

AE-996 (Revised)



A Guide to Plugging Abandoned Wells

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How many abandoned wells are there in North Dakota?

Farm numbers in North Dakota peaked at 85,000 in the 1930s. Today there are about 32,000 farms in the state. That means there have been approximately 53,000 farmsteads abandoned over the last 60 years. Assuming that each of those farmsteads had at least one well, an extremely conservative estimate of abandoned wells in North Dakota would be 53,000. The total number in North Dakota is much higher, if abandoned wells on active farmsteads and in towns are added. Although an actual survey has not been conducted, North Dakota probably has approximately 100,000 abandoned wells.

What are the hazards associated with abandoned wells?

SAFETY HAZARD - This hazard is obvious to anyone who has encountered an unmarked and uncovered large diameter well. Accidents involving abandoned wells have occurred. The liability associated with abandoned wells has not really been tested in North Dakota. A good question for a landowner with an abandoned well to ask is, "Do I want to be the first legal test case?"

GROUNDWATER CONTAMINATION - An abandoned well is a direct conduit from the surface to the aquifer below. Contaminants that enter the well are introduced directly into the aquifer with no opportunity for natural filtration by soils or geologic materials. If a contamination incident occurs with a concentrated chemical, the potential for health threatening levels in the surrounding aquifer is high. This puts other wells in the aquifer at risk, particularly those wells on the same farmstead that are close to the abandoned well. Just one gallon of 2,4-D herbicide can contaminate about 7,000,000 gallons of water. In terms of groundwater, approximately that much water would be held in the upper 3 feet of an aquifer over a 20-acre area.

CO-MINGLING OF GROUND WATER - A well open to more than one aquifer will allow water from an aquifer with higher pressure head to enter an aquifer with lower pressure head. In many areas of North Dakota, deep aquifers under high pressures are extremely salty. In the early years of settlement, people utilized high pressure aquifers to avoid pumping. In many cases shallow aquifers with less salt were drilled through in the process of reaching the high pressure aquifers. When the casing from a flowing well deteriorates and the well is abandoned without proper plugging, continual upward flow of salty water will cause contamination of the shallower fresh aquifer.

LOSS OF AQUIFER PRESSURE HEAD - Pressure head in artesian aquifers is depleted as water discharges either at land surface or to less pressurized aquifers. Unplugged abandoned wells contribute to the regional depletion of pressure head within an aquifer. Eventually the decline in pressure head causes flowing wells to stop flowing and the water level in nearby wells placed in the same aquifer to decline.

Regulations and standards pertaining to abandoned wells

North Dakota regulations for water well construction and water well abandonment are outlined in Article 33-18 of the North Dakota Administrative Code. The article defines an **"abandoned well"** as a well whose use has been permanently discontinued. The article further states that "Any abandoned water wells, including test wells, uncompleted wells, and completed wells shall be sealed by restoring as far as possible the controlling geological conditions which existed before the wells were drilled."

Appendix VI of Article 33-18 provides information regarding methods and materials suggested for abandoned well plugging. For wells in unconsolidated materials under water-table conditions (no artesian pressure) a combination of sand, clay, or concrete and neat cement grouts are considered acceptable plugging materials. As stated in the appendix, "Clay in a relatively dry state, clay and sand, or sand alone may be used advantageously as sealing materials, particularly under water-table conditions where diameters are large, depths are great, formations are caving, and there is no need for achieving penetration of openings in casings, liners, or formations, or for obtaining a watertight seal at any given spot."

Certain types of abandoned wells are strictly regulated. These types of abandoned wells are 1) public drinking water supply wells; 2) irrigation wells and other wells that require a water permit; and 3) flowing artesian wells. If there is any doubt about abandoned well type, the following North Dakota agencies should be contacted:

North Dakota Department of Health and Consolidated Laboratories

Division of Water Quality
1200 Missouri Avenue
Bismarck ND 58505
Telephone (701) 221-5210

North Dakota State Water Commission

900 East Boulevard
Bismarck, ND 58505
Telephone (701) 224-2754

Well plugging materials

Sand and gravel, native clay, commercial sodium bentonite, and neat cement grout are the most common materials used for plugging wells. Use of one or more of these materials will effectively plug many types of abandoned wells.

A mixture of **sand and gravel** makes an excellent filler because little settling will occur as long as it is shoveled (not dumped from a loader bucket or dump-truck box) into the well. Mixtures with excessive amounts of cobbles and boulders should be avoided. Although sand and gravel is a good filler, it allows water and contaminants to easily pass through. Less permeable material is placed over the sand and gravel to reduce the potential for contaminant movement from the surface to the aquifer below.

Native clay serves as a filler but is much less permeable to water flow. Native clay is defined as any material that is found locally below the topsoil that has a medium or loamy texture (excluding sandy loam) according to the USDA Classification System. Comparable materials are classified in the Unified Soil Classification System as silty (CL-ML) or lean clay (CL).

It should be excavated from a zone deep enough below the top soil so that it is free of organic matter. Native clay should be shoveled (not dumped) into the well and tamped continually during the shoveling process. If this procedure is used, little subsequent settling will occur. Because native clay must be tamped, it cannot be effectively used below the depth of 15 feet. The combination of native clay over sand and gravel is similar to natural conditions over shallow aquifers in many areas of North Dakota. It is an effective deterrent to contaminant movement into groundwater.

Commercial sodium bentonite, hereafter referred to as bentonite, is a natural expanding clay that swells and forms an impermeable layer when wet. Bentonite is available in many forms, not all of which are recommended for abandoned well plugging. Bentonite chips that have been processed and graded according to size are generally packaged in 50-pound bags (0.7 cubic feet) and can be an effective plugging material when poured directly into the well. Only bentonite chips that are graded medium to coarse (1/4 to 3/4 inch chips) should be used. When the chips come

into contact with the water in the well, they sink to the bottom of the well and then expand to fill the voids.

About 3 to 4 gallons of water will thoroughly saturate a 50-pound bag of bentonite chips and fill the voids between the chips. Bentonite should not be hydrated beyond this point, because further addition of water will allow the bentonite to expand beyond its original dry bulk volume (0.7 cubic feet / bag). For example, 8 gallons of water added to a 50-pound bag will allow the bentonite to expand to 2 times its original dry bulk volume.

Unfortunately, bentonite loses moisture through the process of evaporation and does have the potential to dry back to its original chipped form. We know that drying of bentonite is extremely slow, particularly if it is placed near the water table and covered by other materials. It is impossible to predict future environmental conditions that may cause drying; therefore, we don't recommend that bentonite be allowed to expand beyond its original dry bulk volume.

On the other hand, sufficient water should be on hand during well plugging to ensure adequate expansion and sealing. When water is added to dry bentonite at the bottom of a dry well, a significant amount of water may be lost initially before the bentonite begins to expand and seal. In this circumstance, calculations of 3 to 4 gallons of water per bag will underestimate the amount of water needed for adequate sealing.

Neat cement grout forms a nearly impermeable layer when hardened. One bag of Portland cement (94 pounds or 1 cubic foot) is mixed with about 6 gallons of water to make neat cement grout. Neat cement grout should have the consistency of thick cream when it is placed in the well. Because of its consistency, it will flow into odd shapes and holes that other materials may not fill. Neat cement grout will shrink only minimally as it hardens. Depending on the exact proportion of water and cement mixed, 1 bag of Portland cement will make a little over 1 cubic foot neat cement grout.

General well plugging recommendations

Before the well plugging procedure begins, decisions must be made regarding the level of health and safety protection desired. There are two levels of protection that well plugging will provide. **Primary protection** covers personal injury from falling or unintentional dumping of concentrated contaminants into an unplugged well. Filling an abandoned well with any of the materials listed above will effectively provide the landowner with primary protection. However, techniques that avoid subsequent settling or slumping must be used. This can generally be accomplished with little financial input other than the landowners time.

Secondary protection covers future health problems that may occur due to accidental spillage over the abandoned well site and percolation of contaminants through the fill materials into the aquifer. Justification for this type of protection will depend on the location of the abandoned well site in relation to possible contaminants.

Secondary protection is accomplished by filling all or part of the well with materials that are impermeable to water flow. A layer of impermeable material such as bentonite may be combined with a permeable layer such as sand and gravel for secondary protection. The degree of secondary protection from contamination depends on the thickness of the bentonite layer.

Water table fluctuations play an important role in determining whether a bentonite layer will be an effective deterrent to aquifer contamination. If the water table rises above the bentonite plug the deterrent is lost. Therefore, if bentonite is used to prevent secondary contamination, it must be thick enough to account for the normal fluctuations of the water table. Under most conditions in North Dakota a 10 foot plug should be adequate.

Native clay is not as impermeable as a layer of hydrated bentonite, but it does slow the movement of water significantly compared to sand and gravel. A 15 foot layer of native clay provides secondary protection from contamination.

Neat cement grout that has hardened provides a nearly impermeable layer. Capping more permeable materials with 3 feet of neat cement grout is an alternative that provides secondary protection. An advantage

of neat cement grout is its relative stability compared to other materials. Disadvantages include the need to strictly adhere to mixing and grouting techniques.

Compared to 10 feet of bentonite or 3 feet of neat cement grout in a large diameter well, 15 feet of native clay is the most economical option. Under some circumstances the landowner may desire more than one form of secondary protection, such as a 10-foot bentonite layer capped with 15 feet of native clay. The landowner should always weigh the benefits of different types of secondary protection against their cost. The landowner considering well plugging should also keep in mind that primary protection is the most important benefit gained.

■ Well plugging steps

The list of well plugging equipment and tools in Appendix I should be reviewed. Making sure that the proper equipment and materials are on hand will make the job much easier, quicker, and effective.

Step 1 Measure the dimensions of the well.

Measurements must be taken of the well diameter, depth, and water level. Accurate measurements (not estimates) will allow the correct calculation of the total well volume and the volume of water in the well. This information is needed to determine the amount of materials needed for plugging. Remember that volume calculations depend on the shape of the well. Most wells are cylindrical; however, some have other shapes that must be considered for accurate calculation of volume. Refer to Appendix II - Area Formulas and Appendix III - Table of Volumes.



Step 2 Remove all obstructing materials from the well.

It is critical that fill materials do not slump or settle; therefore, obstructions that may cause incomplete filling of the voids must be removed. Remove the pump, rods, pipes and any other equipment from the well. Floating debris such as wood staves should also be removed. One method used to accomplish debris removal is flushing. If water is pumped into the well, floating debris will move to the top as the well fills with water. Flushing may not be possible with larger diameter wells due to the volume of water required. In any event, as much debris as possible must be removed from the well before plugging.

Step 3 Disinfect the well by adding household bleach.

All wells containing standing water must be disinfected to kill existing microorganisms. This can be accomplished by adding chlorine bleach at the rate of 1 gallon of bleach for every 500 gallons of water and is equivalent to a "shock" chlorination concentration of 100 parts per million chlorine. The chlorination process ensures that disease causing microorganisms are not sealed in the aquifer.



The chlorination procedure disinfects the well so that disease causing microorganisms are not sealed in the aquifer after the well is plugged.

Initial well plugging steps include accurate measurement of the well dimensions and removal of all obstructions.

Step 4 Fill the well with plugging materials.

Plugging always starts from the bottom of the well. The exact procedure for plugging will depend on well construction, depth, diameter, aquifer type, availability of materials, and the level of protection required.

Large Diameter Wells (10 inches or greater in diameter)

For both primary and secondary protection, most large diameter wells can be effectively plugged by filling with a combination of sand and gravel, native clay, and topsoil (Figure 1A in Appendix IV). A mixture of **sand and gravel** is shoveled into the well up to a depth of 15 feet below the surface. **Native clay** is then shoveled and tamped into the well up to 3 feet below the surface. Tamping is often started with a 16-foot 2 X 4 and finished with an 8-foot length. If more than 2 or 3 feet of standing water remains on top of the sand and gravel, it should be pumped from the well prior to the addition of native clay. If the water is not removed, the addition of native clay creates a muddy slurry that cannot be tamped. **Warning: Adding materials such as sand and gravel or native clay at excessively rapid rates will cause bridging of the materials and inadequate plugging. Dumping directly into the well from a loader bucket or dump-truck box is not acceptable.**

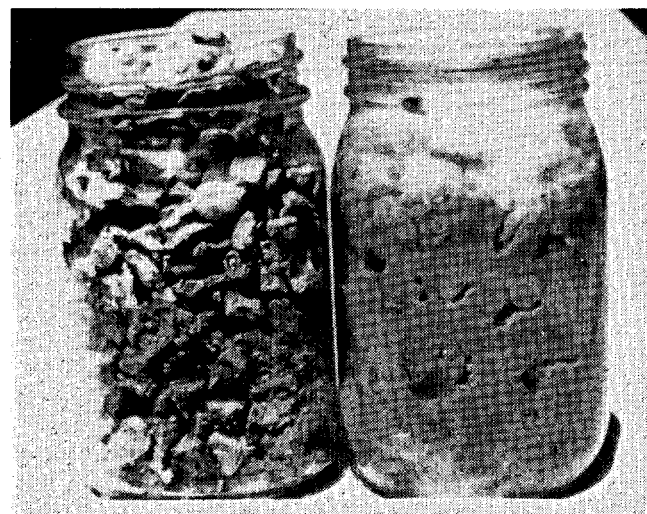
If additional secondary protection is desired for a large diameter well, the most common combination of materials is a mixture of sand and gravel, bentonite, native clay, and topsoil (Figure 2A in Appendix IV). A mixture of **sand and gravel** is shoveled into the well up to a point 5 feet below the measured water table. Ten feet of **bentonite chips** is poured into the well on top of the sand and gravel. It is critical that the bentonite is placed near the water table so that it remains wetted and expanded. Dry bentonite does not provide secondary protection from contamination. If the top of the bentonite is within 15 feet of the surface then **native clay** is shoveled and tamped on top of the



Abandoned wells with diameters of 10 inches or greater are usually plugged with a combination of materials such as sand gravel and native clay. These materials should always be shoveled into the well, as opposed to being dumped rapidly in large quantities.



Tamping native clay as it is shoveled into the well is an important step to insure that all voids are filled and minimal settling will occur.



Commercial chipped sodium bentonite (left jar) is a natural clay that expands in water (right jar). Ten feet of bentonite placed near the water table provides additional protection in locations where secondary contamination is a concern.

bentonite up to 3 feet below the surface. However, if the top of the bentonite is not within 15 feet of the surface, sand and gravel must be added until the 15-foot depth is reached.

A less common well plugging method that provides both primary and secondary protection involves placing a 3-foot layer of neat cement grout on top of the sand and gravel. The neat cement layer is placed 3 to 6 feet below the surface.

Small Diameter Wells (less than 10 inches in diameter)

Fewer options are available for filling small diameter wells, because sand and gravel and native clay tend to bridge in a small diameter casing and leave unfilled spaces. Both primary and secondary protection are provided by filling small diameter wells with medium (1/4 inch) to coarse (3/4 inch) **bentonite chips** (Figure 3A in Appendix IV). Both medium and coarse chips are recommended for well diameters from 4 to 10 inches in size. Only medium chips are recommended for well diameters less than 4 inches.

When pouring bentonite chips into small diameter wells, the chips should be poured over a 1/4 inch screen to allow the fines to drop out before the bentonite reaches the well opening. The rate of pouring should be no greater than one 50-pound bag every three minutes. Following this technique will eliminate bento-



nite bridging over unfilled voids. The bentonite should always be poured into standing water. If there is insufficient water in the well, water should be added at appropriate intervals during the filling process. There should never be more than 2 or 3 feet of dry bentonite chips in the well during the filling process. Wetting dry bentonite after the entire well has been filled is not recommended.

Fill the well with bentonite chips to a depth of 6 feet below surface. Three feet of neat cement grout should then be added above the bentonite. The plug of neat cement grout over the bentonite will ensure that the bentonite will not dry out and lose its seal.

Most small diameter wells that have been plugged in North Dakota using bentonite chips have had diameters from 4 to 10 inches and were less than 250 feet deep. Although this technique is untested for wells of diameters less than 4 inches or greater than 250 feet deep, it appears that it should work for some of these wells. The smaller the diameter of the well or the deeper the well, the greater the chance for bridging and inadequate filling of the entire well. Therefore, if plugging wells of diameters less than 4 inches or greater than 250 feet deep with bentonite chips is attempted, it is extremely critical that the chips are screened and poured very slowly. If the situation dictates that complete filling of the voids is absolutely necessary, it is recommended that bentonite chips not be used. Instead, a certified professional water well contractor should be employed to fill the well using a grouting method.

Because of ease of application, chipped bentonite is the recommended material for plugging abandoned wells less than 10 inches in diameter. The bentonite chips should be poured slowly over a screen prior to entering the well.

Grouting

Plugging wells with neat cement grout is always an effective option for primary and secondary protection no matter what the size of the well. However, it is rarely the most economical method. Proper plugging of the entire well with neat cement grout requires specialized equipment (Figure 1) and trained professional help. The grout is pumped down the well through a tremie line or grout pipe.

Step 5 Remove the upper 3 feet of the well casing. This step should never be done before the fill material is within 3 feet of the surface. Upper casing removal is particularly important if the abandoned well site is farmed. Removing the upper 3 feet of casing eliminates potential damage to tillage equipment.



If the abandoned well site is intended for farming, removal of the upper three feet of the well casing after the abandoned well has been filled will eliminate the possibility of tillage equipment being damaged.

Step 6 Fill the final 3 feet with topsoil and mound. Shaping the site is necessary to prevent ponding of water over the plugged well. Topsoil should be packed into the well and mounded up to 1½ feet over the site. Mounding will help direct surface water away from the site and will also help to absorb any settling of fill materials.

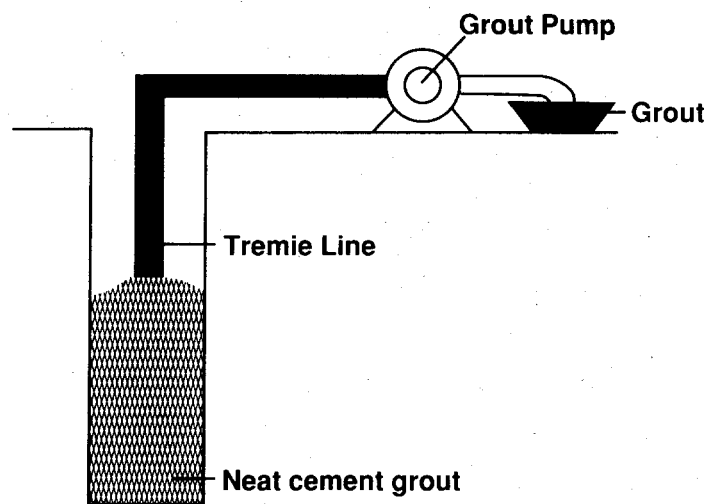


Figure 1. Diagram of an effective well plugging method for all sizes of wells using neat cement grout.

Well pits

If the abandoned well is located in a pit, proceed with the appropriate plugging process described above. To properly abandon the pit after the well is sealed, knock in at least one wall and then fill the pit with compacted native clay, followed by topsoil.

Sand point wells

If the well casing can be pulled, the hole should naturally fill with native material, and no further work is required. However, if the casing cannot be pulled, a certified professional water well contractor's services will be required to properly grout the well. After grouting is complete, the casing should be cut off 3 feet below the surface.

Well plugging records

Make and keep a record of any plugged well. You may want to recall something about the procedure at a later date. Exact recollection of the site may be useful to avoid interference with future building construction. The record should include: well location, well depth, well diameter, static water level, date work performed, personnel on hand, equipment removed from the well, plugging procedure used, type of material used, volumes of material used and the method of placement.

Consider all your alternatives before plugging

The well plugging recommendations in this bulletin are based on field experience with abandoned wells throughout North Dakota over four years. The suggestions for materials and methods are not standards or requirements. North Dakota regulations governing the plugging of most abandoned wells have been interpreted very broadly and allow considerable flexibility regarding plugging techniques and materials.

As with many environmental issues, there is not a consensus on the level of benefits for certain types of protection or the techniques to attain that protection. Except for those special cases where state agencies have jurisdiction, decisions regarding abandoned well plugging rest with the landowner.

Some of the techniques presented have been adopted or may be adopted by other agencies that do set standards. Further, some of the recommendations made in this document may not agree with standards set by other agencies. Presently, adherence to strict well plugging standards established by other agencies is not required unless cost-share funds are involved. The landowner must consider that participating in cost-share programs means some of the flexibility to choose alternative well plugging methods and materials will be forfeited. A much stricter adherence to standards for secondary contamination prevention is likely to be required.

The recommendations made in this publication place the greatest importance on primary protection and practical field methods to accomplish that goal. The task of plugging a significant percentage of the existing abandoned wells in North Dakota is huge. Hopefully, the information and recommendations in this bulletin will help landowners recognize the problem and implement solutions. A measurable reduction in the number of abandoned wells cannot occur without active public support.

Acknowledgements

The North Dakota State Department of Health, North Dakota State Water Commission, and Soil Conservation Service are recognized for their thorough manuscript review and helpful suggestions.

APPENDIX I

Well Plugging Equipment and Tools

1. **10-gallon pail** - used to mix Portland cement and water to make neat cement grout
2. **2-foot by 3-foot 1/4" screen** - when formed into a cone, it is used to pass chipped bentonite through before it is poured into the well to separate out fines
3. **8-foot and 16-foot 2" by 4" wood studs** - used to tamp native clay as it is shoveled into the well
4. **Cutting torch** - used to separate upper 3 feet of metal well casing so that it can be removed
5. **Flashlight** - helps illuminate debris and well casing condition in deep wells
6. **Knife** - used to cut open bentonite and Portland cement bags
7. **Logging chain** - used with tractor and front-end loader
8. **Pump and hose** - used to remove excess water before native clay is added to the well
9. **Spades** - needed to shovel sand and gravel and native clay into the well; to dig around the upper well casing so that it can be removed; to mix portland cement and water to make neat cement grout
10. **Tape measure** - used to accurately determine well dimensions and water table depth
11. **Tractor and front-end loader** - used to pull pumps, pipes, cement pads, upper well casing, and other heavy objects from the well
12. **Treblehook and line** - used to hook and remove floating or obstructing debris
13. **Water tank and hose** - additional water supply when insufficient water is available in the well to wet the bentonite
14. **Weighted line** - used to measure well and water depths
15. **Wrecking bar** - serves to loosen obstructions around the well that must be removed

APPENDIX II

Area Formulas

area of a **circle** = πr^2

where $\pi = 3.14$

r = radius of the circle

area of a **square** = s^2

where s = side of the square

area of an equilateral polygon

(**octagon, hexagon** etc.) = $nr^2 \tan \pi/n$

where n = number of sides

r = radius of the inscribed circle

$\pi = 3.14$

\tan = tangent expressed as radians

APPENDIX III

Table of Volumes

Volume according to diameter of a cylindrical well

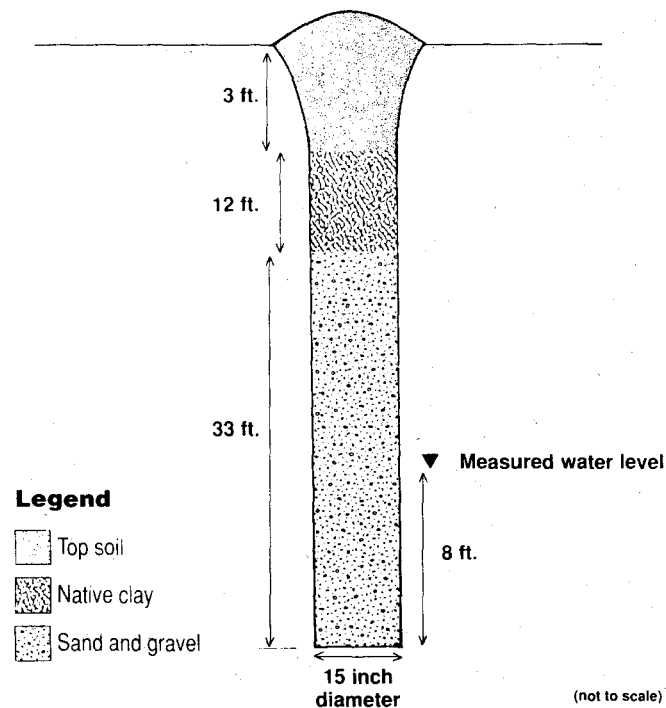
Hole diameter	Volume per foot of depth		
	(in)	(gal/ft)	(ft ³ /ft) (yd ³ /ft)
2	0.15	0.02	
3	0.38	0.05	
4	0.68	0.09	
5	1.05	0.14	
6	1.5	0.20	
7	2.0	0.27	
8	2.6	0.35	
9	3.3	0.44	
10	4.1	0.55	0.02
12	5.9	0.79	0.03
14	8.2	1.1	0.04
16	10.5	1.4	0.05
18	13.5	1.8	0.07
20	16.4	2.2	0.08
24	23.6	3.1	0.11
36	53.0	7.1	0.26
40	65.2	8.7	0.32
44	79.5	10.6	0.39
48	94.2	12.6	0.47

APPENDIX IV

Well Plugging Examples

Two examples of abandoned wells that are representative of large and small diameter wells found in North Dakota are shown. The well plugging methods also represent commonly used techniques that would be effective for these types of wells. These are not the only recommended methods to plug these types of wells, but are likely to be the methods most often selected. These examples are intended to provide the reader with a guide to the general thought process that occurs prior to and during abandoned well plugging.

Figure 1A. Diagram of an effective well plugging method for large diameter wells (10 inches or greater diameter) using a combination of sand and gravel and native clay.



Large Diameter Well Plugging Example (Figure 1A)

Well Dimensions

- 15 inch diameter
- 48 feet deep
- 40 feet to the water table

Volume Calculations

$$\pi r^2 = \text{area of a circle}$$

$$\pi = 3.14$$

$$r = \text{radius of the circle}$$

$$r = 1/2 d = 0.5 \times d$$

$$d = \text{diameter of the circle}$$

$$r = 0.5 \times 15 \text{ in} = 7.5 \text{ in}$$

$$\text{radius in ft} = r \times (1 \text{ ft} / 12 \text{ in})$$

$$7.5 \text{ in} \times 1 \text{ ft} / 12 \text{ in} = 0.62 \text{ ft}$$

$$3.14 \times (.62)^2 \text{ ft} = 1.2 \text{ ft}^2$$

The volume in cubic feet (ft³) can now be calculated for a given length of well casing by multiplying by the area or 1.2 ft².

Your Well

Well Dimensions

- _____ inch diameter
- _____ feet deep
- _____ feet to the water table

Volume Calculations

$$r = 0.5 \times \text{_____ in} = \text{_____ in}$$

$$\text{_____ in} \times 1 \text{ ft} / 12 \text{ in} = \text{_____ ft}$$

$$3.14 \times (\text{_____})^2 \text{ ft} = \text{_____ ft}^2$$

Calculations for Chlorine

Depth of well – Depth to water table = Depth of water

$48 \text{ ft} - 40 \text{ ft} = 8 \text{ ft of water}$

$8 \text{ ft} \times 1.2 \text{ ft}^2 = 9.6 \text{ ft}^3 \text{ of water}$

$1 \text{ ft}^3 = 7.5 \text{ gal}$

$9.6 \text{ ft}^3 \times 7.5 \text{ gal} = 72 \text{ gal water}$

$1 \text{ gal chlorine} / 500 \text{ gal water} = ? \text{ gal chlorine} / 72 \text{ gal water}$

$72 / 500 = 0.14 \text{ gal chlorine needed to disinfect well}$

Calculations for Sand and Gravel

Depth of well - 15 feet = Thickness of sand and gravel

$48 \text{ ft} - 15 \text{ ft} = 33 \text{ ft of sand and gravel}$

$33 \text{ ft} \times 1.2 \text{ ft}^2 = 39.6 \text{ ft}^3$

$27 \text{ ft}^3 = 1 \text{ cubic yard (yd}^3)$

therefore

$39.6 \text{ ft}^3 / 27 \text{ ft}^3 = 1.5 \text{ yd}^3 \text{ of sand and gravel needed}$

Calculations for Native Clay

15 feet – 3 feet for topsoil = 12 feet of native clay

$12 \text{ ft} \times 1.2 \text{ ft}^2 = 14.4 \text{ ft}^3 \text{ of native clay}$

$27 \text{ ft}^3 = 1 \text{ cubic yard (yd}^3)$

therefore

$14.4 \text{ ft}^3 / 27 \text{ ft}^3 = 0.5 \text{ yd}^3 \text{ of native clay needed}$

Approximate Cost of Plugging Materials

Chlorine cost = $\$1.00 / \text{gal} \times 0.14 \text{ gal} = \0.14

Sand and gravel = $\$5.00 / \text{yd}^3 \times 1.5 \text{ yd}^3 = \7.50

Native clay = $= \$0$

Total Cost of Well Plugging Materials = \$7.64

Figure 2A. Diagram of an effective well plugging method for large diameter wells (10 inches or greater diameter) that emphasizes secondary contaminant protection using a combination of sand and gravel, bentonite, and native clay.

Your Well

Calculations for Chlorine

_____ ft – _____ ft = _____ ft of water

_____ ft X _____ ft² = _____ ft³ of water

_____ ft³ X 7.5 gal = _____ gal water

_____ / 500 = _____ gal chlorine needed

Calculations for Sand and Gravel

_____ ft – 15 ft = _____ ft of sand and gravel

_____ ft X _____ ft² = _____ ft³

_____ ft³ / 27 ft³ = _____ yd³ of sand and gravel

Calculations for Native Clay

12 ft X _____ ft² = _____ ft³ of native clay

_____ ft³ / 27 ft³ = _____ yd³ of native clay

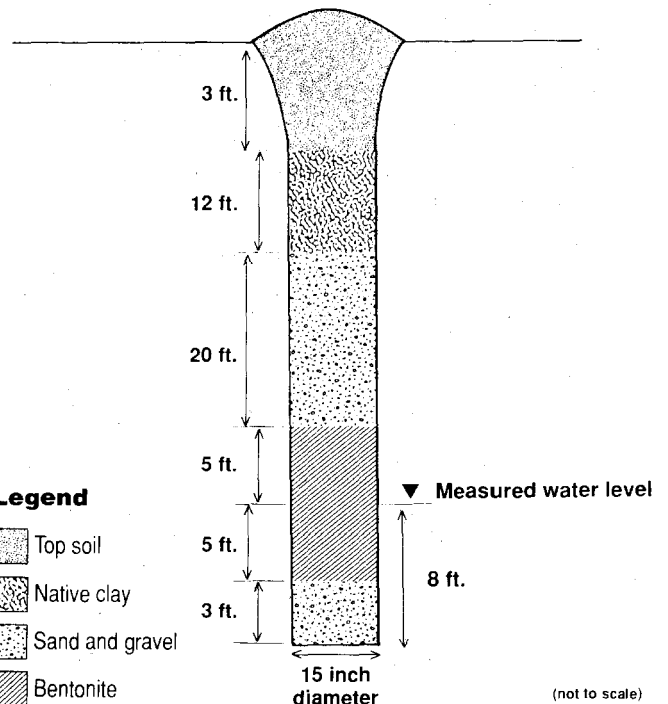
Approximate Cost of Plugging Materials

Chlorine cost = _____ / gal X _____ gal = _____

Sand and gravel = _____ / yd³ X _____ yd³ = _____

Native clay = _____ = _____

Total Cost of Well Plugging Materials = _____



(not to scale)

Large Diameter Well Alternative that includes a 10-foot bentonite plug for additional secondary protection from contamination (Figure 2A)

Calculations for Bentonite Chips

10 ft X 1.2 ft² = 12 ft³ of bentonite needed

50 lb bag of bentonite chips = 0.7 ft³

therefore

12 ft³ / 0.7 ft³ = 17.1 bags of chipped bentonite

Calculations for Water Required to Wet Bentonite Chips

4 gal of water is required to hydrate one 50 lb bag of bentonite chips

17 bags of bentonite chips are needed

therefore

4 gals X 17 = 68 gals needed

Assume 40 % porosity and 60 % solids for sand and gravel

therefore

3 ft X 0.6 = 1.8 ft of water displaced by sand and gravel

First layer of sand and gravel ends 5 ft below the measured water table

therefore

displaced water + 5 ft = total water available in well for bentonite wetting

1.8 ft + 5 ft = 6.8 ft of water

6.8 ft X 1.2 ft² = 8.2 ft³ of water

1 ft³ = 7.5 gal

therefore

8.2 X 7.5 gal = 62 gal of water available

Water needed - water available = additional water required

68 gal - 62 gal = 4 gal of additional water is required

Sand and Gravel Recalculation

12 ft³ of bentonite will replace the same amount of sand and gravel used in the first alternative (Figure 1A)

12 ft³ / 27 ft³ = 0.4 yd³ less sand and gravel needed

therefore

Original sand and gravel calculation - 0.4 yd³ = sand and gravel needed

1.5 yd³ - 0.4 yd³ = 1.1 yd³ sand and gravel needed

Your Well

Calculations for Bentonite Chips

10 ft X _____ ft² = _____ ft³ of bentonite needed

_____ ft³ / 0.7 ft³ = _____ bags of chipped bentonite

Calculations for Water Required to Wet Bentonite Chips

4 gals X _____ = _____ gals needed

_____ ft X 0.6 = _____ ft of water displaced

_____ ft + 5 ft = _____ ft of water

_____ ft X _____ ft² = _____ ft³ of water

_____ X 7.5 gal = _____ gal of water available

_____ gal - _____ gal = _____ gal additional water

Sand and Gravel Recalculation

_____ ft³ / 27 ft³ = _____ yd³ less sand and gravel

_____ yd³ - _____ yd³ = _____ yd³ sand and gravel

Approximate Cost of Plugging Materials

Chlorine cost = \$1.00 / gal X 0.14 gal = \$0.14
Sand and gravel = \$5.00 / yd³ X 1.1 yd³ = \$5.50
Bentonite = 6.00 / bag X 17 bags = \$102.
Native clay = \$0
Total Cost of Well Plugging Materials = \$107.64

Small Diameter Well Plugging Example (Figure 3A)

Well Dimensions

4 inch diameter
140 feet in depth
20 feet to the water table

Volume Calculations

πr^2 = area of a circle
 $\pi = 3.14$
 $r = \text{radius in ft} = .17$
 $3.14 \times (.17)^2 \text{ ft} = 0.09 \text{ ft}^2$

The volume in cubic feet (ft³) can now be calculated for a given length of well casing by multiplying the area or 0.09 ft².

Calculations for Chlorine

Depth of well - Depth to water table = Depth of water
 $140 \text{ ft} - 20 \text{ ft} = 120 \text{ ft of water}$
 $120 \text{ ft} \times 0.09 \text{ ft}^2 = 10.8 \text{ ft}^3 \text{ of water}$
 $1 \text{ ft}^3 = 7.5 \text{ gal}$
 $10.8 \text{ ft}^3 \times 7.5 \text{ gal} = 81 \text{ gal water}$
 $1 \text{ gal chlorine} / 500 \text{ gal water} = ? \text{ gal chlorine} / 81 \text{ gal water}$
 $81 / 500 = 0.16 \text{ gal chlorine needed to disinfect well}$

Calculations for Bentonite Chips

$134 \text{ ft} \times 0.09 \text{ ft}^2 = 12.1 \text{ ft}^3 \text{ of bentonite needed}$
50 lb bag of bentonite chips = 0.7 ft³
therefore
 $12.1 \text{ ft}^3 / 0.7 \text{ ft}^3 = 17.3 \text{ bags of chipped bentonite}$

Your Well

Approximate Cost of Plugging Materials

Chlorine cost = ____ / gal X ____ gal = ____
Sand and gravel = ____ / yd³ X ____ yd³ = ____
Bentonite = ____ / bag X ____ bags = ____
Native clay = ____
Total Cost of Well Plugging Materials = ____

Small Diameter Well Plugging Example (Figure 3A)

Well Dimensions

____ inch diameter
____ feet in depth
____ feet to the water table

Volume Calculations

$r = \text{radius in ft} = \text{_____}$
 $3.14 \times (\text{_____})^2 \text{ ft} = \text{_____ ft}^2$

Calculations for Chlorine

____ ft - ____ ft = ____ ft of water
____ ft X ____ ft² = ____ ft³ of water
____ ft³ X 7.5 gal = ____ gal water
____ / 500 = ____ gal chlorine needed

Calculations for Bentonite Chips

____ ft X ____ ft² = ____ ft³ of bentonite
____ ft³ / 0.7 ft³ = ____ bags

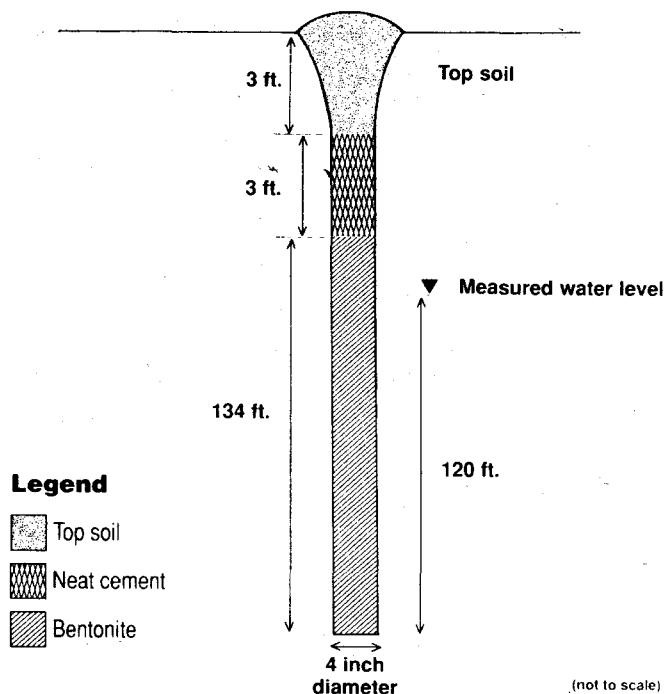


Figure 3A. Diagram of an effective well plugging method for small diameter wells (less than 10 inches) using chipped bentonite.

Calculations for Water Required to Wet Bentonite Chips

4 gal of water is required to hydrate one 50 lb bag of bentonite chips

17 bags of bentonite chips are needed
therefore

$$4 \text{ gals} \times 17 = 68 \text{ gals needed}$$

Water needed - water available = additional water required
68 gal - 81 gal = 0 gal of additional water is required

Calculations for Neat Cement

$$3 \text{ ft} \times 0.09 \text{ ft}^2 = 0.27 \text{ ft}^3 \text{ of neat cement needed}$$

94 lb bag Portland cement = 1 ft³ neat cement grout
therefore

$$0.27 \text{ ft}^3 / 1 \text{ ft}^3 = 0.27 \text{ bags of Portland cement needed}$$

Calculations for Water Required to Make Neat Cement

94 lb bag of Portland cement requires 6 gals of water
therefore

$$0.27 \times 6 \text{ gals} = 1.6 \text{ gals of water needed for neat cement}$$

Approximate Cost of Plugging Materials

$$\text{Chlorine cost} = \$1.00 / \text{gal} \times 0.16 \text{ gal} = \$0.16$$

$$\text{Bentonite} = \$6.00 / \text{bag} \times 17 \text{ bags} = \$102.$$

$$\text{Neat Cement} = \$6.00 / \text{bag} \times 0.27 \text{ bags} = \$1.80$$

$$\text{Total Cost of Well Plugging Materials} = \$103.96$$

Your Well

Calculations for Water Required to Wet Bentonite Chips

$$4 \text{ gals} \times \underline{\hspace{1cm}} = \underline{\hspace{1cm}} \text{ gals needed}$$

$$\underline{\hspace{1cm}} \text{ gal} - \underline{\hspace{1cm}} \text{ gal} = \underline{\hspace{1cm}} \text{ gal additional water}$$

Calculations for Neat Cement

$$3 \text{ ft} \times \underline{\hspace{1cm}} \text{ ft}^2 = \underline{\hspace{1cm}} \text{ ft}^3 \text{ of neat cement}$$

$$\underline{\hspace{1cm}} \text{ ft}^3 / 1 \text{ ft}^3 = \underline{\hspace{1cm}} \text{ bags of Portland cement}$$

Calculations for Water Required to Make Neat Cement

$$\underline{\hspace{1cm}} \times 6 \text{ gals} = \underline{\hspace{1cm}} \text{ gals of water}$$

Approximate Cost of Plugging Materials

$$\text{Chlorine cost} = \underline{\hspace{1cm}} / \text{gal} \times \underline{\hspace{1cm}} \text{ gal} = \underline{\hspace{1cm}}$$

$$\text{Bentonite} = \underline{\hspace{1cm}} / \text{bag} \times \underline{\hspace{1cm}} \text{ bags} = \underline{\hspace{1cm}}$$

$$\text{Neat Cement} = \underline{\hspace{1cm}} / \text{bag} \times \underline{\hspace{1cm}} \text{ bags} = \underline{\hspace{1cm}}$$

$$\text{Total Cost of Well Plugging Materials} = \underline{\hspace{1cm}}$$

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