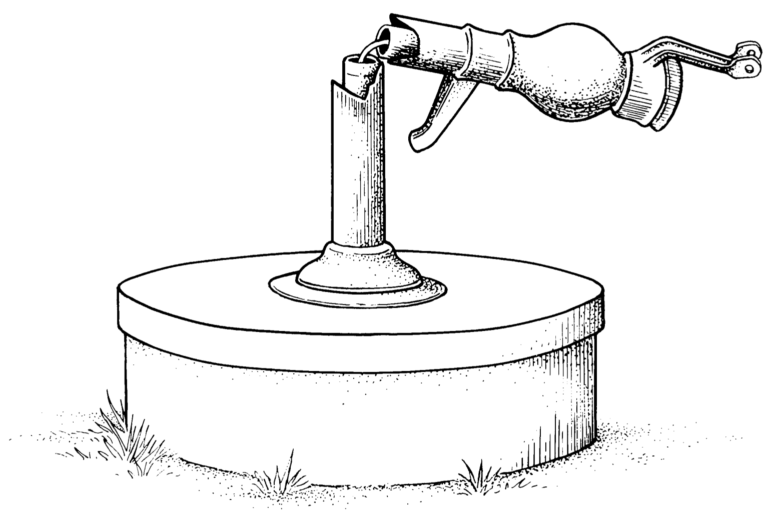
GUIDELINES FOR PLUGGING ABANDONED WATER WELLS

Technical Information Series 15



Iowa Department of Natural Resources
Larry J. Wilson, Director
October 1988

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Technical Information Series 15

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FOREWORD

Abandoned wells in Iowa probably number in the tens of thousands. They exist in both rural and urban settings. They can present a serious physical hazard for people and for livestock. Most certainly, they represent a significant threat to human health and to the overall quality of the State's groundwater resources. Pitted, cracked, or collapsed well casings cease to be effective in maintaining the sanitary and hydrologic integrity of wells, and permit contaminants to enter into them.

Technical Information Series 15, Guidelines for Plugging Abandoned Wells, provides information on well-plugging materials and on recommended methods for plugging typical abandoned wells in Iowa. This publication was prepared in conjunction with rule development for Environmental Protection Commission Chapter 39 on Requirements for Properly Plugging Abandoned Wells. Guidelines for Plugging Abandoned Wells supersedes Public Information Circular 1, Optimal well-plugging procedures, and Public Information Circular 11, Plugging procedures for domestic wells.

Donald L. Koch
State Geologist & Bureau Chief

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INTRODUCTION

Rural areas of Iowa have traditionally relied upon groundwater as a source of water supply for domestic and livestock needs. Early settlers found relatively abundant groundwater resources that could be tapped by shallow "dug wells." At that time there was little need to be concerned about the chemical purity of the water. Demands for water were generally low, and shallow wells, in most cases, provided an ample quantity of water. It was common to have several wells on each farmstead because it was easier to dig wells at points of use rather than develop a central well and distribution system.

Farm consolidation, rural electrification, and general modernization in rural areas have caused many old wells to be abandoned. With modernization and more water-intensive fixtures and appliances, sources of shallow groundwater could not sustain greater demands for water, necessitating a transition to deeper, more productive wells. Of course, this historic progression does not account for all the abandoned wells that exist across the State. Early commerce and industry relied heavily on the State's groundwater resources. At one time, most Iowa communities had creameries that operated wells for cooling and processing water--these creameries no longer exist. Railroad routes established across Iowa prior to 1940 were dotted by a number of wells. The first air-conditioned buildings in the State were cooled by groundwater. A significant number of wells in these categories are probably abandoned and forgotten. In addition, there are many abandoned wells in parks and recreation areas that have failed due to age or lack of maintenance.

In certain areas of the State, private well owners have chronic problems in finding adequate sources of good quality water. In these areas, rural residents have joined rural water distribution systems and have essentially abandoned their former private water systems.

Not all private abandoned wells are located on farmsteads. There are hundreds and possibly thousands to be found in communities around the State. At one point in history, most properties in communities had their own water-supply systems. Wells that have been replaced by community water treatment and distribution systems still adorn lawns in many communities.

Improperly abandoned wells are a liability. They can contaminate our drinking water and present safety hazards. Once groundwater is contaminated, it is difficult if not impossible to clean up, and the process is always expensive. The logical course of action is to remove the liability by properly plugging and sealing all abandoned wells.

What is an Abandoned Well?

The Iowa Department of Natural Resources defines an abandoned well as follows: "Abandoned well means a water well which is no longer in use or which is in such a state of disrepair that continued use for the purpose of accessing groundwater is unsafe or impracticable."

Private well owners have a variety of opinions as to what constitutes an abandoned well. There are wells in the "standby" category; i.e., those that are not used, but possibly could be in an emergency. There are also those in the "spare" category. Generally, these are used infrequently and for other purposes than domestic or livestock water supply. Typical uses may include garden and lawn watering, vehicle washing, etc.

Unused or infrequently used wells in the above categories can be temporarily abandoned if they are well maintained or tightly capped. However, if wells are in poor condition, do not contain operational pumping equipment, or produce undesirable water, they should probably be considered for permanent abandonment. In this case they should be permanently "plugged" or sealed.

How Many Abandoned Wells are There in Iowa?

No accurate accounting of abandoned wells exists for the State of Iowa. However, some existing information suggests that they number in the tens of thousands. A well inquiry conducted by county assessors in 1983 and 1984, and summarized by Hallberg et al. in 1985, indicated that there were 21,775 abandoned wells reported by rural property owners. The inquiry was a voluntary program and property owners were given a postcard-type inquiry card to complete and forward to assessors' offices. About 60 percent of the distributed inquiry cards were returned. It is suggested by Hallberg et al. (1985) that if the well-card inventory represented an accurate 60 percent sample, there may be as many as 36,300 abandoned wells in the State. As this estimate is based on voluntary reporting and only covers rural wells, it must be viewed as very conservative. In 1900, there were nearly 225,000 inhabited farmsteads in Iowa--most had at least one well. Today, only half of those farmsteads are still used. This fact, coupled with all other known types of abandoned wells, could yield a total number in the hundreds of thousands.

What Threat do Abandoned Wells Pose?

Abandoned wells exist in all ninety-nine Iowa counties. They tap every principal aquifer, and vary considerably in design and depth. As such, they represent a significant threat to human health and safety, to the overall quality of the State's groundwater resources, and to private-sector investments in operating wells and pumping systems.

Abandoned wells have one common denominator--they all can serve as direct conduits from the landsurface to groundwater-producing zones or aquifers. Therefore, they can be very efficient in delivering land-derived pollutants to the groundwater system.

There are two fundamental types of abandoned wells in Iowa: large-diameter, shallow, hand-dug or bored wells completed in surficial soils materials; and small-diameter, steel-cased, drilled wells that draw water from deeper glacial drift and bedrock aquifers. If not properly plugged, wells in the first category represent a major safety hazard for humans and livestock. Many of these wells are thirty or more inches in diameter and usually have standing water several feet below the land surface. Many are uncovered and receive surface drainage. Wells of this type are very susceptible to contamination because they are recharged by percolating surface water. However, in many areas of the State this is the only option for a private water supply. In these areas, it is therefore imperative that old wells be plugged when replacements are installed, and the quality of drinking water carefully monitored by well owners.

The design life of drilled wells is possibly 20 to 40 years. This is primarily due to the corrosion of the steel casing. Pitted, cracked, or collapsed well casings cease to be effective in maintaining the sanitary and hydrologic integrity of wells, and allow surface water and contaminants to seep into wells. They can exacerbate iron and other types of bacterial problems. They may also allow the commingling of groundwater between one aquifer and another. Here, good water from one aquifer may be contaminated by undesirable water from another. Most importantly, wells in poor repair, if not properly sealed, can contribute to the contamination of a replacement well or other wells in the vicinity.

Rationales for Plugging Abandoned Wells

If unused or unserviceable wells are to be properly abandoned, careful attention must be paid to the manner in which they are plugged and sealed. The ideal situation would be to plug and seal all abandoned wells in a manner that would restore the original hydrologic conditions of the well site. The fundamental objectives for restoring the well site are: to eliminate all physical hazards, to obviate conditions which lead to the degradation of groundwater quality, to prevent the commingling of desirable and undesirable groundwater, to preserve hydrostatic conditions within aquifers, and to protect investments in groundwater-supply systems or in replacement wells.

As there are many different types of abandoned wells, strict attention must be paid to the methods and materials chosen for sealing them. Fundamentally, all abandoned wells must be sealed such that polluted surface water cannot reach groundwater-producing zones, either by flowing directly into the well or by moving down the annular space between the well bore and the casing. To assure that this particular objective is accomplished, the well should be tightly sealed and all surface drainage directed away from the former well site. In situations where wells are completed in confined aquifers (under hydrostatic pressure), they must be plugged and tightly sealed at the top of the aquifer to preserve original head conditions. Where abandoned wells penetrate two or more separate aquifers, tight seals must be placed between each successive aquifer to prevent commingling of water and preserve head conditions. The uppermost aquifer in such wells should be tightly sealed to prevent surface-water contamination and/or to preserve existing hydrostatic conditions. All large-diameter wells should be sealed and filled with load-bearing materials to obviate the physical hazard they represent. The successful accomplishment of these tasks should guarantee that abandoned wells have been effectively sealed and the objectives for proper well abandonment satisfied.

WELL-PLUGGING MATERIALS

The materials that are recommended for well plugging depend upon the design and dimension of the particular well, the hydrologic setting in which the well exists, and the cost and availability of materials. If wells require large volumes of plugging materials, cost can be a very important consideration and, therefore, a range of options should be evaluated. This report outlines a variety of materials and methods which are felt to be hydrologically feasible and cost-effective for specific well types. Basically, two categories of well-plugging materials are considered: sealing materials which are placed in a well to prevent water from migrating into or between water-producing zones, and low-cost granular-fill materials which are used to occupy space where sealing is not needed.

Sealing Materials

Sealing materials are fundamentally mixtures of Portland cement and water (with or without aggregates such as sand, gravel, or crushed stone) or any of a variety of bentonite products. Sealing materials can be placed below or above the static water level of a well being plugged. However, it is important that the material selected for sealing will maintain its integrity and provide a permanent seal. The only materials recommended for sealing zones below the static water level in a well are neat cement and bentonite clay products. Above the static water level, recommended sealing materials include the above, and sand/cement grout or concrete. It is recommended that any sealing materials to be placed below the static water level be placed with a tremie line. Neat cement, bentonite slurries, or other bentonite products are specifically recommended in such contexts. The addition of sealing materials will cause the displacement of water above the orginal static water level. If sand/cement grout or concrete are to be placed below static water level or in standing water, they should be introduced with a dump bailer to avoid dilution or the separation of aggregrate and cement. All materials placed with a tremie line or dump bailer should be introduced such that the well is filled from the bottom up. The tremie line or bailer should be raised as the well fills and be in contact with the sealant continually to avoid air pockets.

Bentonite materials are available in a wide variety of processed forms: powdered, coarse granules, pellets, and graded bentonite. All but the graded bentonite are kiln dried to drive off their natural moisture content before they are further processed. The graded bentonite is excavated from its natural setting, crushed, and sized (commonly 3/8 to 3/4 or 1/4 to 3/8 inch particles). Bentonite owes it sealing properties to its characteristic of expanding when mixed or placed in contact with fresh water. Processed forms of bentonite will expand their volume in excess of ten times when hydrated. Graded natural bentonite will expand its volume about six times. There may be instances where a well's volume is small and a decision is made to seal it completely. This can be accomplished, in some cases, by pouring graded bentonite or bentonite pellets into the well. Bentonite pellets and graded bentonite settle through standing water rapidly, but caution must be exercised with both as they can readily bridge in a well. Bridging is a condition where blockage occurs in a well column which is caused by the binding together of aggregate particles. This is a particular problem in smaller diameter wells. If pellets are used, they should be added to the well slowly. Pouring these materials through a funnel that has a spout with a diameter one-half that of the well casing is recommended. If bridging does not take place in the funnel, theoretically it shouldn't in the well casing. This method should not be used when the well-casing diameter decreases with depth, is damaged, or has deteriorated to the extent that bentonite would be impeded in completely sealing the well. When using graded bentonite, it is good practice to tumble it across a 2-foot long, v-shaped trough formed of steel mesh. The mesh openings should be large enough to allow particles less than 1/4 inch to drop through. This is a method of removing excess fines likely to cause bridging. Fine materials are hydrated rapidly and adhere to each other and well casings at the top of the water column. This condition prevents coarser particles from dropping through and causes a bridge to develop. If pellets or graded bentonite are used, it is also a good practice to prevent bridging by periodically lowering an object, such as a "sash weight" or length of pipe, and moving it up and down to dislodge any bridging materials. Filling should not continue until it is certain that such blockages have been eliminated. More information can be found concerning sealing materials in the Glossary.

Fill Materials

There are a variety of low-cost materials which can be used to fill space where sealing is not required. Depending upon application, these materials may be sand, gravel, crushed stone, or agricultural lime. In all cases, the material should be clean--free of sticks, leaves, or other foreign matter. Additionally, the material should be free of any toxic chemical residue. All fill materials considered for well emplacement should be sized to the well being plugged, meaning that the material should have particle-size diameters small enough not to cause bridging.

There are two fundamental reasons for using fill materials in well plugging; both relate to cost. In wells that have exceedingly large volumes, it may not be economically feasible to recommend complete filling with a sealing material. Also, most wells in this category are of large diameter and, therefore, a physical hazard. This type of well must be filled with load-bearing materials. There are other well types--for instance, wells completed in fractured limestones or extremely coarse gravels--that can contribute to the excessive loss of sealing materials. In such instances, fill materials can be used to bridge fractures and large voids in the water-producing zone before sealants are emplaced. These methods are outlined in the section of the report entitled "Recommended Methods for Plugging Typical Wells in Iowa."

PLAN BEFORE PLUGGING

Earlier sections of this report discussed several objectives that should ideally be achieved if a well is to be effectively plugged. Fundamentally, the objectives relate to the protection and preservation of groundwater quality and to the restoration of the hydrologic integrity of the well site. The attainment of the various objectives implies that certain facts are known about the well (depth, casing schedule, liners, screens, etc.), the water-producing formation(s), and the geology of the well site in general. If such information is not contained in the personal records of the owner, other sources should be sought. If possible, the well contractor who drilled the well should be consulted. Other contractors familiar with the area may be of assistance. The well is possibly on record with the Department of Natural Resources (Geological Survey Bureau). Geological Survey Bureau staff can also be of assistance in determining the geology and nature of construction of wells in most areas of the State. In cases where well-construction records are unavailable or cannot be determined from other information, it is recommended that the well be filled completely with sealing materials.

Prior to any attempt in sealing a well, all pumping equipment and other obstructions should be removed from the well. The depth of the well should be measured in addition to the static water level. Based on well depth and available well-construction information, the volumes of plugging materials required should be determined. It is important during the plugging process that the amounts of materials used are monitored and compared with calculated volumes and depths (see Appendices A, B, and C). If materials used and calculated volume of fill are not consistent, the indication is that materials are either being lost (to crevices, etc.) or that materials are bridging in the well. In either case, plugging operations should cease and a solution for the problem sought.

Because such a wide variety of conditions exist, it is important for well owners to decide whether or not they can plug abandoned wells themselves. Therefore, it is recommended that individuals contemplating the "do-it-yourself" approach seek advice and review the pertinent rules governing the correct procedures for well plugging. The Department of Natural Resources regulations require all wells less than 18 inches in diameter or greater than 100 feet deep be plugged by a registered well driller. Individuals should seek advice of appropriate city or county officials, County Extension offices, registered well contractors, or the State Departments of Health or Natural Resources before attempting to do the work themselves.

The time taken in seeking advice and the planning for plugging a well are essential. The effort should guarantee that the cost of plugging will be reasonable, and that the environmental objectives for plugging the well are met.

RECOMMENDED METHODS FOR PLUGGING TYPICAL WELLS IN IOWA

Wells in Surficial Soils Materials

Large-Diameter Bored or Dug Wells

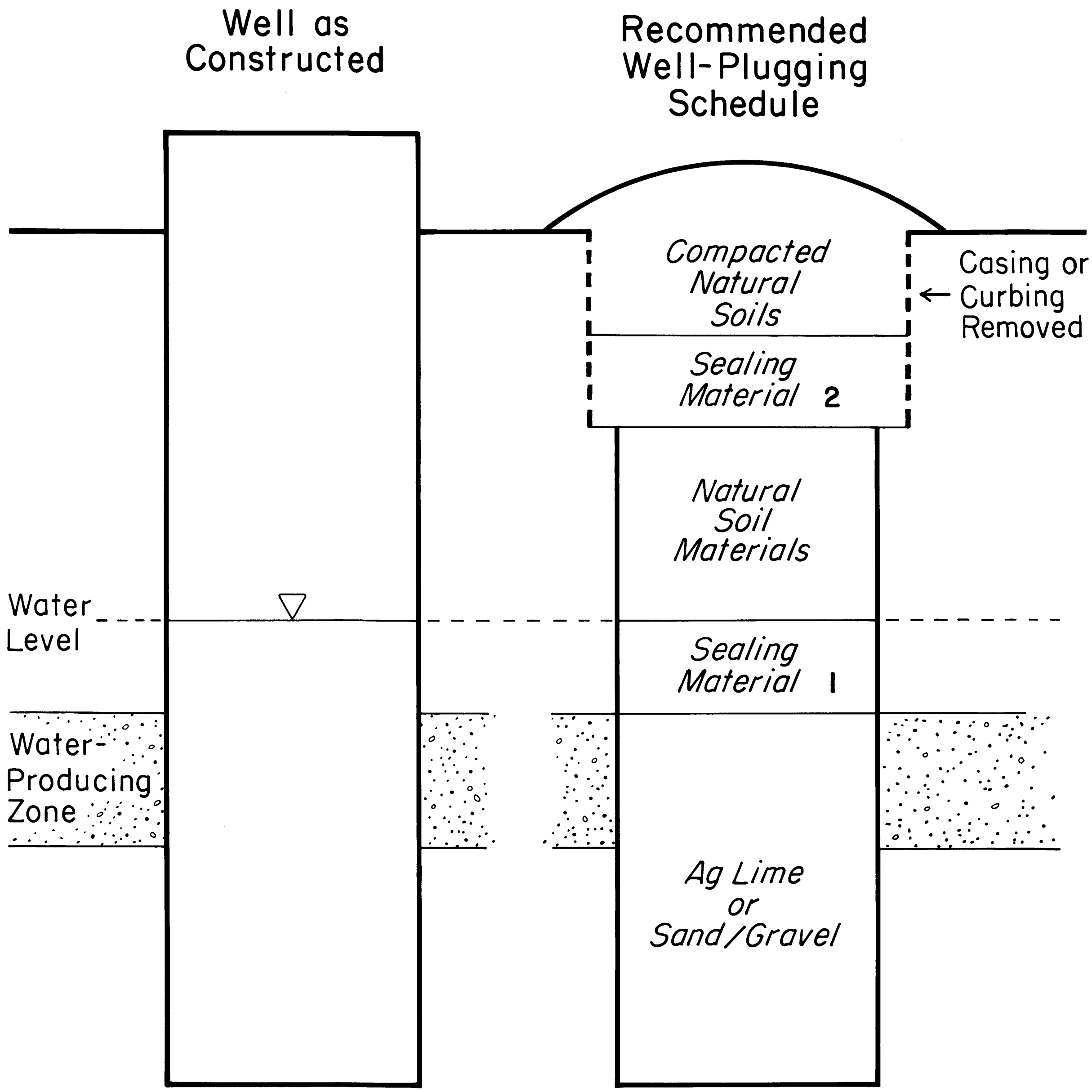
Wells in this category are probably the most numerous and widely distributed abandoned wells in Iowa. Because of their large diameter, typically 30 to 42 inches, they are a safety hazard for humans and livestock. Also, because of their large volume, they can be costly to plug, depending on the materials used. These wells are also unique in that they are the only class of wells where plugging materials can be introduced from the top without concern of bridging.

After required material volumes have been determined, clean fill material (i.e., sand, sand and gravel, pea gravel, or ag lime) can be placed in the well to within one foot of the static water level. When measurements are made during the evaluation of the well, one should keep in mind that as fill material is added, water in the well will be displaced and the water level will rise. If neglected, this could cause an error in the placement of the sealing material across the top of the water-producing zone.

A minimum of one foot of graded bentonite, bentonite pellets, or neat cement should be placed on top of the fill material. The upper four feet of casing or curbing should be removed below grade. If the well is in a well pit, the pit walls should be removed. Additional fill, any clean, disaggregated soil, or other recommended fill material may then be used to fill the rest of the well to within four feet of the land surface. This should be capped by a minimum of twelve inches of graded bentonite, bentonite pellets, neat cement, sand/cement grout, or concrete. In this interval, the sealing material should extend six or more inches beyond the outside diameter of the well casing. Compacted native soil should be used to fill the remainder of the well bore, and should then be mounded over the well to divert surface drainage away from the well (see Fig. 1). Any native soils used should not have been subject to ag-chemical application (fertilizer or pesticide).

Alluvial Wells

Alluvial wells are typically 4-inch to 12-inch diameter steel-cased, screened wells that are usually less than 100 feet deep. When the details of well construction are known, the required volume of fill material (sand, gravel, pea gravel) can be used to fill the screened interval. Bentonite products or neat cement can then be placed above the fill material with a tremie line. The sealing material should extend to four feet below the land surface. When sealing materials are emplaced by a tremie line, care should be taken that filling occurs from the bottom of the hole up, and that the tremie



1. Graded bentonite, bentonite pellets, neat cement.
2. Graded bentonite, bentonite pellets, neat cement, sand/cement grout, concrete.

Figure 1. Large-diameter dug or bored wells.

line is withdrawn as the hole is filled. The bottom of the tremie line must remain immersed in the grouting material at all times to prevent the development of air pockets. As an alternative to this method, it may be expedient in some cases to use coarse bentonite products (pellets or graded natural bentonite). In these instances, the products should be poured slowly and agitated to make sure no bridging occurs. In situations where a well's construction is unknown, the entire well should be filled with neat-cement grout, bentonite grout, or other applicable bentonite products. Where bentonite grout is used, the upper six feet of the well casing should be filled with neat cement. These alternatives may also be considered where it is not expedient to spend the time using several different plugging materials. After enough material has been emplaced to seal the well, the top four feet of casing can be removed and the hole filled with available natural materials. Compacted soil should be placed on top of the plug and mounded to direct surface drainage away from the well site (see Fig. 2).

Sandpoint Wells

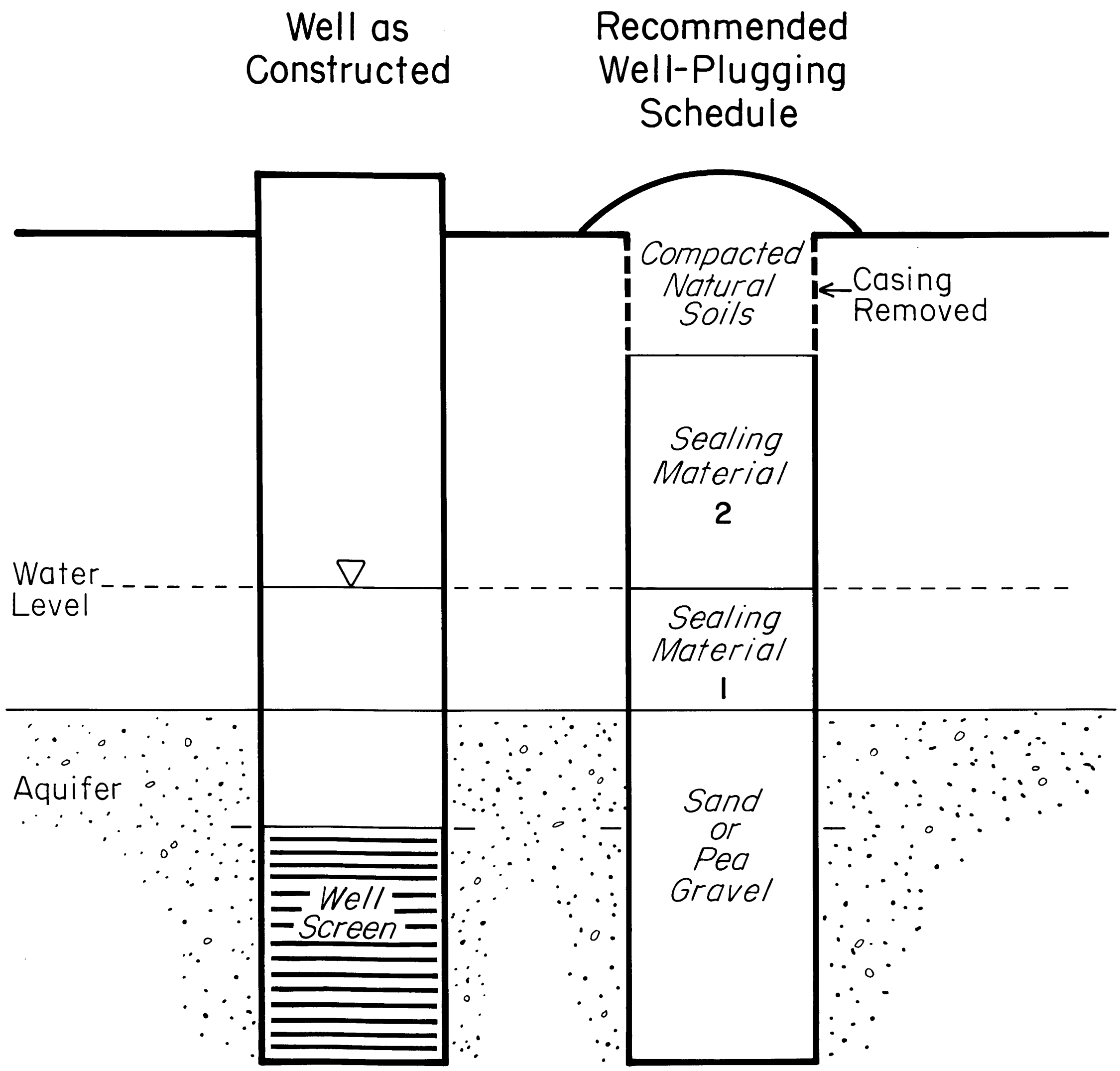
A sandpoint well usually has a small diameter (1 1/2") and is very shallow, less than 30 feet deep (these wells may occasionally be 75 to 175 feet deep). They are commonly driven or jetted into shallow sand-and-gravel aquifers. One available option for abandoning this type of well is to pull the casing and sandpoint out of the ground. With the casing removed, the hole should collapse and fill. If a sandpoint cannot be extracted, it should be tremied full of neat cement or completely sealed with bentonite.

Steel-Cased/Screened Wells in Glacial-Drift Aquifers

In many areas of the State, private water supplies are drawn from wells completed in sand-and-gravel bodies within glacial-drift deposits. These wells are moderately deep (75 to 175 feet), and usually steel cased. The well opposite the water-producing zone may be screened or the well casing may simply be slotted. Plugging procedures for these types of wells should follow the same methods recommended for screened alluvial wells.

Bedrock Wells

All private bedrock wells in Iowa can be grouped into two categories: wells that tap only a single bedrock aquifer (the most common type), and wells that tap multiple aquifers separated by confining layers. A confining layer is an interval in the geologic sequence composed of materials that do not yield water (i.e., shale layers) and usually separate aquifers.



1. Bentonite products, neat cement.
2. Bentonite products, neat cement, sand/cement grout, concrete.

Figure 2. Alluvial and glacial-drift wells.

Wells Completed in a Single Aquifer

These are drilled wells with steel casing extending from the land surface to bedrock or, more commonly, seated several feet into the bedrock. Below the casing, the well is a drilled open hole through the bedrock aquifer. Two hydrologic conditions can exist in this type of well: if the nonpumping water level lies below the top of the aquifer, the aquifer is referred to as being unconfined or water table; if the water in the well rises to a level above the top of the aquifer, the aquifer is confined or artesian. The recommended plugging procedures for both situations are approximately the same. Fill material can be used in the uncased "open hole" portion of the well to within ten feet of the bottom of the casing. In confined aquifers, neat cement or bentonite products should be placed from the top of the fill to at least ten feet above the bottom of the casing. Where pressure in confined aquifers is great enough to cause the wells to flow at the surface, it may be necessary to stop the flow by emplacing a bridge plug or packer at or below the bottom of the casing. In such cases, fill material can be brought up to the bottom of the well casing and the bridge plug set. The balance of the well can be sealed with neat cement or a bentonite slurry, if tremied in place. If there is standing water in the well and either sand/cement grout or concrete is used to complete the sealing of the well, a dump bailer must be used to place them. Graded bentonite or bentonite pellets can be introduced from the top of the well, if done with care. The sealing material should extend to four feet below the land surface, and the casing cut off at that point. Native soils can be used to fill the remaining hole and mounded over the well head to divert surface water away from the well.

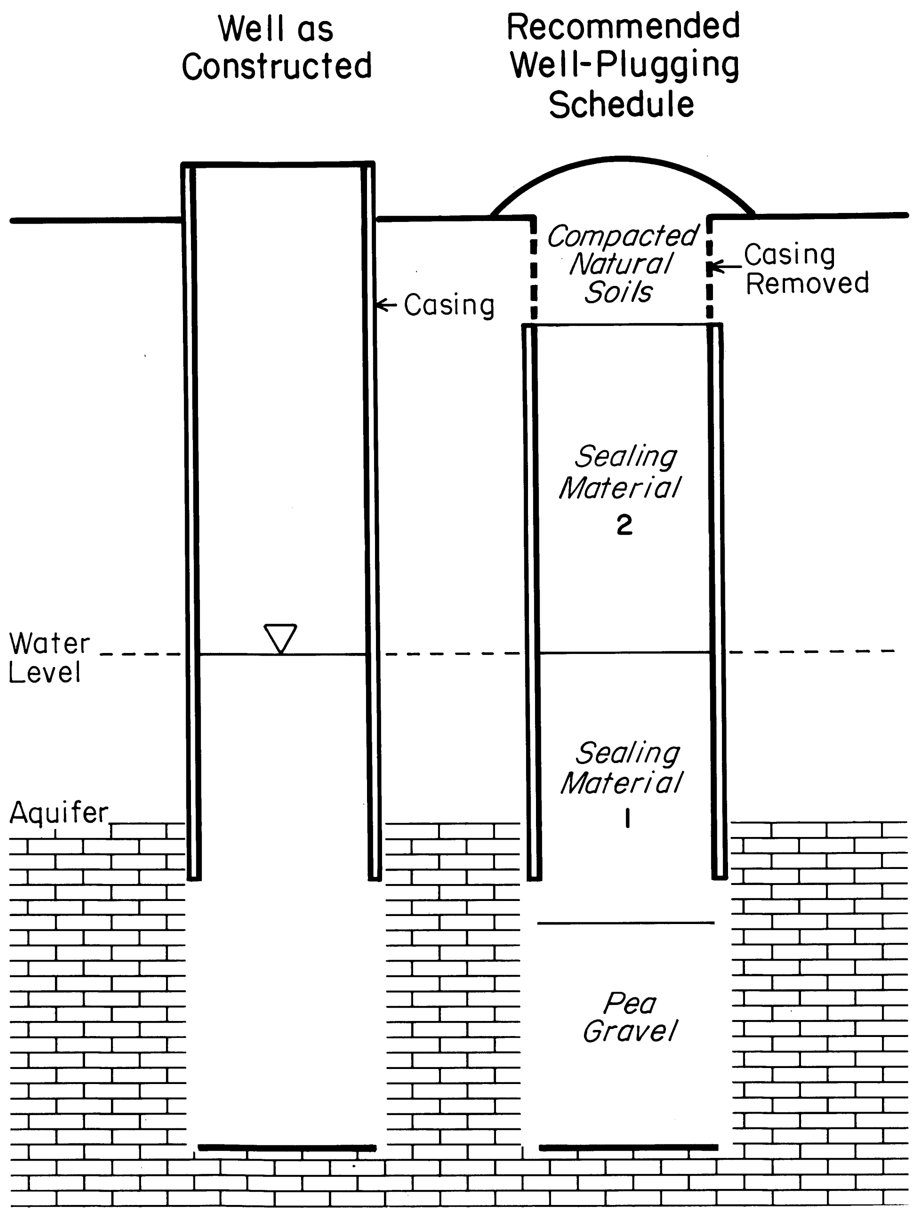
Wells in unconfined bedrock aquifers are plugged in essentially the same way, however, excepting that any of the recommended sealing materials may be used above the fill material if there is no standing water in the well casing (see Figs. 3 and 4).

For both well types (confined and unconfined), the details of well construction must be known to follow the illustrated methods; if not, the well should be tremied full of neat cement, bentonite slurry, or filled with other bentonite products. If bentonite is used, it should be capped by at least six feet of neat cement.

Wells Completed in Multiple Bedrock Aquifers.

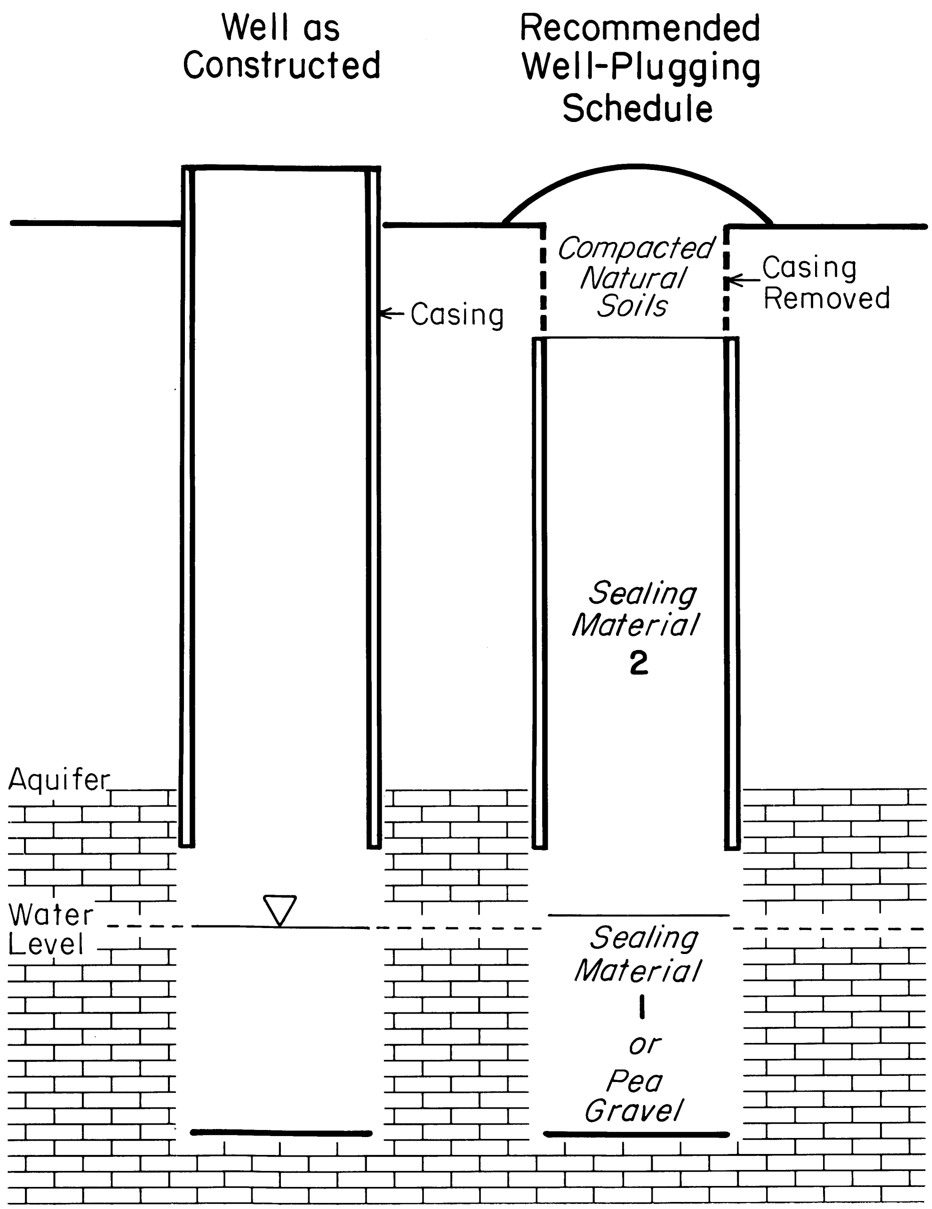
Wells in this category are open to and draw water from more than one aquifer. Typically, the well casing extends from the land surface into the uppermost aquifer. Usually the well below the casing is an open hole in the rock units penetrated. Liners are frequently placed in the open hole portions of these wells opposite confining layers. In many cases the confining layers are comprised of clayey or shaly materials which tend to cave or slough and create problems in a well. Liners prohibit this and allow water to be produced from two or more water-bearing zones simultaneously.

For these wells, when construction details are known and the well is not artesian (static water level at or below the top of the uppermost aquifer),



1. Bentonite products, neat cement.
2. Bentonite products, neat cement, sand/cement grout, concrete.

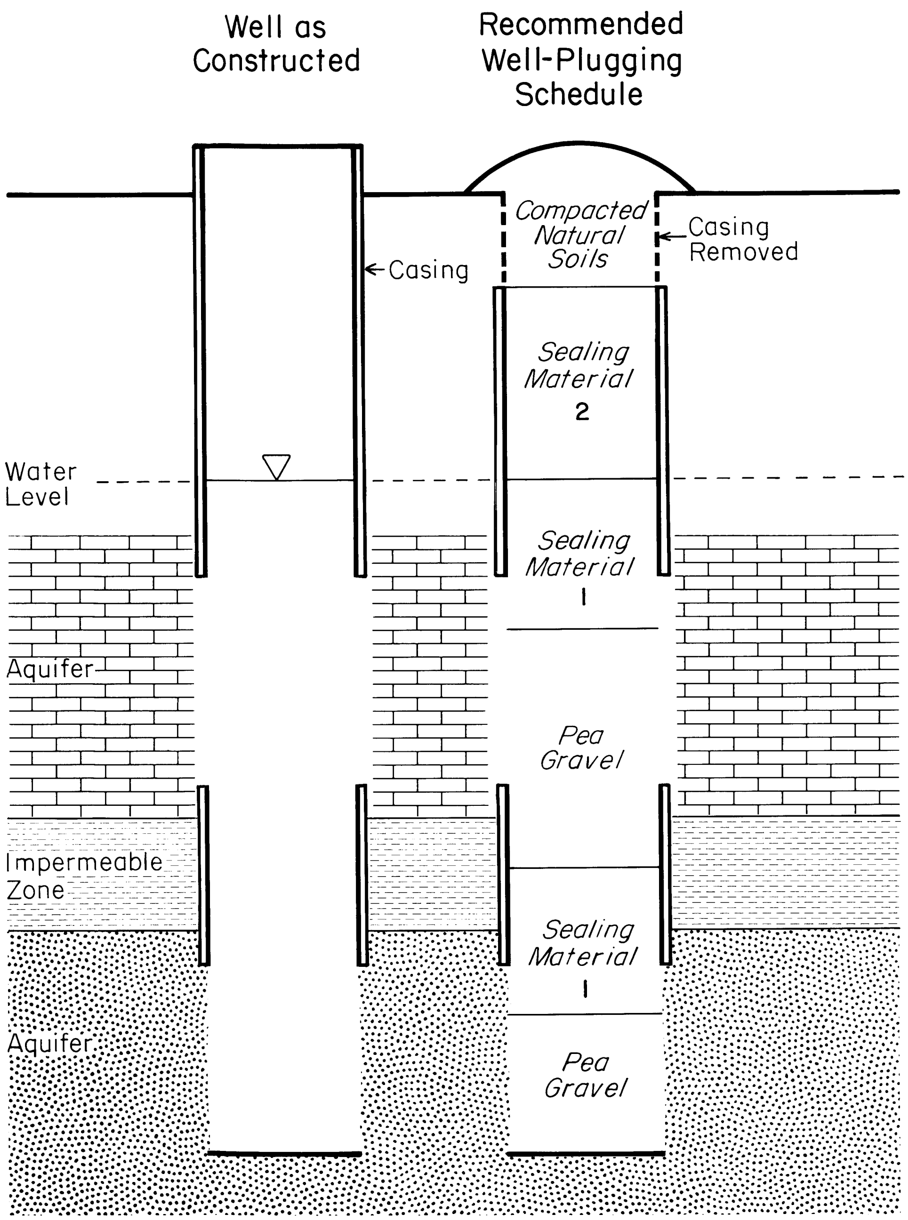
Figure 3. Bedrock well in confined aquifer.



1. Bentonite products, neat cement.
2. Bentonite products, neat cement, sand/cement grout, concrete.

Figure 4. Bedrock well in unconfined aquifer.

the fill material can be placed to within ten feet of the bottom of the steel liner or confining layer for the deepest aquifer. Only neat cement is recommended to seal the interval between the fill material to a minimum of ten feet above the bottom of the steel liner or confining layer. Fill material can then be placed in the well above the cement plug until the uppermost aquifer is filled to within ten feet of the bottom of the casing. The seal for the uppermost aquifer should extend from at least ten feet below the bottom of the casing to at least ten feet above the bottom of the casing. The well column above static water level can be filled with any of the recommended sealing materials to four feet below land surface where the casing should be cut off. Native soils should be used to fill the remaining hole, and should then be mounded over the well head to divert surface water away from the well (see Fig. 5). Many multiaquifer wells are artesian, with static water levels standing above the surface of the uppermost aquifer. In such situations, it may be more expedient to seal the well from bottom to top with neat cement or bentonite products capped by at least six feet of neat cement.



1. Neat cement.
2. Bentonite products, neat cement, sand/cement grout, concrete.

Figure 5. Bedrock well in multiple aquifers.

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The author would like to acknowledge the States of Illinois, Nebraska, Michigan, Minnesota, and Wisconsin for providing information concerning their respective positions on well abandonment and plugging. I am also especially appreciative of the efforts of Andrea Jilovek of the Iowa Water Well Association in coordinating with the above States. I want to thank the members of the work group on well abandonment for their counsel and technical review of this document. The work group members were Ken Choquette (Iowa Department of Health), Dennis Alt, Connie Cousins-Leatherman (Department of Natural Resources), Tom Glanville (Iowa State University Extension Service), Jack Johnson, Jeff Joslyn, Jim Schumacher (Iowa Water Well Association), Roger Bruner (Department of Natural Resources), and the author. Special thanks go to Roger Bruner, Paul Horick, Bob Libra, and Carol Thompson for their counsel and review of the report. I also want to thank Mary Pat Heitman for processing the manuscript, and also Kay Irelan and Pat Lohmann for their talents in preparing the graphics for the report.

GLOSSARY OF TERMS

Abandoned Well A water well which is no longer in use or which is in such a state of disrepair that continued use for the purpose of accessing groundwater is unsafe or impracticable.

Annular Space The space between the well bore and the outside of the well casing.

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 body of soil or rock materials that contains sufficient saturated permeable material to yield significant quantities of water to wells.

Artesian Well A well in an aquifer where the groundwater is confined under pressure and the water level stands above the top of the confined aquifer it taps.

Augered Well A well which is constructed by using a bucket-auger drill to bore the hole and extract earth materials.

Bentonite A processed, natural clay material composed principally of the mineral montmorillonite. It has a great affinity for fresh water and when hydrated will increase its volume more than eight times. Water/bentonite suspensions are essentially impermeable.

Bentonite Slurry A mixture of 10% processed bentonite (by weight) and clean water. In these proportions the mixture has a Marsh fluid viscosity of 70 seconds per quart (as measured through a standard Marsh funnel viscometer).

Bored Well Synonymous with an augered well.

Casing A tubular retaining structure, generally metal, which is installed in the excavated hole to maintain the well opening.

Clay A fine-grained inorganic material (grains less than 0.0005 mm in diameter) which has very low permeability and is plastic.

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 six gallons of clean water.

Curing Time Minimum time required for particular types of cementing or grouting materials to harden.

Domestic Water Supply One family water supply.

Disaggregate To separate into components, as a soil separated into its component granules.

Drilled Well A well which 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 bore.

Dug Well A hand-dug well usually curbed with brick or field stone.

Filling Materials Well-plugging materials that are used to take up space in a well.

Graded Bentonite A naturally occurring clay which 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 prevent fine-grained sediments from entering the well.

Groundwater Water in the zone of saturation.

Grout A pumpable, fluid mixture of cement or bentonite and water that can be forced through a pipe and placed as required.

Hydrologic Properties The properties of rocks or soil which control the entrance of water and the capacity to hold and transmit water.

Neat-Cement Grout A mixture of one sack (94 pounds) of Portland cement to not more than 6 gallons of clean water. Bentonite up to 2% by weight may be added to reduce shrinkage.

Permeability A measure of the relative ease with which a porous medium can transmit a liquid.

Sand/Cement Grout A mixture of one sack (94 pounds) of Portland cement, an equal amount by volume of clean masonry sand, and not more than six gallons of clean water.

Sandpoint A well constructed by driving or jetting a pointed well screen affixed to a small-diameter pipe into water-bearing sand or gravel.

Sealing Materials Well-plugging materials that will effect a tight seal in a well because of their characteristic impermeability.

Slurry A fluid mixture of cement or bentonite, or other solids and water. In this report synonymous with grout.

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.

Tremie 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.

Water Table The level at which water stands in wells that penetrate an unconfined aquifer.

Well Screen The intake section of a well that allows water to flow freely into the well from water-saturated sand, and serves as a structural retainer to support the bore hole in unconsolidated material. Numerous types are available, and their application depends on the specific hydrogeologic conditions present.

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APPENDIX A.

Weights and Volumes of Materials

	lbs./ft.^{3}	lbs./yd.^{3}
SOIL		
Loam, dry	78	2,100
Loam, moist	90	2,430
SAND		
Loose, dry	100	2,700
Damp	120	3,240
SAND AND GRAVEL		
Dry	108	2,916
Wet	125	3,375
LIMESTONE		
Crushed	97	2,625
NEAT CEMENT		
Grout	112	3,024
SAND CEMENT		
Grout	135	3,645
WATER	62.5	1,688

APPENDIX B.

Dimensions, Capacities, and Cement Requirements for Steel Well Casings

Nominal (inches)	Schedule† or Strength	O.D.* (inches)	I.D.** (inches)	Section (ft.^{2})	gallons/ lineal ft.	sacks/ft.	lineal ft./sack***
2	40	2.375	2.07	0.023	0.17	0.021	47.83
	80	4.500	1.94	0.021	0.15	0.019	52.38
4	40	4.500	4.02	.088	0.66	0.080	12.50
	80	4.500	3.82	.080	0.60	0.073	13.75
5	40	5.563	5.04	.139	1.04	0.126	7.91
	80		4.81	.126	0.95	0.115	8.73
6	40	6.625	6.06	.201	1.50	0.182	5.47
	80		5.76	.181	1.35	0.165	6.08
8	30	8.625	8.07	.355	2.66	0.323	3.10
	40		7.98	.347	2.60	0.316	3.17
	80		7.62	.317	2.37	0.288	3.47
10	30	10.75	10.13	.560	4.19	0.510	1.96
	40		10.02	.548	4.10	0.498	2.01
	XS		9.75	.519	3.88	0.471	2.12
12	30	12.75	12.09	.797	5.96	0.725	1.38
	STD		12.00	.785	5.88	0.714	1.40
	40		11.93	.777	5.81	0.707	1.42
14	STD	14.00	13.25	.957	7.16	0.871	1.15
	XS		13.00	.922	6.90	0.838	1.19
16	STD	16.00	15.24	1.268	9.49	1.153	0.87
	XS		15.00	1.227	9.18	1.116	0.90
18	STD	18.00	17.25	1.623	12.14	1.476	0.68
20	STD	20.00	19.25	2.021	15.12	1.837	0.54
24	STD	24.00	23.25	2.948	22.06	2.680	0.37
30	STD	30.00	29.25	4.666	34.91	4.242	0.24

* outside diameter
** inside diameter
***based on 1.1 ft.^{3}/sack

† Several years ago the American Standards Association (ASA) set standards for the designation of pipe strength, wall thickness, and diameter. Generally, higher pipe-schedule numbers indicate thicker-walled pipe. Standard (STD) is the most common combination of pipe diameter and wall thickness, (XS) denotes extra strength and greater wall thickness.

APPENDIX C

Dimensions, Capacities, and Cement Requirements for PVC Well Casings

Nominal hole size (inches)	Schedule or Strength	O.D. (Inches)	I.D. (Inches)	Section ($ft.^2$)	gallons/ lineal ft.	sacks/ft.	lineal ft./sack*
1.0	40	1.315	1.049	.0060	.0449	.006	183.33
	80		.957	.0050	.0374	.005	220.00
1.5	40	1.900	1.610	.0140	.1044	.013	78.57
	80		1.500	.0123	.0918	.011	89.43
2	40	2.375	2.067	.0233	.1743	.021	47.21
	80		1.939	.0205	.1534	.019	53.66
3	40	3.500	3.068	.0513	.3840	.047	21.44
	80		2.900	.0459	.3431	.042	23.97
4	40	4.500	4.026	.0884	.6613	.080	12.44
	80		3.826	.0798	.5972	.073	13.78
6	40	6.625	6.065	.2006	1.5008	.182	5.48
	80		5.761	.1810	1.3541	.165	6.08

* Based on 1.1 $ft.^3$/sack

APPENDIX D

Nominal Hole Size, Capacities, and Volumetric Requirements for Graded Bentonite

Hole diameter (inches)	Hole volume ft.^{3}/ft.	Pounds Graded Bentonite per foot	Lineal feet per 50 lb. bag
2	0.022	1.6	31.3
4	0.087	6.3	7.9
5	0.136	9.8	5.1
6	0.196	14.1	3.5
8	0.349	25.1	2.0
10	0.545	39.2	1.3
12	0.785	56.5	0.89
14	1.069	77.5	0.65
16	1.396	101.2	0.49
18	1.767	127.2	0.39
20	2.182	151.1	0.32
24	3.142	227.7	0.22
30	4.909	353.4	0.14

APPENDIX E

Groundwater Sources and Typical Private Wells in Iowa

Wells In Quaternary Sediments

Quaternary sediments in Iowa constitute a wide variety of materials that have been transported and deposited by wind, water, and glacial ice. They range in age from Pleistocene to recent. They are dominantly surficial soils materials such as clay, silt, sand and gravel, or mixtures thereof. Depending upon the erosional, depositional, and glacial history of various regions of the State, these materials in many instances have been mechanically segregated into beds, layers, and channels that locally function as aquifers. Aquifers in unconsolidated sediments in certain areas of the State yield only minimal quantities of water; however, thick sand-and-gravel bodies along major rivers are excellent water producers.

There are three fundamental contexts in which groundwater exists in Quaternary sediments in Iowa: within the glacial drift, in buried channels, and in alluvial sands and gravels along rivers and streams. Iowa's glacial history is complex and so are the sediments that remain from multiple periods of glaciation. The result is a diverse system of glacial-drift aquifers that vary from region to region across the State. In certain regions, the only water available from the drift aquifer is found at the contact between loess and underlying, less permeable glacial till. In other areas, groundwater is found in sand/gravel lenses within the drift section. In yet other areas, groundwater is associated with outwash and terrace deposits.

Alluvial and buried-channel aquifers are more continuous, generally more dependable sources of supply that produce larger quantities of groundwater than drift aquifers. The sand-and-gravel bodies that form alluvial aquifers vary in thickness and continuity, but are present along most larger streams and rivers. Buried channels are found beneath the glacial drift at various locations within the State. They are typically sand- and gravel-filled channels in bedrock valleys.

Wells in various regions of the State that draw water from Quaternary aquifers are designed and constructed according to the geologic setting in which groundwater occurs. On this basis, regions can be delineated where certain kinds of wells predominate. Six such areas or zones are outlined in Figure 6. All six zones include a common well type that draws water from alluvial aquifers. These may vary from small-diameter, driven sandpoints to drilled wells that are cased and screened. The diameter of drilled alluvial wells may vary from 4 inches to more than 10 inches, and most are relatively shallow. Generally, they do not exceed 50 feet in depth.

Zone 1. Quaternary wells in this region draw water from sand-and-gravel units within the drift section. A few wells may draw water from buried channels which are not well defined in this part of the State. Available records indicate that Quaternary wells in the region are drilled with casing diameters of 4 to 6 inches, and vary in depth from a few tens of feet up to 400 feet. Most private wells in this category do not yield large quantities of water.

Zone 2. This region is referred to as the Des Moines Lobe, the area of most recent glaciation in Iowa. This area owes its unique character to a receding glacier which left the area with a number of lakes, outwash plains, thick gravel terraces, and former lake beds. Thick gravel deposits are found within the drift section as well as in the near-surface in outwash plains and former lake basins. Most serve as containers for groundwater. Wells in the

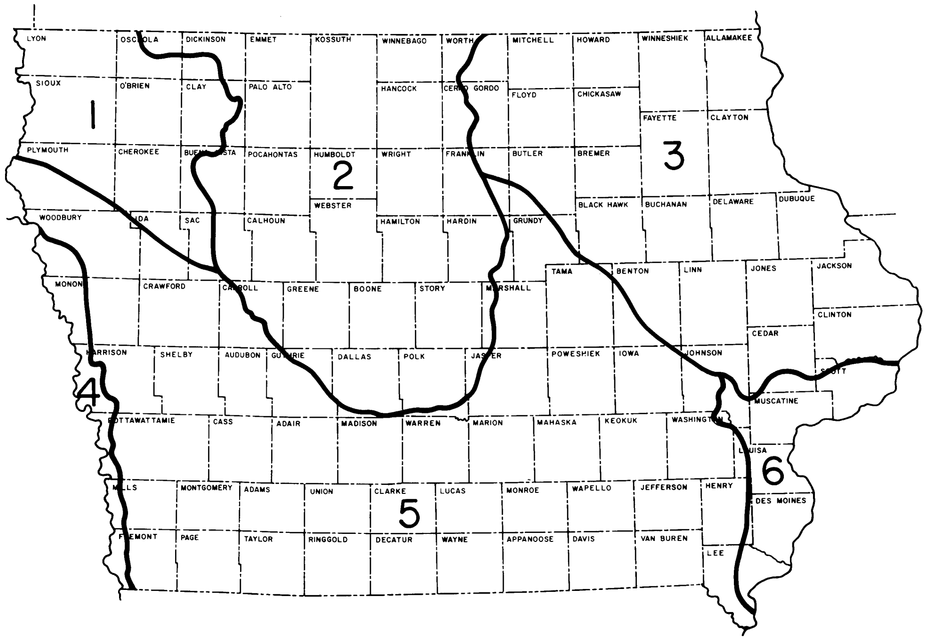

Figure 6. Index map of Iowa groundwater sources for private wells in Quaternary sediments.

region tap these sources of supply at varied depths. Available information indicates that many do not exceed 300 feet in depth. A majority are drilled wells with casing diameters in the 4- to 6-inch range. Well yields vary according to the type and extent of materials comprising the water-producing units.

Zone 3. Most wells in the region draw water from either bedrock or alluvial sources. Available records indicate that a few southern counties in the region have wells that draw water from sand-and-gravel lenses within the drift section. The wells are generally less than 300 feet deep, and range between 4 and 6 inches in diameter. The units that provide water will usually yield adequate quantities for most domestic needs.

Zone 4. Wells in this region typically draw water from sediments associated with the Missouri River floodplain. There are numerous irrigation wells in this corridor, particularly in Harrison and Monona counties. The majority of wells in the Missouri River alluvial system will produce large quantities of water (500 to over 1000 gpm), and generally range between 75 and 175 feet in depth.

Zone 5. In this area, west of the Des Moines River, wells in Quaternary materials draw water from the contact between loess and underlying glacial till, from sand-and-gravel lenses within the drift, from buried channels, and from alluvium along rivers and streams. Most of these wells are shallow, from 25 to 125 feet, and many are large-diameter bored or dug wells. Many, particularly the wells drawing water from the loess/till contact, produce limited quantities of water. Wells in this category generally yield less than 5 gpm, and frequently dry up when rainfall is deficient. East of the Des Moines River, Quaternary wells draw water from the same sources as in the western part of the region; however, fewer wells draw water from the loess/till contact. More reliance is placed on alluvial, drift, buried-channel, and bedrock sources of water. Well depths are variable in the region, but available information indicates that the majority of private wells do not exceed 300 feet in depth.

Zone 6. Private wells in this region draw water from a variety of Quaternary sources. Principal among these are alluvial, buried-channel, and within-drift sand-and-gravel sources. Yields from these sources are variable, ranging from 5 to 10 gpm from within-drift sources to over 600 gpm from some buried-channel and alluvial sources. The majority of private wells in the region do not exceed 300 feet in depth.

Wells in Bedrock Aquifers

Major regional bedrock aquifers underlie at least two-thirds of the State. Where present, nearly all will provide an adequate, sustained supply of water to meet most private water system needs. There are, however, many areas throughout the State where the water contained in these aquifers is of poor quality and cannot be consumed by humans or livestock. In these areas, the only option for potable supplies are Quaternary sources.

Private water supplies in approximately the eastern half of Iowa (zone 1, Fig. 7) draw water from Mississippian, Devonian, Silurian, Ordovician, and

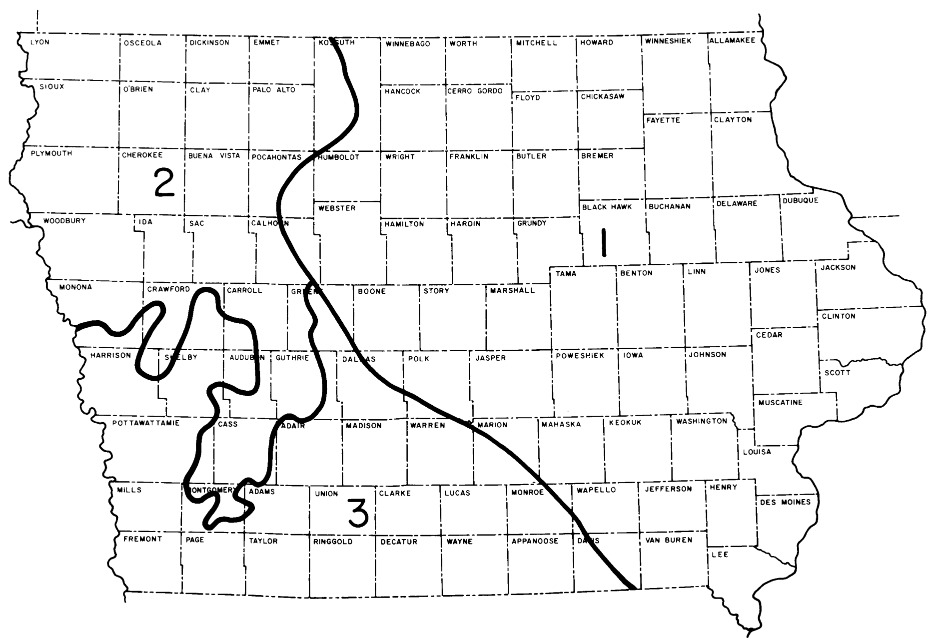

Figure 7. Index map of Iowa groundwater sources for private wells from rock aquifers.

Cambrian rocks. The rocks that comprise the aquifers in this region are principally carbonates (limestones and dolomites) and sandstones. The groundwater associated with these aquifers circulates through joints, cracks, and crevices which occur in carbonate rocks and between the grains in sandstones.

Well yields vary depending on which aquifer is developed and local hydrologic conditions. However, most of the regional systems (Mississippian, Silurian-Devonian, Cambro-Ordovician) will yield from 10 to 100 gpm in most localities. Well depths throughout the region are variable; landsurface topography, drift thickness, and bedrock topography influence the depth of wells drilled in rock aquifers. Available information indicates that private wells in the region are in a range between 75 and 500 feet in depth.

The area comprising zone 2 in Figure 7 is underlain by Cretaceous limestone, shale, and sandstones. The sandstone units within the Dakota Group form an aquifer of regional significance. Where the quality of the water in this aquifer is acceptable, it is heavily used and is capable of furnishing significant quantities of water, commonly 50 to 100 gpm. Throughout most of this region, due to the thickness of the glacial drift, rock wells are comparatively deep, probably ranging between 100 and 500 feet.

In zone 3 in southwest Iowa, few private wells draw water from bedrock aquifers. Those about which information is available are found principally in Dallas, Greene, and Guthrie counties. Zone 3 is typified by thick glacial drift underlain by a thick sequence of Pennsylvanian rocks which yield little potable water. Older rocks below the Pennsylvanian that provide water to other areas of the State contain highly mineralized water. Therefore, the region is dominantly served by groundwater drawn from shallow Quaternary sources. The bedrock wells in the northeastern part of the zone range between 200 and 600 feet in depth.