DRAFT BSR/NGWA 01-2X Water Well Construction Standard

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Contents

1. Well Site Selection

1.1 General

The well shall be sited for the protection of the groundwater, while considering the following:

- well location criteria required under applicable state or local regulation;
- desired yield;
- desired water quality;
- availability and restrictions of water rights;
- vulnerability to known or suspected natural risks (e.g., flooding, saltwater intrusion);
- distance from potential contaminant sources (e.g., septic tanks, oil wells);
- property boundaries and set-backs;
- potential for interference with other wells, surface water flows, or environmentally important waters (e.g., wetlands or springs);
- potential for interference with utilities;
- accessibility for rigs and equipment, proximity to power source (either for testing or eventually for production wells), and logistics associated with infastructure such as pump houses and transmission pipelines; and
- safety of the public and project personnel.

1.2 Field Verification

The water well professional shall confirm the location in the field prior to the initiation of drilling, especially if a well site is designated in a permit issued by a regulatory agency or in a third party specification document. The accuracy of the location method shall be suitable for the most stringent regulatory requirement. If site conditions warrant, confirmation should be accomplished by triangulation of the point designating the well location to a minimum of two permanent landmarks such as a building corner or permanent iron pin.

2. Well Casing and Well Casing Installation

Water well casing is a string of pipe which is placed into the borehole during well construction to provide structural stability in the wellbore. The casing also accommodates the installation and operation of pump equipment.

2.1. Water Well Casing Materials

Water well casing shall conform to the material standards in Table 1 Water Well Casing Material Standards. Stenciling and/or mill test reports shall be made available to the well owner as required.

Table 1. Water Well Casing Material Standards

Carbon Steel	ASTM A589-89a
	ASTM A53-90b
	ASTM A139 Grade B
	API Spec, 5L and 5LS
Copper Bearing Steel	ASTM A139 Grade B
High-Strength Low-Alloy	ASTM A606 Type 4
Stainless Steel	ASTM A778
	ASTM A312
	ASTM A409
Thermoplastic Polyvinyl Chloride	ASTM F480
Fiberglass	No Applicable Standard
Concrete Tile	No Applicable Standard

2.2. Casing Properties

Well casing materials shall have the proper characteristics to ensure integrity of the well during construction and through its anticipated life. When calculating strength requirements, an added safety margin shall be considered for dynamic forces encountered during installation.

2.2.1. Casing Diameter

The inside diameter of the casing shall allow for the maximum flow capacity and minimal head loss during expected well life, and the size and type of installed pumping equipment as shown in Table 2.

Table 2. Recommended Well Diameters for Various Pumping Rates

Anticipated Well Yield		Nominal Size of Pump Bowls		Optimum Size of Well Casing†		Minimal Size of Well Casing†	
m^3/day	GPM	mm	in	mm	in	mm	in
< 545	< 100	102	4	152 ID	6 ID	127 ID	5 ID
409 to 954	75 to 175	127	5	203 ID	8 ID	152 ID	6 ID

Anticipated Well Yield		Nominal Size of Pump Bowls		Optimum Size of Well Casing†		Minimal Size of Well Casing†	
m³/day	GPM	mm	in	mm	in	mm	in
818 to 1,910	150 to 350	152	6	254 ID	10 ID	203 ID	8 ID
1,640 to 3,820	300 to 700	203	8	305 ID	12 ID	254 ID	10 ID
2,730 to 5,450	500 to 1,000	254	10	356 OD	14 OD	305 ID	12 ID
4,360 to 9,810	800 to 1,800	305	12	406 OD	16 OD	356 OD	14 OD
6,540 to 16,400	1,200 to 3,000	356	14	508 OD	20 OD	406 OD	16 OD
10,900 to 20,700	2,000 to 3,800	406	16	610 OD	24 OD	508 OD	20 OD
16,400 to 32,700	3,000 to 6,000	508	20	762 OD	30 OD	610 OD	24 OD
* For specific pump information, the well-designer should contact a pump supplier, and provide the anticipated yield, the head conditions, and the required pump efficiency.							
† The size of the well casing is based on the greater outside diameter (OD) of the pump bowls or, for submersible pumps, the motor. Although done, it is not good practice to place the pump bowls (or submersible) in the screen area, particularly in high-capacity wells.							

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2.2.2. Resistance to Collapse

Industry standard formulas, such as the Timoshenko formula for steel[1] or the F480 formula for PVC, shall be used to calculate casing collapse strength, appropriate to the casing material. Minimum collapse stregth should consider:

- dynamic forces during grouting and installation of filter pack materials;
- external and internal differential fluid pressures;
- temperature due to heat of hydration of neat cement grout, if used (PVC casing); and
- formation pressures at the depth to which the casing will be set.

2.2.3. Tensile Strength

The casing shall have:

- strength to withstand weight of casing and screen; and
- strength to withstand tensional and compressional forces due to filter pack installation.

2.2.4. Resistance to Corrosion

Well casing materials shall be selected to support structural integrity and minimize degradation throughout the intended life of the well.

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[1] Timoshenko formula for steel:

$$P_e^2 - P_e \{2S/[(D_0/t)-1] + P_{cr}(1+3e[(D_0/t)-1]\} + \{2SP_{cr}/[(D_0/t)-1]\}=0$$

Where $P_{cr} = (2E/1-u^2)\{1/[(D_0/t)-1]\}^3$

Where P_e = Collapse pressure with ellipticity (psi)
E = Young's Modulus for Steel (3×10^7)
u = Poisson's Ratio (0.3)
D_o = Outside diameter of casing (inches)
t = Wall thickness (inches)
S = Yield strength (mild steel = 35,000 psi)
e = ellipticity, frequently assumed as 0.01

2.3. Methods of Casing Installation

2.3.1. Centralizer Placement and Use within an Annulus

Centralizer(s) shall be placed at a maximum of forty (40) foot (12.192 m) intervals. When the casing length is less than forty (40) feet (12.192 m), a centralizer shall be placed at the top (below grade) of the casing and at the bottom of the casing. Professional judgment shall be used in all cases for the placement and spacing of centralizers. Casing shall be grouted in accordance with parameters described in Section 4, Grouting. When grouting casing, the casing shall be mechanically centered in the borehole throughout the entire length of the casing.

2.3.2. Steel Casing

Steel casing can be lowered, jacked, driven, or rotated into place. The placement method shall not compromise the alignment or roundness of the casing.

2.3.2.1. Lowering

The lowering method is used to install a casing string in a predrilled hole. The casing string shall be suspended in tension and supported at all times during installation.

2.3.2.2. Jacking and Driving

Steel casing material shall be selected to withstand the forces applied during installation. A casing drive head shall be installed over the top of the casing to prevent damage to the casing while driving. A commercially available drive shoe shall be welded or threaded on the lower end of the casing string. The shoe shall have a cutting edge of metal forged, cast, or fabricated for this purpose.

2.3.2.3. Rotating

The steel casing shall be able to withstand the physical turning of the casing by mechanical means used in conjunction with other installation methods.

2.3.3. Thermoplastic, Concrete Tile, and Fiberglass Casing

Thermoplastic, concrete tile, and fiberglass casing shall not be jacked, driven, spudded or forced into place. The placement method shall not compromise the alignment or roundness of the casing.

2.3.3.1. Lowering

The lowering method is used to install a casing string in a predrilled hole. The thermoplastic or fiberglass casing string shall be suspended in tension and/or supported at all times during installation.

2.4. Methods of Joining

All joints shall be compatible with casing material, specific to the task, and be watertight above the screened interval under normal operating conditions. The joining of casing sections and casing to screens shall be made by direct joint connection or friction seal.

2.4.1. Steel Casing

Steel casing sections shall be joined by:

- welding;

- threaded and coupled;
- flush-threaded; or
- spline-locking.

2.4.1.1. Welded Connection

Casing may be joined by welding (with or without weld collars). Each weld joint shall be continuous, of proper thickness to provide adequate strength, and corrosion resistance over the life of the well. Welding materials shall be compatible with the casing materials being joined.

Weld collars shall have the same chemical and physical properties as the corresponding casing section. The height and other dimensions of the collar shall be in accordance with the manufacturer's recommendations. The collars shall be rolled to fit the outside diameter and factory welded to one end of each section. Three inspection holes shall be provided in each collar to assure proper matching of the casing sections.

2.4.2. Thermoplastic Casing

Thermoplastic casing sections shall be joined in a manner that does not damage the surface of the casing. Casing sections shall be joined by the use of:

- solvent welding in accordance with ASTM F480;
- spline-locking;
- flush-threaded; and/or
- threaded and coupled.

2.4.3. Fiberglass Casing

Fiberglass shall be joined following the manufacturer's directions.

2.4.4. Concrete Tile and Other Materials

Casing made of concrete tile and other materials shall be joined in accordance with the manufacturer's instructions.

2.5. Casing Termination Point

The surrounding aquifer material must be stabilized before and during grout placement. Temporary casing or adequate fluid pressure is necessary to prevent borehole collapse and loss of necessary space for sealing the annulus. Regardless of size, weight, or length of the well casing, it is important in all conditions that proper seals are achieved at design termination depths.

2.5.1. Consolidated Formations

In consolidated formations, the bottom of the casing shall extend a sufficient distance into competent, unfractured rock, to create an adequate bottom seal. Where an annular space exists, it shall be grouted as described in Section 4, Grouting.

2.5.2. Unconsolidated Formations

In unconsolidated formations, the bottom of the casing shall extend a sufficient distance into the formation to create an adequate bottom seal at the desired depth. Where an annular space exists, it shall be grouted as described in Section 4, Grouting. When casing is driven, a drive shoe shall be used at the bottom of the casing, and shall be driven into the desired formation. The casing can be pulled back to expose a screen.

2.6. Wellhead Completion

Casing shall be completed with steel or another metal material from the frost line upward.

Thermoplastic material shall not be permanently installed where it will be exposed to ultra-violet light or freezing conditions.

The casing shall extend not less than one (1) foot (30.48 cm) above the final ground surface elevation or the one-hundred (100) year floodplain elevation, whichever is higher. The top of the casing shall be vented and secured with a sanitary well cap to prevent tampering, entry of surface water, precipitation, animals, or foreign objects.

When used, pitless units and pitless adapters shall be attached to the casing by threading, welding, or compression connection in a manner that will make the connection watertight.

Pitless equipment shall be certified as watertight and listed as meeting the requirements of PAS-97. If an access port is installed, it must be watertight.

3. Well Screens, Filter Pack, and Formation Stabilizer

3.1. Screen

A screen is a factory-manufactured interval of a well that allows water to pass from the aquifer into the well through designed slots or perforations. The well screen also provides structural support to stabilize the borehole. Numerous types of screens are available, and selection of the appropriate screen type depends on the specific hydrogeologic conditions and the specific application for which the well is to be used. Well screen types include wire-wrap screen, louvered screen, bridge slot screen, or factory slotted screens. The end fittings of the screen shall be made of the same material as the screen body to reduce galvanic corrosion.

3.2. Types of Designs

3.2.1. Single String

A completion where the casing and screen, single or multiple, are continuously joined by accepted mechanical joining methods.

3.2.2. Telescoping

A completion where an upper casing is a larger diameter than the screen and the screen is installed through and extends below the upper casing.

3.3. Production Velocities

3.3.1. Radial and Axial

Wells shall be designed to maintain laminar flow into the production interval.

3.4. Screen Parameters

3.4.1. Length and Positioning

Screen length shall be selected by the following criteria to obtain the maximum yield and efficiency from the well:

- in a confined aquifer, where material is homogenous, the screen shall be constructed across at least eighty (80) percent of the aquifer and the uppermost screen shall be located below the pumping water level to prevent cascading water;
- in an unconfined aquifer, the uppermost screen shall be located below the pumping water level to prevent cascading water, and the bottom thirty-three (33) to fifty (50) percent of the aquifer shall be screened; and
- professional judgment shall be used in determining the length of screens in all aquifers. Current and future aquifer conditions and design capacity should be taken into consideration in deciding screen length.

3.4.2. Openings

In addition to the design requirements of Section 3.4.5, Slot Size Selection, consideration shall be given to make the openings as wide as possible, with even spacing, and with the largest percentage open area possible to facilitate development, reduce biofouling, maximize production of water, and maintain the entrance velocity at a rate which provides laminar flow.

3.4.3. Diameter

The diameter shall be such that the axial velocity does not exceed five (5) ft/sec (1.5 m/sec), considering all related factors. If any components are placed inside the screen, the axial velocities around those components shall not exceed five (5) ft/sec (1.5 m/sec). If the pump is to be placed within the screened portion of the well, the diameter must accommodate the pumping equipment as presented in Table 3.

Table 3. Recommended Well Diameters for Various Pumping Rates (For reference only; identical to Table 2)

Anticipated Well Yield		Nominal Size of Pump Bowls		Optimum Size of Well Casing†		Minimal Size of Well Casing†	
m³/day	GPM	mm	in	mm	in	mm	in
< 545	< 100	102	4	152 ID	6 ID	127 ID	5 ID
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* For specific pump information, the well-designer should contact a pump supplier, and provide the anticipated yield, the head conditions, and the required pump efficiency.							
† The size of the well casing is based on the greater outside diameter (OD) of the pump bowls or, for submersible pumps, the motor. Although done, it is not good practice to place the pump bowls (or submersible) in the screen area, particularly in high-capacity wells.							

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3.4.4. Materials

The screen materials shall be selected and designed to have sufficient tensile, collapse, and column (compression) strength to withstand the maximum forces during installation, completion, development, and operation. The selection of the materials must have corrosion resistance appropriate for the water quality, longevity, and the intended use.

3.4.5. Slot Size Selection

3.4.5.1. Naturally Developed Well

Slot size for a naturally developed well shall be designed to retain at least forty (40) percent of the native formation material, based on a sieve analysis of representative samples of the water bearing formations in the production interval.

In uniform sediments (uniformity coefficient less than 2.5) the percentage of formation retained shall be at least fifty (50) percent.

In layered aquifers of varying sand and gravel size, if different slot sizes are utilized in zones where a finer sand overlies a coarser sand, the finer slot screen must extend a minimum of 2 feet (0.61 m) into the underlying coarse sand. The larger slot size must be less than twice the finer slot size.

In all cases, professional judgment shall be utilized to properly select the screen slot openings in concert with the screen location(s) in the well. Such judgment may deem it necessary to deviate from the above limits in order to minimize risk of sand production, to maximize yield, and/or to enhance longevity.

3.4.5.2. Filter Pack Completion

A filter pack and screen slot opening shall be selected based on a sieve analysis of representative samples of the water bearing formations in the production interval. The frequency of sampling shall adequately represent the vertical interval to be screened. Typical sampling intervals are every five (5) to ten (10) feet or at each formation change. A uniform filter pack either derived from natural gravel or glass beads shall be clean, well-rounded, and shall have less than two (2) percent acid soluble impurities. The filter pack shall be placed by a method that prevents bridging and creates a uniform envelope and prevents the pumping of fines.

3.4.5.2.1. Filter Pack Sizing

Filter pack shall be sized by multiplying the seventy (70) percent retained size of the sediment by a factor of between three (3) and eight (8). Use a three (3) to six (6) multiplier if the formation is uniform and the forty (40) percent retained size is 0.010 inch (0.25 mm) or smaller or the filter pack material has a uniformity coefficient less than 1.5. Use a six (6) to eight (8) multiplier when using a filter pack with a uniformity coefficient greater than 1.5 for semi-consolidated or unconsolidated aquifers when formation sediment is highly non-uniform and includes silt or thin clay stringers to aid in complete development. Select a filter pack that has a seventy (70) percent size approximating the selected multiplier times the seventy (70) percent size of the formation with the smallest seventy (70) percent size. The pack shall have a uniformity coefficient less than 2.5.

3.4.5.2.2. Screen Slot Sizing

Select a screen slot size that will retain ninety (90) percent or more of the filter pack material if the uniformity coefficient is between 2.5 and 1.5 and ninety five to one hundred percent (95 to 100) if the uniformity coefficient is less than 1.5, based on a sieve analysis of the pack material.

3.4.5.2.3. Filter Pack Interval

The pack shall extend above the uppermost screen to compensate for any settling occurring during development at the time of construction and future redevelopment. The pack height above the screen shall be determined by professional judgment.

3.4.5.2.4. Special Design for Filter Pack Installation in a Telescoping Well

A reserve of pack shall be placed above the top of the screen. In addition, a mechanical seal between the screen and the casing shall be considered and included in the design parameters. If such a seal is utilized on telescoping well wherein filter pack is utilized, then the seal shall be designed to be readily removable in order to measure and add additional filter pack material over the life of the well.

3.4.5.2.5. Formation Stabilizer

3.4.5.2.5.1. Consolidated Formations

A formation stabilizer is not to be confused with the term filter pack. A formation stabilizer gravel may be emplaced to stabilize the borehole in poorly consolidated rock which tends to disintegrate and sluff during pumping. Formation stabilizer gravel is designed to allow for passage of fines into the well during development and pumping. Screen slot size where formation stabilizer is used shall be designed to retain at least ninety (90) percent of the formation stabilizer material, based on sieve analysis of that material.

3.4.5.2.5.2. Unconsolidated Formations

A formation stabilizer shall be placed around the screen in oversized borehole conditions. The screen slot size shall retain thirty (30) to fifty (50) percent of the formation stabilizer. The formation stabilizer shall be at least as coarse as the formation native material.

3.4.5.2.6. Casing and Screen Diameter to Borehole Size

The annular thickness for the filter pack or formation stabilizer shall be minimized. Centralizers shall be uniformly spaced vertically to maintain the screen in the center of the borehole. The casing and screen centralizers will also facilitate uniform placement of the filter pack three-hundred and sixty (360) degrees around the screen. The annulus shall be large enough to accommodate a tremie pipe or sounding tube as needed. In all cases, professional judgment shall be utilized to select the proper annular thickness based on site conditions and local regulatory requirements, but typically 2- to 3-in (52- to 75-mm) is required for placement of filter pack.

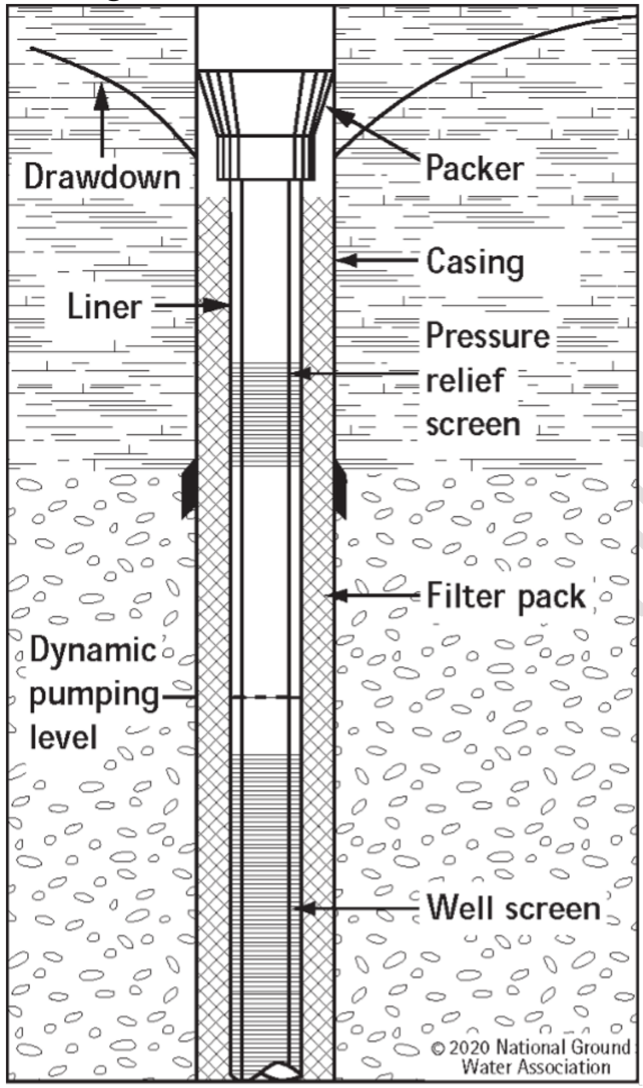
3.4.5.2.7. Centralizer Placement and Use for Screens

When a filter pack is used and the screen is placed in the borehole it shall be mechanically centered in the borehole throughout the entire section of the screened interval. Centralizers should be placed a maximum of forty (40) foot (12.2 m) intervals. When the screen length is less than forty (40) feet (12.2 m) a centralizer shall be placed at the top and bottom of the screen.

3.4.6. Pressure Relief Screen

A pressure relief screen or tell-tale screen can be used in telescoping screen applications to relieve the differential pressure between the liner and outer casing. The pressure relief screen shall be placed between the top of the production screen and below the top of the riser pipe or packer to relieve differential pressure during pumping. Differential pressure has a tendency to expel the filter pack material and packer. The pressure relief screen shall have a minimum three (3) foot (91.4 cm) overlap of the screen inside the casing.

Figure 1: Pressure Relief Screen



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3.5. Joining Methods

Connections of screen to casing shall be by continuously joined as described in 2.4 Methods of Joining. Direct connections between dissimilar metals shall be addressed in the design phase. In telescoping wells, a packer assembly shall be considered as applicable to the design and usage of the well.

3.6. Bottom Completions

The bottom of a screen shall be closed to reduce the possibility of filter pack, formation stabilizer, or native formation from entering the well. A closed bottom may not be required for screens installed in rock formations. The closed bottom materials shall be designed to resist deterioration and dislodgment during well construction, development, pumping, and future maintenance. Types of bottom completions include but are not limited to the following.

3.6.1. Bottom Plate or Cap

The bottom shall be sealed with a plate, cap, or point made of the same material joined as described in 2.4 Methods of Joining.

3.6.2. Self-Closing Valve (e.g., Washdown/Float Shoe)

The bottom of the deepest screen shall be sealed by means of a self-closing valve on the bottom of the screen.

3.6.3. Cement Plug

A cement plug shall be either prefabricated and placed as a component of the casing, or after the well is completed using a tremie pipe, dump bailer, or bag cement method.

3.6.4. Sump Assembly

A sump assembly shall serve to contain sediment that enters the well during casing installation or well development and use. The sump assembly shall be minimized in length to reduce biofouling.

4. Casing Grouting

4.1. Well Grouting

Well casings are typically grouted to both stabilize the casing in the borehole and to restrict borehole migration between aquifer units penetrated by the borehole. Well grouting consists of completely filling the annular space between a casing and the formation, or outer casing, with a low permeability (not to exceed 1×10^{-7} cm/sec) grout from the bottom of the annular space to the top of the annular space. Grouting procedures apply to the decommissioning of an abandoned well, test hole, or borehole. For decommissioning and grout placement in an open borehole see Section 11, Permanent Well and Test-Hole Decommissioning.

The annular space is defined as the offset between a cylindrical object centered in a cylinder, such as the space between the drill pipe or casing and the borehole wall. For example, a borehole with a 12.75-inch diameter and a 6.625-inch outer diameter casing will have a 3.0625-inch annular space.

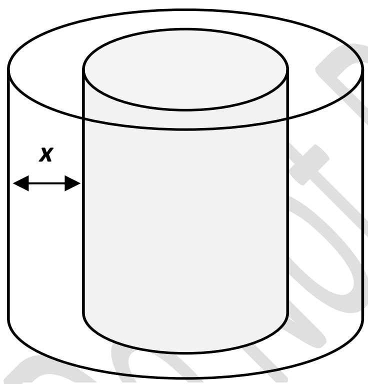


Figure 2 Annular space (x)

4.2. Centralizer Placement and Use

When the casing is installed in the borehole, it shall be mechanically centered in the borehole throughout the entire length of the casing. Centralizers shall be placed at a maximum of forty (40) foot (12.192 m) intervals. When the casing length is less than forty (40) feet (12.192 m), a centralizer shall be placed at the top of the casing (below grade) and at the bottom of the casing. A centralizer shall consist of at least three fenders evenly spaced about the circumference of the casing.

4.3. Placement of Grout

Whenever a casing is grouted in place, the casing shall be in a state of tension while grouting is taking place in order to ensure a grout seal can surround the casing. If the casing is in a state of compression, the grout may channelize and lead to an incomplete grout seal.

4.3.1. Placement of Grout from Outside the Casing

4.3.1.1. Grouting with a Tremie Pipe

When grouting the annular space using a tremie pipe, the annular space shall accommodate the diameter size of tremie required to emplace the grout from the bottom to the top of the annular space. The borehole required to create the annular space shall be a minimum of three (3) inches (7.62 cm) in diameter greater than the outer diameter of the casing or coupling. See Figure 2 for an illustration of annular space. The bottom of the tremie pipe shall be continuously submerged in grout during placement of the grout.

4.3.1.2. Placing Bentonite Chips or Pellets

Placement of bentonite chips or pellets shall be by manufacturer's specification. Adequate annular spacing and centralizers are critical in the proper placement of chip or pellet bentonite. The centralizer design shall ensure adequate space for the placement of a continuous envelope of bentonite chips or pellets.

When utilizing chip or pellet bentonite as a grouting material, the borehole required to create the annular space shall be a minimum of four (4) inches (10.16 cm) in diameter greater than the outer diameter of the casing or coupling. See Figure 2 for an illustration of annular space.

Bentonite chips shall be placed at the surface of the annulus and allowed to free-fall to depth while measuring frequently to confirm a continuous envelope, or shall be placed through a tremie pipe. The tremie pipe shall be rigid and a minimum of four (4) times the diameter of the pellet or chip to be placed.

4.3.1.3. Placement of Grout with Driven Casings

A funnel-shaped depression shall be excavated around the casing to create a reservoir of granular bentonite (eight (8) to thirty (30) mesh) around the casing. The bentonite shall be poured dry around the casing and replenished as the bentonite is lost to the casing annulus.

4.3.2. Placement of Grout from Inside the Casing

When the grout is pumped from inside the casing, the annular space shall be a minimum of three (3) inches (7.62 cm) greater in diameter than the outer diameter of the casing or coupling.

Care shall be taken to maintain the grout level inside the casing following tremie or grout line flushing.

4.4. Grouts

4.4.1. Cement Grouts

4.4.1.1. Mixing Water Quality

Grout to be used for drinking water supply wells shall be mixed with water generally meeting drinking water standards and be free of foreign objects.

4.4.1.2. Neat Cement Grout

Slurry of cement and water, with no aggregate. A mixture of portland cement (ASTM C-150) and water in the proportion of five (5) to six (6) gallons (18.93 to 22.71 L) of water per bag (ninety-four (94) pounds (42.64 kg) or one (1) cubic foot (28.32 L)) of cement.

4.4.1.3. Sand-Cement Grout

A mixture of one (1) ninety-four (94) pound (42.64 kg) sack of Portland cement, and equal amount by volume of clean masonry sand, and not more than six (6) gallons (22.71 L) of clean water.

4.4.1.4. Bentonite-Cement Grout

A cement grout with unbeneficiated (not high yield) bentonite added to a maximum content of five (5) percent by dry weight. An additional 0.65 gallons (2.46 L) of water per bag of cement (ninety-four (94) pounds (42.64 kg)) shall be added, per one (1) percent increase in bentonite.

4.4.2. Bentonite Grout

Bentonite grouts consist of different forms of sodium bentonite clay, mixed with or hydrated by water. Bentonite pellets and granular bentonite are a grout.

4.4.2.1. Mixing Water Quality

Water shall have a maximum 100 milligrams per liter total hardness and be free of foreign objects. Water shall have a maximum 1500 milligrams per liter chlorides.

4.4.2.2. High Solids Bentonite Grout

High solids bentonite grout is highly plastic sodium clay, and is defined as twenty (20) percent solids, or greater, by weight.

4.4.2.3. Granular Bentonite Grout

A naturally occurring sodium bentonite clay that is crushed and sized for pouring and easy handling. When hydrated by fresh (less than 1,500 milligrams per liter total dissolved solids) water, it will form a plastic, low permeability mass.

4.4.2.4. Bentonite Chips and Pellets

Chip and pellet bentonite shall be uniform size and installed in incremental lifts to avoid bridging, and measured frequently to confirm placement.

5. Plumbness and Alignment

Wells shall be completed to allow proper operation of the pumping equipment intended for the well. The well shall be tested for plumbness and alignment in accordance with procedures set forth herein. The contractor shall provide a plumbness profile of both East-West and North-South and an overview and shall provide a drawing showing the effective diameter of the well (alignment) to show the projected pump diameter at the setting expected will not bind in the well. All casing in this section is nominal size.

5.1. Plumbness Requirements

Plumbness is the measurement of the horizontal deviation of the well centerline from vertical.

5.1.1. Casing Twelve (12) Inches (30.48 cm) or Less

The casing shall be sufficiently plumb that it will not interfere with the installation and operation of the pump. In the event a well having a nominal diameter casing of twelve (12) inches (30.48 cm) or less and will be equipped with a line shaft turbine pump, the plumbness of the well shall be as specified for wells having casing diameters greater than twelve (12) inches (30.48 cm).

5.1.2. Casing Greater Than Twelve (12) Inches (30.48 cm)

The maximum allowable horizontal deviation of the well from vertical shall not exceed ⅔ times the smallest inside diameter of the casing per one hundred (100) feet (30.48 m) of that part of the well being tested, to the depth of the expected pump installation.

5.2. Alignment Requirements

Alignment is the horizontal deviation between the actual well centerline and a straight line.

5.2.1. Casing Twelve (12) Inches (30.48 cm) or Less

The casing shall be sufficiently straight that it will not interfere with the installation and operation of the pump. When a well has a nominal diameter casing of twelve (12) inches (30.48 cm) or less and will be equipped with a line shaft turbine pump, the alignment of the well shall be as specified for wells having casing diameters greater than twelve (12) inches (30.48 cm).

5.2.2. Casing Greater Than Twelve (12) Inches (30.48 cm)

Alignment shall be such that a dummy shall pass freely through the casing to the depth of the expected pump installation. As such, there should be no appreciable loss or gain of string weight through the tested casing, as recorded by the weight indicator.

Alternatively, a plummet or gyroscopic survey may be utilized to determine plumbness and alignment.

5.3. Methods of Testing

5.3.1. Dummy test

5.3.1.1. Dummy Types

5.3.1.1.1. Casing Twelve (12) Inches (30.48 cm) or Less

A minimum forty (40) foot (12.192 m) rigid apparatus having an outside diameter no smaller than ½ inch (1.27 cm) less than the inside diameter of the well being tested.

5.3.1.1.2. Casing Greater than Twelve (12) Inches

A minimum forty (40) foot (12.192 m) rigid apparatus having an outside diameter no smaller than 1 inch (2.54 cm) less than the inside diameter of the well being tested.

5.3.1.2. Dummy Pipe

A steel pipe meeting the requirements specified in Section 5.2.3, Dummy Types. If the pipe is less than twelve (12) inches (30.48 cm) in diameter, it shall be Schedule forty (40) Iron Pipe Size (IPS). If it is twelve (12) inches (30.48 cm) or larger, it shall be Schedule thirty (30) IPS or a minimum 0.375-inch (9.525 mm) wall thickness.

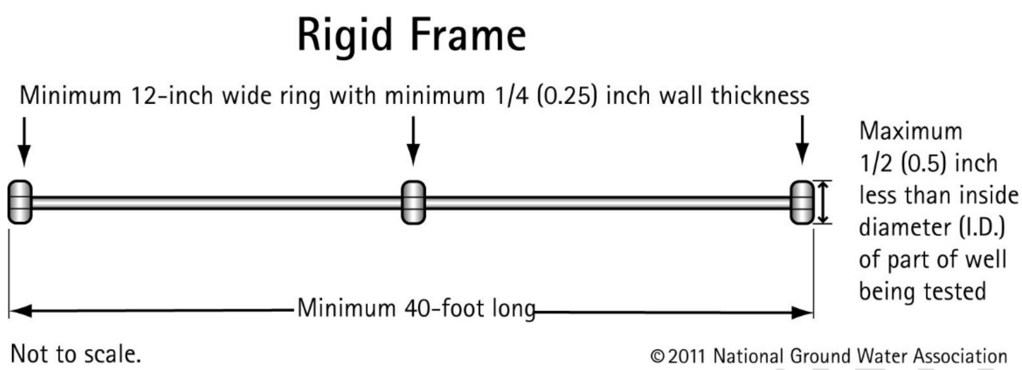
5.3.1.3. Dummy Frame with Rings

A rigid steel frame meeting the requirements specified in Table 4, Dummy Types with a minimum of three rings twelve (12) inches (30.48 cm) wide located at the top, bottom, and center (see Figure 3: Dummy Frame with Rings).

Table 4: Dummy Frame with Rings Minimum Rigidity (IPS)

Nominal Diameter Casing or Open Borehole Completion	Rigid Frame
8 inch, up to 12 inch (20.32 to 30.48 cm)	6 inch (15.24 cm) Schedule 40
Greater than 12 inch (30.48 cm), up to 20 inch (50.8 cm)	8 inch (20.32 cm) Schedule 30
Greater than 20 inch (50.8 cm)	12 inch (30.48 cm) Schedule 30

Figure 3: Dummy Frame with Rings (For 12-inch and smaller casing)



5.3.2. Plummet test

For wells requiring plummet testing, ANSI/AWWA A100 Water Wells, Appendix D. Plumbness and Alignment-Procedure for Testing should be used.

6. Well Development

Well development is the act of repairing damage to the formation caused during drilling procedures and increasing the porosity and hydraulic conductivity of the materials surrounding the intake portion of the well. Well development is a necessary step in the construction of a water well and requirements are directly related to well design and aquifer characteristics. Well development is crucial to optimizing efficiency or specific capacity (gal/ft of drawdown) of the well and increasing well life. Wells that are properly designed and developed should produce less than 5 mg/l sand at the design pumping rate.

Disinfection (Section 9), water sampling and analysis (Section 10) and performance testing (Section 7) shall not be conducted on a well which has not been developed.

6.1. Development Process

The development process is the application of mechanical energy and/or chemicals to disturb the natural formation or filter pack, mobilizing fine formation material and/or residual drilling fluids to make the well hydraulically efficient and prevent pumping of fines. Mechanical methods that can be applied include surging, flushing, pumping, jetting, and bailing. The method of development chosen may be influenced by the type of well.

Development (1) removes drilling fluids and formation damage caused by borehole drilling and well completion processes, (2) removes native formation fines near the wellbore to increase hydraulic conductivity and create a filter medium, (3) establishes optimal hydraulic contact between the well and the geologic formation (aquifer) supplying water, (4) provides for an acceptable level of sand and turbidity, and (5) provides for an appropriate level of drawdown for a given production rate. The following shall be monitored and recorded to evaluate development effectiveness:

- type of development utilized;
- type and volume of chemical(s) used;
- duration of each development method applied;
- dynamic and static water level(s);
- production (pumping) rate and corresponding drawdowns; and
- amount of sand(s) and turbidity.

Additional parameters shall be monitored as necessary, including—but not limited to—pH, electrical conductivity, and temperature.

6.2. Chemical Development

If bentonite or polymers are used in the drilling process, chlorine and dispersants shall be used to break down polymers and disperse clays and silts to aid development. If acidization is to be used to stimulate the aquifer or aid in removing of residual drilling fluids, the acid shall be appropriate for the chemistry of the aquifer and well materials.

6.3. Evaluating Well Development

The well shall be considered developed when the yield, specific capacity, and sand content goals, as determined by pumping test, have been met.

6.3.1. Testing for Productivity

Upon completion of development, and when specifically required in a document referencing this standard, testing for efficiency shall be determined in accordance with Section 7, Testing for Performance.

6.3.2. Testing for Sand

The sand content (or total sediment content) may be determined by the results of samples collected over the course of a final constant-rate pumping test (keeping the rate as constant as possible). The determination of sand concentration during pumping is completed by averaging the results of 5 samples collected during the constant–rate aquifer test at the following times:

1 – 15 min after start of test
2 – After 25% of the total aquifer test
3 – After 50% of the total aquifer test
4 – After 75% of the total aquifer test
5 – Near the end of the aquifer test.

A quantitative method shall be used for measuring sand content accurate to 0.5 parts per million (by volume). Sand testing devices are available for this purpose and may be utilized. Personnel shall be trained and familiar in the use of such equipment to ensure accuracy.

7. Testing for Performance

A well performance test (WPT) is performed when specifically required in a document referencing this standard. A WPT is conducted to collect data to determine peak capacity, long-term capacity, aquifer hydraulic properties, or well efficiency. The WPT shall always be conducted on a fully developed well. All equipment shall be calibrated for accuracy prior to taking test measurements.

7.1. Test Measurements

7.1.1. Pumping Rates

The pumping unit shall be operated without interruption for the testing period. Discharge shall be maintained within plus or minus five (±5) percent of the designated rate.

7.1.2. Water Levels

All measurements shall be made relevant to the same base datum. Water levels shall be measured to the nearest 0.1 foot (approximately 3 cm). Well performance tests should be initiated only after confirmation of static water-level conditions.

7.1.2.1. Determination of Static Water Level

Static water level conditions occur when there is less than one (1) foot (30.48 cm) difference between two (2) consecutive water-level measurements taken a minimum of sixty (60) minutes apart.

7.1.2.2. Frequency of Water-Level Measurements

Water-level measurements shall be taken in the manner specified by the data requirements of the performance test, and at time intervals that reflect the logarithmic nature of a drawdown response. Recovery readings of water level in the well are started immediately upon shutdown of the test pump and taken at specified time intervals thereafter until water levels in the well have recovered to within ninety (90) percent of the static water level.

7.1.3. Linear Measurements to Observation Wells

Horizontal distances from the pumping well to observation wells shall be measured to the nearest 1.0 foot (approximately 30.48 cm).

7.2. Well Performance Test Types

7.2.1. Step-Discharge Test

The step-discharge WPT shall have at least four (4) steps at rates between fifty (50) to one-hundred ten (110) percent of the design capacity. The first step shall be run (duration) until the drawdown stabilizes in a trend that is apparent over a logarithmic time interval. The duration of each subsequent step shall equal the duration of the first step.

7.2.2. Constant-Rate Test

The constant-rate WPT shall be conducted at a constant discharge rate. The constant-rate WPT is run a minimum of twenty-four (24) hours. Recovery water levels should be recorded in the pumping well and all monitoring wells for a period of time equal to the pumping time or until water levels have returned to the static water level.

7.2.2.1. Terminated Tests

Whenever the specified parameters to determine peak and long-term capacity and well efficiency of the performance test cannot be met or pumping rate or minimum water level recording frequency are outside acceptable ranges, the test shall be terminated. The test shall resume after the water levels in the pumping and observation wells have recovered to within ninety (90) percent of the pre-test static water level.

7.2.3. Location of Discharge

Withdrawn water shall be conveyed away from the test and observation wells. If there is a potential for local recharge of the well being tested, the water shall be conveyed beyond the anticipated final limits of drawdown to prevent recirculation of discharged water.

7.3. Record of Performance Tests

For each well used in a WPT, the record shall include physical data describing the construction features including, but not limited to, the following.

- physical/location data:
  - test pump attributes (pump type, pump capacity, column diameter, depth setting, etc.);
  - flow measurement equipment attributes (water meter, orifice, weir, etc.);
  - well depth and diameter;
  - completion interval, screen details (slot size, length, screen and borehole diameter, material, special condition, etc.) or open borehole diameter;
  - water level measurement equipment (type, identification number per well);
  - test and observation well locations (see Section 8, Data Recording);
  - reference point elevation for each well (top of casing, grade, etc.);
  - calibration records for equipment as required;
  - map of wells, distance between test well and all observation wells, and other key locations; and
  - discharge location and method.
- test data:
  - depth to water before start of test;
  - time records (starting point, measurement points, and elapsed time);
  - measurement reference depth in each well;
  - discharge measurement and recording time (pumping rate, total gallons);
  - water level measurement and recording time (Table 5);
  - sand production collected at intervals presented in Section 6.3.2; and
  - field water-quality sample measurements and date and recording time.

Table 2. Frequency of Water Level Measurements

Time After Pump Starts (min)	Frequency of Measurements (min)
0 – 20	2
20 – 60	5
60 – 120	10
120 – end	30

In addition to data listed above, documentation of field activities and special conditions shall be made to assist data interpretation. Appropriate water quality samples shall be collected for laboratory analysis (see Section 10, Water Sampling and Analysis).

7.4. Analysis of Performance Tests

The data from the pumping test should be analyzed by a qualified water well professional to determine the performance characteristics of the well. In addition to the well performance data, the sand production should be evaluated to determine if the well produces less than 5 mg/l sand as described in Section 6.3.2. If the well does not meet performance criteria for efficiency or flow rate and sand production, professional judgment shall be used to evaluate the need for further well development or corrective action to meet the design criteria.

8. Data Recording

Appropriate field records shall be maintained in order to report the as-built condition, as required herein and including those required to be filed by permit conditions or regulations. The field records will be very useful for future maintenance operations. It is beneficial for the well owner to have at least a copy of all field records and daily reports.

8.1. Well Log or Completion Reports

A completion report shall be prepared for each well which will include:

- well identification (e.g., regulatory notification number);
- name of responsible party, property owner/well owner;
- name of drilling company;
- regulatory permit information;
- date well completed;
- purpose of well, e,g., monitoring, domestic, irrigation, public water supply, etc.;
- type of work (e.g., new completion, decommission, rehabilitation);
- well location (see Section 8.1.1, Well Location);
- reference point for all depth measurements (elevation, grade);
- drilling method (mud/air rotary, cable tool, dual rotary, etc.);
- description and depth of each formation or hydrogeologic change;
- nominal borehole diameter(s) and depth(s);
- open hole diameter and interval depths;
- nominal diameter, depth, materials, length of any casing and screen, and screen slot size;
- sieve analysis report, if performed;
- type, size, and location of filter pack (if used);
- type, volume, depth of emplacement, and grout interval;
- static water level (SWL) and date measured;
- pumping water level (PWL) and date measured;
- pumping information; and
- specific capacity (gallons per foot of drawdown).

Many wells may have geophysical data collected during drilling, such as borehole logs. Such data must be included in the records.

8.1.1. Well Location

Well location shall be measured and reported using the accuracy suitable for the most stringent regulatory requirement. The error in measuring well location shall not exceed three (3) feet (1 m). When possible, more than one type of location information data should be used. Additional location information data may include the following:

- Address, City, State
- Township, Range, Section, Quarter
- locally accepted position designations; and

- measured well location indicated, by a drilling contractor, on the deed of the property.

9. Disinfection with Chlorine

Due to the potential of interference with groundwater quality testing programs, chlorination shall be optional for monitoring wells.

9.1. Approved Compounds

Compounds used in the disinfection process shall either meet the requirements of NSF 60 Chemical, or be approved by the U.S. Environmental Protection Agency (USEPA) for use in water well applications.

9.2. Chlorine Concentrations

Chlorine concentration in new well or well-repair disinfection shall be applied in a quantity of water/chlorine solution to equal at least 1.5 well volumes to ensure a minimum of fifty (50) to two-hundred (200) mg/L of available chlorine throughout the well and immediate formation. Adjustments to pH shall be made to the water to maintain a pH of 5.5 to 7.5 in the well during the chlorination treatment. The chlorine solution shall be actively agitated through the well. Contact time shall equal a minimum of one-thousand (1000) contact units.[2] Chlorine solution shall be mixed in such a way to ensure uniformity from bottom to top of the well.

9.3. Above Static-Water-Level Chlorination

All accessible portions of the well above the static water level should be maintained in a wet condition with water containing the required concentration of disinfecting agent for a period of not less than twenty (20) minutes.

9.4. Filter Pack Material Chlorination

Filter pack material being installed in new wells or replenished in existing wells shall be chlorinated upon installation to minimize microorganisms introduced from the surface. A chlorine solution with a concentration of fifty (50) to two-hundred (200) mg/L active chlorine shall be introduced with the filter pack at a rate of three (3) gallons (11.36 L) per cubic foot (28.31 L) of filter material.

9.5. Pre-Treatment of Permanent Equipment

All installed equipment shall be clean and free of soil or other contaminant material. Exposed surfaces shall be treated with a two-hundred (200) mg/L chlorine solution.

9.6. Dechlorination

Where necessary, proper dechlorination techniques must be utilized to protect the environment and public health.

[2] Contact units are calculated by multiplying the concentration of available chlorine by the hours of exposure (e.g., one-hundred (100) mg/L chlorine × ten (10) hours = one-thousand (1000) units).

10.Water Sampling and Analyses

Water sampling shall be performed following construction and development of the well. Appropriate field and laboratory analyses shall be based upon the intended use of the water. When a well is constructed pursuant to a permit issued by a state or local regulatory authority, water sampling and analyses shall conform to the regulations under which the permit is issued; including required tests, laboratory accreditation, and analytical reporting.

10.1. Sample Collection for Analyses

Water samples collected from a well shall be representative of the source water quality intersected by the well. Generally, that will require removal of any disinfectant remaining in the well, and application of a method to ensure that formation water is being collected, such as purging a defined multiple of water column volumes and/or monitoring for stabilization of field parameters prior to sample collection. Care shall be taken to minimize potential for sample contamination.

The method of sample collection shall be selected based on:

- the type of well (e.g, public supply, private potable, private non-potable, observation or monitoring well);
- the analytical tests to be performed (e.g., microbial, inorganic parameters, volatile organic compounds, semi-volatile organic compounds, radiological);
- the determination of whether a "first flush" sample is desired.

Sample bottle volume and material, and sample preservation, shall be in accordance with the test method used (e.g., Standard Methods, EPA).

10.2. Analytical Considerations and Choices

10.2.1. Field Tests

These tests shall be conducted according to procedures prescribed by the manufacturer of the test equipment employed or as set forth in standard publications dealing with this method of analysis. Instruments shall be calibrated, in proper working order (batteries with clean, functional electrodes, etc.), and fresh reagents shall be used. All health-related parameters shall be determined by laboratory analyses before final decisions are made on water potability or treatment requirements. It may be necessary to repeat samplings and analyses at periodic time intervals prior to finalizing decision regarding treatment.

10.2.2. Laboratory Tests

Personnel who collect water quality samples shall ensure the samples are appropriately identified as to sample location, date and time of collection, method of collection, point of collection, other relevant particulars (e.g., water bearing formation, depth) as required, and the name and affiliation of the sample collector and well owner. Water testing shall be performed by laboratories certified in the test method being used.

11. Permanent Well and Test-Hole Decommissioning

The proper decommissioning of abandoned wells or boreholes is critical to protecting aquifer and groundwater resources. Proper decommissioning and sealing eliminates the decommissioned boring as a conduit for loss of hydrologic pressure in confined formations, intermingling of groundwater of differing quality, and entry of contaminated and polluted water. Proper decommissioning shall be performed by licensed/certified water well contractors.

11.1. Decommissioned Borehole or Well

Decommissioned boreholes or wells shall be properly sealed to prevent physical injury, entry into the borehole, and contamination of groundwater from:

- solids, gases, or liquids;
- commingling of water penetrated by the borehole; and
- compression of backfill near the surface.

11.2. Abandoned

A well or borehole that has gone dry, is contaminated, or no longer serves a useful purpose is considered abandoned.

A temporarily abandoned well is intended to be returned to service as a source of water at a later time; for example, a well at an unoccupied dwelling. Temporarily abandoned wells shall be sealed with a water-tight cap or seal and maintained so that the well will not be a source or conduit for contamination to groundwater during temporary abandonment.

11.2.1. Decommissioning a Borehole

An abandoned borehole shall be decommissioned as soon as possible. Any abandoned borehole that presents an immediate threat to public safety or the groundwater resource shall have an action plan initiated by the responsible party within seventy-two (72) hours upon discovery. All boreholes shall be secured and never used for disposal prior to decommissioning.

11.2.2. Decommissioning a Well

An abandoned well shall be decommissioned as soon as possible. Any abandoned well that presents an immediate threat to public safety or the groundwater resource shall have an action plan initiated by the responsible party within seventy-two (72) hours upon discovery. All wells shall be secured and never used for disposal prior to decommissioning.

11.3. Obstruction Removal

All wells and boreholes that are to be decommissioned shall be opened to original depth. If an obstruction is encountered, the obstruction shall be removed before decommissioning.

11.4. Casing/Liner

If the abandoned well or borehole was constructed and installed per Section 2, Casing and Casing Installation and Section 4, Grouting, and is open to its original depth, and is undamaged, the casing/liner may be left in place. When the original well or borehole construction is not known, has been damaged, or has not been installed per Section 2, Casing and Casing Selection and Section 4, Grouting, the casing/liner shall be removed. Where casing/liner removal is not possible, it shall be ripped or perforated to allow the plugging fluid to penetrate the annular space and formation to facilitate proper sealing in accordance with Section 4, Grouting.

11.5. Disinfection

Disinfection shall be performed per Section 9, Disinfection with Chlorine. Disinfection is required for all wells. When bentonite grouting materials are used, chlorine contents shall not exceed fifty (50) parts per million.

11.6. Grout

Any of the grouts described in Section 4, Grouting can be used as a grout.

11.7. Grout Placement

Grout shall be emplaced as per Section 4, Grouting from the original depth to the surface. The well casing shall be cut off below ground level to a depth not to interfere with anticipated land uses.

11.8. Well Decommissioning Records

The well location and abandonment procedures shall be documented. All materials used in decommissioning the well must be documented for method of placement, volume, and description.