic considerations.

POZZOLAN-A siliceous or siliceous and aluminous material, which in itself possesses little or no cementitious value, but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties. See ASTM C 618: Fly Ash and Raw or Calcined Natural Pozzolans for Use in Portland Cement Concrete.

PPM OR PARTS PER MILLION-Unit weight of solute per million unit weights of solution (solute plus solvent), corresponding to weight-percent except that the basis is a million instead of a hundred. The results of standard API titration of chloride, hardness, etc. are correctly expressed in milligrams (mg) of unknown per liter but not in ppm. A correction for the solution specific gravity or density in g/ml must be made as follows:

Thus, 316,000 mg/I salt is commonly called 316,000 ppm or 31.6 percent, which correctly should be 264,000 ppm and 26.4 percent, respectively.

$$ppm = \frac{mg/l}{solnden,\ g/ml}$$

$$\%\ by\ wt = \frac{mg/l}{(10{,}000)(solnden,\ g/ml)}$$

$$= \frac{ppm}{10{,}000}$$

PRESSURE-Force per unit area

Bottom Hole Circulating Pressure-The pressure at the bottom of a well during circulation of any fluid. It is equal to the hydrostatic head plus the annular friction loss required to move the fluid to the surface plus any back pressure held at the surface.

Bottom Hole Static Pressure-The pressure at the bottom of a well after the well is shut-in long enough to reflect ambient formation pressure.

Circulating Pressure-The pressure at a specified depth required to circulate a fluid in a well at a given rate.

Final Squeeze Pressure-The pressure at the completion of a squeeze cementing operation. Final squeeze pressure usually refers to the surface pressure.

PRESSURE GRADIENT-Uniform change in pressure from one point to another. For example, the pressure gradient of a column of pure water is about 0.433 psi/ft of vertical elevation.

PRIMARY CEMENTING-The original cementing operation performed immediately after casing has been run into the hole. See Casing Cementing.

PRODUCTION CASING (PRODUCTION STRING)-The last string of casing set in a well; the casing string set to the top or through the producing formation and inside of which is usually suspended the tubing string. Also called the OIL STRING or LONG STRING.

PRODUCTION CASING-Full-length pipe string extending between the wellhead and elevation at or below pay formation inside of protective or surface casing and cemented in place to seal off productive zones and water-bearing formations.

PROTECTION CASING-A string of casing set to protect a section of the hole and to permit drilling to continue to a greater depth. Sometimes called INTERMEDIATE CASING.

PSI-Pounds per square inch pressure.

PSIG-Pounds per square inch pressure obtained from a pressure gauge.

PUBLIC SUPPLY WATER WELL-A well which provides water for drinking, cooking or washing use by the public, or transients, or by persons other than the immediate family of the owner of the supply. A public supply water well may be either a community water well or a non-community water well.

PUMP-THROUGH TUBING PLUG-A plug set inside the tubing string which will not permit back flow, but will permit pumping through from the top side.

PVC WELL CASING-A polyvinyl chloride plastic pipe conforming to current AWWA Standard A100 and/or ASTM F-480 Standard for water well casing.

Q

QUALIFIED PERSON-A person who, by possession of a recognized degree, certificate, or professional standing, or who by knowledge, training, or experience, has successfully demonstrated the ability to solve or resolve problems relating to the subject matter, the work, or the subject.

R

RAT HOLE-Hole that is drilled ahead of the main wellbore and which is of a smaller diameter than the bit used in the main borehole (refer to Pilot Bit).

REAM-Enlargement of the wellbore to straighten the hole.

REAMING-The operation employed to enlarge the hole to the size originally planned.

RETARDER-A chemical which is added to cements or slurries to lengthen thickening time.

REVERSE CIRCULATION-Normal course of fluid circulation is downward inside the pipe and upward in the wellbore annular space surrounding the pipe. This normal circulation is sometimes reversed and the fluid returns to the surface through the pipe after being pumped down the annular space.

RIG SUPPLY WELL-A water well drilled at an oil- or gas-drilling site to supply water for drilling and/or other oilfield related activities.

RUNOFF-The portion of rainfall, melted snow, or irrigation water that flows across ground surface and eventually is returned to the streams. Runoff can pick up pollutants from the air or the land and carry them to the receiving waters.

S

SALINITY-The degree of salt in water, expressed as ppm or as mg/L.

SALT-In drilling fluid terminology, the term "salt" is applied to sodium chloride, NaCl. Chemically, the term salt is also applied to any one of a class of similar compounds formed when the acid hydrogen of an acid is partly or wholly replaced by a metal or a metallic radical. Salts are formed by the action of acids on metals, or oxides and hydroxides, directly with ammonia, and in other ways.

SALTWATER DRILLING FLUIDS-A drilling fluid containing dissolved salt (brackish to saturated). These fluids may also include native solids, oil, and/or such commercial additives as clays, starch, etc.

SALTWATER FLOW-An influx of formation salt water into the wellbore.

SALTWATER INTRUSION-The invasion of salt water into a body of fresh water, occurring in either surface or groundwater bodies. When this invasion is caused by oceanic waters, it is called sea-water intrusion.

SALTWATER DISPOSAL-The method and system for the disposal of salt water produced with crude oil. A typical system is composed of collection centers and disposal wells in which treated saltwater is injected into a suitable formation.

SAND-A loose material most commonly composed of small quartz grains formed from the disintegration of preexisting rocks.

SAND-CEMENT GROUT-A mixture of one 94-pound sack of Portland cement, and equal amount by volume of clean masonry, sand, and not more that 7 gallons of clean water.

SANDPOINT WELL-A well constructed by driving or jetting a pointed well screen connected to a small-diameter pipe into water-bearing sand or gravel.

SCRATCHER-A device fastened to casing which aids in removal of mud cake from the annulus while the pipe is being moved during the cementing operation.

SCREEN-A structural tubular retainer, usually metal or PVC, used to support the hole in unconsolidated material with openings which are selected on the basis of adopted standards, and which allows sand free water to flow freely into the well in ample quantities and with a minimum loss of head. In agricultural wells, slotted pipe is sometimes used as a screen.

SCREEN ANALYSIS-Determination of the relative percentages of substances, passing through or retained on a sequence of screens of decreasing mesh size. Analysis may be by wet or dry methods (synonym SIEVE ANALYSIS). See Mesh.

SEALING MATERIALS-Well-plugging materials that will cause a tight seal in a well because of their characteristic impermeability.

SEEPAGE-Water that flows through the soil.

SERVICE WELLS-A service well is one drilled or completed for the purpose of supporting production in an existing field. Wells of this class are drilled for the following purposes: gas injection (natural gas, flare gas, inert gas, propane, or butane), water injection, steam injection, air injection, saltwater disposal, water supply for injection, and observation. In certain states, these service wells require API Well Number assignments.

SET CASING-The installation of pipe or casing in a wellbore. Usually requires mudding up, reconditioning or at least checking the drilling fluid properties.

SETTING TIME-A term defining the hardening time of construction cement. This term is not normally used with reference to well cement.

SHALE-A fine-grained sedimentary rock composed of silt and clay sized particles. The most frequently occurring sedimentary rock.

SHUT-IN PRESSURE-Pressure as recorded at the wellhead when the valves are closed and the well is shut in.

SIDE TRACKING-Usually drilling past an obstacle which has become permanently lodged in the hole.

SILICA SAND-A high purity graded sand of a particle size in the range of about 0.210 mm, to 0.088 mm. It is used in cementing formations where a high density slurry with strength deterioration protection from high temperatures is required.

SILICATE-A compound containing SiO_{3-} which may be used for the prevention of metal corrosion caused by oxygen.

SLOUGHING-The partial or complete collapse of the walls of a hole resulting from incompetent, unconsolidated formations, high angle of repose, and wetting along internal bedding planes. See Heaving.

SLURRY-Suspension of solids in water, oil, or mixture of both.

SLURRY DENSITY-The density of a cement slurry expressed in either pounds per gallons (kg/L) or pounds per cubic foot (g/cm^3).

SLURRY VOLUME-The sum of the absolute volumes of solids and liquids that constitute a slurry.

SLURRY YIELD-The volume of cement slurry in cubic feet that is obtained from a sack of cement.

SOUR GAS-Natural gas containing hydrogen sulfide.

SPECIFIC GRAVITY-The ratio of the weight of a substance to the weight of an equal volume of a standard substance. Water is the standard for liquids and air is the standard for gases.

SQUEEZE CEMENTING-The process of forcing cementing material under pressure into a specific portion of a well, such as fractures, openings, or permeable zones.

Hesitation-Squeeze Cementing-The process of forcing cementing material under pressure into the points to be squeezed with a final pressure equal to or greater than the formation breakdown pressure and with a final temperature equal to the bottom hole static temperature.

High Pressure Squeeze Cementing-The forcing of cement slurry into the desired position with a final pressure equal to or greater than the formation fracture pressure.

Low Pressure Squeeze Cementing-The forcing of cement slurry into the desired position with a pressure less than the formation fracture pressure.

STAGE CEMENTING-A procedure that permits using a cement column height in the borehole that normally would cause fracture of a subsurface formation. Stage-cementing operations are conducted after the primary cement job has been completed in a normal manner. When the primary cement hardens, ports are opened in a stage-cementing tool which was placed in the casing string as casing was being installed into the borehole. The second-stage cement is pumped through the ports into the borehole above the top of the primary cement.

STANDING WATER-Water that is displaced in a well due to the addition of sealing or filling materials; water displaced above the normal static water level.

STRATIGRAPHIC (CORE) TEST-A stratigraphic test is a drilling effort, geologically directed, to obtain information pertaining to specific geological conditions that might lead to the discovery of an accumulation of hydrocarbons. Such wells are drilled without the expectation of being completed for hydrocarbon production. This classification also includes tests identified as core tests by some operators.

STRIPPER-A well nearing depletion that produces a very small amount of oil or gas.

STUCK PIPE-A condition in which the pipe sticks or hangs and cannot be moved.

SULFATE RESISTANCE-The ability of a cement to resist deterioration in the presence of sulfate ions.

SURFACE CASING-The shallowest casing string required to protect fresh water zones, to provide sufficient pressure control during drilling operations, and to support the wellhead. It is not to be confused with a drilling conductor pipe nor with a large caisson in an offshore area which encloses several and unique surface casings at the surface.

SWAB-A rubber-faced, hollow cylinder mounted on a hollow mandrel with a pin joint on the upper end to connect to the swab line. A check valve installed on the lower end of the swab and opening upward may be used to unload a well (remove fluids) when the well ceases to flow.

T

TAIL PIPE-Pipe run in a well below a packer.

TEMPERATURE-The degree of heat, usually expressed in either U.S. customary units as degrees Fahrenheit (°F) or metric equivalent units as degrees Celsius (°C).

Casing Cementing Temperature-The temperature of a cement slurry at any point while it is being displaced in a cementing operation.

Circulating Temperature-The temperature of any fluid at any specified depth in a well while it is being circulated.

Squeeze Cementing Temperature-The temperature of a cement slurry while it is being displaced at the maximum cementing depth in a squeeze cementing operation.

Static Temperature-The temperature attained at a specified depth in a well after the well is shut in long enough to reflect the ambient formation temperature at that depth.

TEMPERATURE SURVEY-An operation to determine temperatures at various depths in the hole. This survey is used to find the location of inflows of water into the hole, where doubt exists as to proper cementing of the casing and for other reasons.

THIXOTROPY-The ability of fluid to develop gel strength with time. That property of a fluid which causes it to build up a rigid or semi-rigid gel structure if allowed to rest, yet can be returned to a fluid state by mechanical agitation. This change is reversible.

TOTAL DEPTH (OR TD)-The greatest depth reached by the drill bit

TOXIC SUBSTANCE-A substance or material which can be detrimental to human health or the functional capacity of a person having exposure to it, TOXICITY-The quality or degree of being poisonous or harmful to plant or animal life.

TREMIE PIPE OR LINE-A device, usually a small-diameter pipe or hose that carries grouting materials to the bottom of the hole and allows pressure grouting from the bottom up without introduction of appreciable air pockets.

TUBING-Pipe used in wells to conduct fluid from the well's producing formation into the christmas tree. Tubing is distinguished from casing as being susceptible to manipulation under operating conditions, whereas casing is ordinarily considered a fixed or permanent installation.

U

UPSET TUBING-Tubing that is "upset" is made with a thicker wall and larger outside diameter on both ends of a joint to compensate for cutting the threads.

V

VERTICAL DEPTH-Vertical component of the measured well depth.

VERTICAL HOLE-A hole in which the wellbore is nearly maintained in a position vertically below the surface location.

W

WAITING ON CEMENT-The time necessary for the cement to set or harden in the wellbore.

WALL CAKE-The solid material deposited along the wall of the hole resulting from filtration of the fluid part of the drilling fluid or cement slurry into the formation.

WALL STICKING-See Differential-Pressure Sticking.

WASTE WATER-Water carrying wastes from homes, businesses, and industries that are a mixture of water and dissolved or suspended solids.

WATER-BASE DRILLING FLUID-Common conventional drilling fluids. Water is the suspending medium for solids and is the continuous phase, whether or not oil is present

WATER CEMENT RATIO-The ratio by weight of water to cement in a cement slurry (abbr. W/Q).

WATER POLLUTION-The addition of sewage, industrial wastes, or other harmful or objectionable material to water in concentrations or in sufficient quantities to result in measurable degradation of water quality.

WATER QUALITY STANDARD-A plan for water-quality management containing four major elements: the use (recreation, drinking water, fish and wildlife propagation, industrial, or agricultural) to be made of the water; criteria to protect those uses; implementation plans (for needed industrial-municipal waste treatment improvements); and enforcement plans and an antidegradation statement to protect existing high-quality waste waters.

WATER SOLIDS RATIO-The ratio by weight of water to the total solids In a cement slurry.

WATER TABLE-The upper level of groundwater.

WATER TABLE-The surface between the vadose zone and the groundwater; that surface of a body of unconfined groundwater at which the pressure is equal to that of the atmosphere.

WATER WELL-A well drilled to (1) obtain a fresh water supply to support drilling and production operations, or (2) obtain a water supply to be used in connection with an enhanced recovery program.

WELL DEPTH-Measured depth in the wellbore. Usually measured from the kelly bushing, derrick floor, or foundation as a datum. Refer to Measured Depth.

WELL LOG-A record of one or more physical parameters of geological formations as a function of depth in a borehole. Distinction is sometimes made between a log as an entire record which may contain several curves showing specific measurements and the individual curves themselves, which are also called "logs."

WELL PERMIT-The authorization to drill a well issued by a governmental regulatory agency.

WELL SCREEN-A filtering device used to keep sediment from entering a water well.

WELL SERVICING RIG-Equipment and machinery assembled primarily for the purpose of any well work involving pulling or running tubulars or sucker rods, to include but not limited to, redrilling, completing, recompleting, workover, sucker rod or tubing pulling, and abandoning operations.

WELL YIELD-The volume of water discharged from a well in gallons per minute or cubic meters per day.

WELLHEAD-The wellhead is a composite of equipment used at the surface to maintain control of the well. Included in wellhead equipment are casing heads-lowermost and intermediate – Aubing heads, christmas tree equipment with valves and fittings, casing and tubing hangers, and associated equipment.

WHIPSTOCK-A device inserted in a wellbore used for deflecting or for directional drilling.

WORKOVER-Operations on a producing well to restore or increase production. A workover may be done to wash out sand, acidize, hydraulically fracture, mechanically repair or for other reasons.

WORKOVER FLUID-Any type of fluid used in the workover operation of a well.

[1]Compiled by Stewart Smith and from terms in *Guidelines for Decommissioning Water Wells*.