15. Abandonment: How to Plug & Seal Wells

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Chapter Description

This chapter covers the step-by-step process involved in abandoning a well as required by the **Wells Regulation**. This chapter outlines the sequential approach and materials used to plug and seal a well.

Regulatory Requirements – Abandonment: How to Plug and Seal Wells

Relevant Sections – The Wells Regulation

Abandonment – Subsection 21(13) and Section 21.1 (How to abandon a well)

The Requirements – Plainly Stated

The Wells Regulation requires the following:

The person abandoning the well is considered:

The person constructing a well that has been discontinued prior to the completion of the well's structural stage and must be immediately abandoned.

The well purchaser for a dry well that must be immediately abandoned.

The well owner of a well that must be immediately abandoned because it:

- is not in use or being maintained for future use as a well;
- is producing water that is mineralized or not potable;
- contains natural gas or other gas;
- permits the movement of materials including natural gas and contaminants; or
- is constructed in contravention of the **Wells Regulation** requirements for location, methods, materials or standards and the measures taken to rectify the problem have failed.

The person abandoning the well must:

Hire a licensed well contractor; and

Ensure that the contract between them requires that a well technician licensed to construct the type of well that is being abandoned be used to abandon the well.

The person abandoning the well does not need to hire a licensed well contractor to plug and seal the abandoned well if:

The person who works on the abandonment of the well is the owner of the land or is a member of the owner's household;

The person who works on the abandonment of the well is working without remuneration (i.e. no fees or other forms of compensation) for another person on land owned by the other person or by a member of the other person's household.

The person who works on the abandonment of the well holds a valid class 1 (drilling) well technician licence.

How to Abandon a Well:

The person abandoning the well must ensure the following nine (9) steps are taken in this sequence, unless otherwise specified:

1. If the well has a well tag, it must be removed and returned to the Director within 30 days of its removal.
2. If the well casing or well screen has collapsed, reasonable efforts must be made to remove the well screen or well casing. All other equipment and debris in the well must be removed.
3. The well, including any annular space (i.e. any open space beside the casing or between casings), must be plugged in the following manner:

For Any Well:

Abandonment barrier material must be placed continuously from the bottom of the well upward to approximately 2 metres (6.6′) below the ground surface. This does not prevent the placement of clean, washed sand or gravel adjacent to water producing zones or bedrock fractures.

The abandonment barrier must be placed in a manner that prevents any movement of water, natural gas, contaminants or other material between subsurface formations (which include aquifers) or between a subsurface formation and the top of the abandonment barrier material.

An Alternative Method For Wells with a Diameter >65.0 centimetres (2.1 feet):

A continuous column of abandonment barrier must be placed up to approximately 2 metres (6.6′) below the ground surface as follows:

- Clean sand or pea gravel must be placed from the bottom of the well to the top of the deepest water producing zone or the top of the well screen, whichever is deeper
- At least 0.1 m (4″) of bentonite chips or pellets must be placed over the sand or pea gravel
- If the water level is below or can be drawn down to the top of the bentonite chips or pellets:
  - i. it must be drawn down to the top of the bentonite chips or pellets
  - ii. at least 0.3 metres (1′) of a bentonite slurry that consists of clean water and at least 20% bentonite solids and that is compatible with the quality of the water found in the well must be placed over the bentonite chips or pellets, and
  - iii. clean gravel, sand, silt or clay must be dropped over the bentonite slurry to fill the remainder of the well, while maintaining at least 0.3 metres of the bentonite slurry above the rising accumulation of gravel, sand, silt or clay.
    - If the water level cannot be drawn down to the top of the bentonite chips or pellets:
      - i. The remainder of the well must be filled to approximately 2 metres (6.6′) below the ground surface with an abandonment barrier, which may be interspersed (layered) with clean sand or pea gravel placed in each water producing zone of the well.

The sealing materials that are selected and placed must provide the appropriate structural strength to support the weight of persons and vehicles that may move over the area after it is filled.

4. After or during the placement of the abandonment barrier, the well casing or well screen must be removed, if reasonably possible. During the removal of the well screen or well casing, the bottom of the casing must be immersed in the rising accumulation of the abandonment barrier material until the required level has been reached.
5. If all of the casing and well screen cannot be reasonably removed as above, then at least 2 metres (6.6′) of casing below the ground surface must be removed if reasonably possible.
6. If the abandonment barrier contains cement, it must set until firm and, if necessary, it must be topped up to approximately 2 metres (6.6′) below the ground surface.
7. At any time before sealing the well to the ground surface, any below ground concrete structures, foundations, and slabs must be removed unless the removal may cause the remaining structures to become destabilized, damaged or unsafe. The structures have to be removed to a depth adequate to accommodate the sealing measures described below in step 8.
8. To prevent inadvertent or unauthorized access, the well and the well opening (including any excavation) must be sealed up to the ground surface by placing:
   - 50 cm (20″) to 150 cm (59″) of bentonite chips, pellets, granules or powder in accordance with the manufacturer's specifications; and
   - Soil cover, or other material that is more in keeping with the material immediately adjacent to the well opening, over the bentonite and up to the ground surface to prevent inadvertent and unauthorized access.
9. The disturbed area must be stabilized to prevent erosion.

Overdrilling

Requirements for the removal of well casing and well screen in sequence (i.e. steps 2, 4 and 5 previously) do not apply if a person overdrills (reams) the entire well before filling the well with abandonment barrier.

Abandonment Barrier

Abandonment Barrier - General

The abandonment barrier must:

- be compatible with the quality of the water found in the well
- not contain any materials that may impair the integrity of the abandonment barrier, including soil or drill cuttings
- be stable in the presence of any contaminants, if the well is in contact with contaminants

Abandonment Barrier - Wells ≤6.5 cm (2.5") in Diameter

If the well casing and well screen have been removed or are being removed, the abandonment barrier must be a slurry consisting of:

- clean water, Portland cement and not more than 5% bentonite solids by weight, or
- clean water and at least 20% bentonite solids by weight, and the abandonment barrier must be placed using a tremie pipe, with the bottom of the tremie pipe immersed in the rising accumulation of the abandonment barrier until the required level has been reached.

The above also applies, with necessary modifications, to an uncased well that is less than or equal to 6.5 cm (2.5″) in diameter.

If the well casing and well screen have not been removed the abandonment barrier must be:

- a slurry consisting of clean water, Portland cement and not more than 5% bentonite solids by weight, or
- bentonite chips or pellets that have been screened and placed in accordance with the manufacturer's specifications.

Abandonment Barrier - Wells > 6.5 cm (2.5") in Diameter

The abandonment barrier must be:

- A slurry consisting of clean water and at least 20% bentonite solids by weight;
- A slurry consisting of clean water, Portland cement and not more than 5% bentonite;
- A slurry consisting of clean water and Portland cement;
- A slurry consisting of clean water, Portland cement and clean sand;
- A slurry consisting of equal weights of Portland cement and clean gravel, mixed with clean water;
- A slurry (sometimes called a concrete slurry) consisting of clean water, Portland cement, clean sand and clean gravel;
- Bentonite chips or pellets that have been screened and placed in accordance with the manufacturer's specifications; or
- other material approved in writing by the Director, if the Director is of the opinion that the performance of the other material is the equivalent of the performance of a slurry referred to above.

A wet abandonment barrier must be placed using a tremie pipe, with the bottom of the tremie pipe immersed in the rising accumulation of the abandonment barrier until the required level has been reached.

Alternative Abandonment Barrier - Wells > 65 centimetres (2.1 feet) in Diameter:

The alternate abandonment barrier material and method has previously been described in step 3 of How to Abandon a Well in the Plainly Stated on page 8.

Abandonment of Flowing Wells:

If the well is a flowing well, commercially manufactured drilling mud that does not impair the quality of the water with which it comes in contact may be used, in taking the steps required above to assist with drilling or placement of an abandonment barrier, but the drilling mud may not be used as an abandonment barrier.

Excavation of Entire Well:

Except for Step 1 (referring to well tags) the above plugging and sealing requirements do not apply when a person abandons a well by excavation of the entire well in the course of work carried out for another purpose (e.g. construction of a foundation).

Well Pits:

A well pit must be abandoned like a well, with necessary modifications.

Relevant Sections – Additional Regulations or Legislation

Ontario Regulations 164/99 (Electrical Safety Code) as amended made under the *Electricity Act*, 1998. S.O. 1998. Chapter 15, Schedule A

Ontario Regulation 632/05 (Confined Spaces) as amended made under the *Occupational Health and Safety Act*, R.S.O. 1990, Chapter 0.1

Relevant Guidance Documents

Fleming College. 2008. Manual for Continuing Education Course *Safety (for Ontario Well Technicians).*

Key Concepts

The well abandonment process can vary depending on multiple factors including the diameter of a well, the well casing, the environment, and the state of the well.

Initial Considerations

Prior to plugging a well, a person should review background records, including well records and hydrogeological reports, and conduct a site assessment.

Another initial factor to consider is who will be plugging and sealing the well. A well owner needs to assess the well and determine if it is feasible for the owner to plug the well or if a professional is required. Although the **Wells Regulation** and the *Ontario Water Resources Act* allow residential well owners to abandon their own wells without a licence, the equipment, materials and expertise needed to comply with the requirements under the **Wells Regulation** far exceed the average well owner's abilities and resources. For instance, if residential well owners cannot properly calculate and mix chemicals, do not have the necessary equipment, or cannot employ proper safety procedures, licensed professionals must be retained to abandon the well.

Typical Types of Wells Encountered

This chapter discusses well abandonment as it applies to:

- Narrow wells with a diameter less than or equal to 6.5 cm (2.5″), typically diamond drilled or point wells
- Medium wells with a diameter greater than 6.5 cm (2.5″) and less than or equal to 65 cm (2.1′) typically drilled wells
- Large wells with a diameter over 65 cm (2.1′), typically dug or bored wells

Table 15-1: Examples of Typical Types of Narrow, Medium and Large Diameter Wells Encountered

Characteristic	Narrow Diameter Wells	Medium Diameter Wells	Large Diameter Wells
Hole Diameter (includes casing plus filled annular space)	≤6.5 cm (2.5″)	>6.5 cm (2.5″) to ≤65 cm (2.1′)	>65 cm (2.1′)
Depth	Point: ≤9m (30′) Diamond drilled: > 9m (30′)	Drilled: >9m (30′)	Dug: <9m (30′) Bored: >9m (30′) to <30m (100′)
Well Screen	Point: Yes Diamond drilled: No	Overburden: likely Bedrock: No (with some exceptions)	Yes[1]
Casing Material	Steel or plastic	Steel or plastic	Concrete, steel, galvanized steel, fibreglass, plastic, brick, stone, wood
Construction Method	Point: driven and/or possibly jetted Diamond drilled: typically air track rotary	Rotary or cable-tool	Dug: Backhoe, highhoe, other excavating machine or by hand Bored: Boring or augering machine
Annular Seal	Point: No Diamond drilled: Possible depending on age	Yes	Possible depending on age

[1] See definition of Well Screen in Chapter 2: *Definitions and Clarifications*, Table 2-1.

This table does not represent all possible situations due to changing technology, variation in construction techniques and changes in regulatory requirements.

Well pits and narrow diameter wells extending out of the bottom of large diameter wells are discussed further on page 65.

PHOTOGRAPHS OF COMMON WELLS

FIGURE 15-1: TYPICAL DRIVEN POINT WELL SCREEN PLACED IN DRIVEN POINT WELL

FIGURE 15-2: TYPICAL DUG WELL

A typical dug well with circular concrete tiles supporting the sides of the well and the well cover.

FIGURE 15-3: OLDER HAND DUG WELL

Inside view of older hand dug well with hand lain stone supporting the sides of the well.

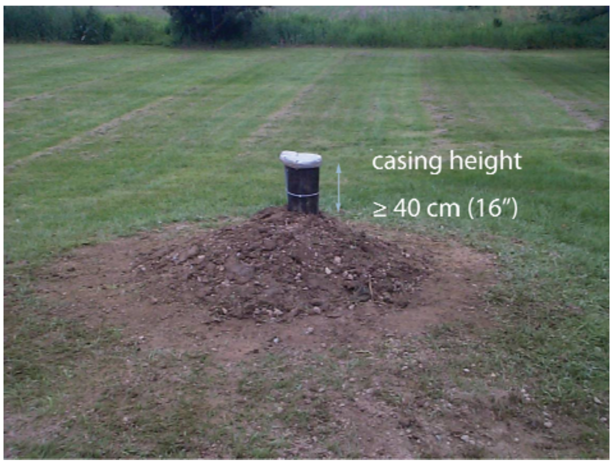


FIGURE 15-4: TYPICAL DRILLED WELL

A typical drilled well with steel casing extending out of the ground with a vermin-proof well cap

FIGURE 15-5: DRILLED WELL IN A WELL PIT

Inside view of an older drilled well housed below ground surface in a large well pit. In this case, contaminated water is entering the pit, moving through top of the well and contaminating the well water and groundwater.

Types of Plugging Materials and Abandonment Barriers

It is necessary to use plugging materials that will ensure proper sealing of the well. The choice of plugging materials is important to:

- Ensure the abandoned well does not act as preferential pathway for water, gas or foreign materials between:
  - Groundwater zones
  - Between groundwater and the land surface
- Provide the best overall strength to the abandoned well to support the weight of persons, animals and vehicles
- Provide sufficient viscosity to minimize leakage of the plugging material out of the well and into the groundwater resource or formation
- Provide the best adhesion of the plugging material to the casing, soil or bedrock to achieve a good seal

Selecting the type of materials will depend on the:

- Location (e.g. hazards, access restrictions)
- Environment (e.g. flowing conditions, presence or absence of contaminants or natural gases, chemistry of the water)
- Type of well
- Diameter and depth of the well
- Condition of the well (e.g. damage to the well structure, collapsed casing equipment/debris caught in the well)
- Requirements of the **Wells Regulation**

There are a variety of materials used to plug a well. Plugging materials are made up of:

- Abandonment barriers (e.g. concrete, cement and sodium bentonite) to prevent the creation of preferential pathways
- Filling materials which include:
  - Clean, washed sand or gravel placed in large voids, fracture areas or adjacent to water producing zones to:
    - Support abandonment barrier
    - Prevent leakage of the abandonment barrier into the groundwater resource or formation, and
    - Restore natural groundwater flow at the well site
  - Clean gravel, sand, silt or clay placed in large diameter wells [>65cm (2.1′)] to reduce the quantity of abandonment barrier required to seal the well and to provide increased strength

Field Notes and Well Records

During the process of well abandonment, field notes must be made and kept up to date.

A well record documenting the abandonment of the well must be completed by the person abandoning the well (often the well owner) and submitted to the owner of the land on which the well is located as well as the Ministry (see Chapter 13: *Well Records, Documentation, Reporting & Tagging*).

How to Abandon a Well

The steps involved in the abandonment of a well are as follows:

Initial Procedures

1) Obtaining and Reviewing Relevant Records and Conducting a Site Assessment
2) Determining Expertise Required
3) Selecting Plugging Materials
4) Estimating Plugging Material Volumes Required
5) Preparing Equipment, Selecting Methods and Obtaining Approvals Needed to Plug the Well

Nine Sequential Step Procedure to Plug and Seal a Well

1) Safeguarding and Returning the Well Tag
2) Removing Equipment, Structures, Debris and Any Collapsed or Broken Well Casing or Well Screen
3) Plugging and Sealing Within 2 Metres of Ground Surface
4) Removing Entire Casing and Well Screen During Sealing
5) Casing Removal
6) When Cement or Concrete are Used (steps only followed if these materials are used)
7) Removing Below Ground Concrete Structures and Slabs
8) Plugging and Sealing the Upper 2 Metres of the Well Opening
9) Stabilizing Disturbed Area

After the Well is Plugged and Sealed

1) Completing and Submitting a Well Record
2) Providing Important Information to the Well Owner
3) Removing the Well Tag and Returning it to the Ministry

Initial Procedures

1) Reviewing Relevant Records and Conducting a Site Assessment

Persons plugging wells can use the well record information along with a site assessment of the well to determine the method and materials needed before plugging and sealing the well.

To obtain relevant information on the abandoned well, a person should consider if there are any historical records of the well.

For example, a contractor may have completed a well record and log for the original construction of the well. A copy of the original well record may be available from the:

- Current or previous land owner
- Original well contractor
- Ministry of the Environment

Well records provide valuable information including the:

- Depth and diameter(s) of the well
- Overburden and bedrock encountered during construction
- Depth where groundwater was found
- Depth to static water level in the well
- General water quality information (e.g. salty, sulphurous)
- Presence of naturally occurring gases (e.g. methane, hydrogen sulphide)
- Construction materials used in the well (e.g. casing, screen)
- General location of the well (e.g. UTM co-ordinates, township or municipality information, map)

In some cases original well records may not be available for the well.

Another example of relevant information is hydrogeological reports that may include assessments of the well. These reports may be found at the local:

- Ministry of the Environment office
- Municipality
- Conservation authority

Best Management Practice – Assessing the Well

Prior to plugging and sealing the well, it is important to conduct an assessment of the well depth, the water level, the pumping equipment, the structure of the well and the geological formations around the well. The use of video technology by trained professionals should be included in deep wells to visually confirm the wells' characteristics and current conditions (see Figures 15-6 to 15-9).

There are many serious dangers that must be considered when assessing and working on abandoned wells. Some dangers include the following:

- When inspecting a well, make sure that the power supply to the pump has been shut off to minimize the risk of shock or electrocution.
- Many older wells especially dug wells have structural integrity problems and could collapse. As such, it is important to wear appropriate safety gear and to guard against falling into the well. Falling into the well could result in serious injury or death by drowning.
- An abandoned well could contain contamination or explosive or poisonous gases that could affect a person's health and safety. As such, it is important to use proper field detection equipment and personal protective gear.

It is important for anyone not enter any confined space (e.g. non-ventilated areas including well pits, pump house, and others defined in the Confined Space Regulation (Regulation 632/05 as amended[1] made under the *Occupational Health and Safety Act*) unless the person is properly trained in confined space entry and is properly equipped. Confined spaces present asphyxiation hazards and some wells produce naturally occurring gases that may be poisonous and/or explosive.

[1] *Occupational Health and Safety Act*, R.S.O. 1990, Chapter 0.1; Ontario Regulation 632/05: Confined Spaces

FIGURE 15-6: VIDEO TECHNOLOGY USED WITHIN A DRILLED WELL

Figure 15-6 is a still shot from a video showing the open hole portion of a drilled well in bedrock that has a large crevasse which could not be observed from land surface. With the video information, the contractor can more accurately calculate the amount of plugging material needed and select the best method and equipment to seal the hole.

FIGURE 15-7: VIDEO CAMERA AND CABLE

In Figure 15-7 the video camera and cable are about to be installed in an abandoned drilled well.

FIGURE 15-8: VIDEO DISPLAYING A WELL'S INTERIOR.

In Figure 15-8 the orange and white (mottled) areas shown on the video display indicate that the well water has a significant organic biofilm problem. Therefore, the well will need to be cleaned out and treated prior to plugging to reduce the chance of microorganisms moving from the well and impairing the groundwater resource.

FIGURE 15-9: ENCRUSTED METAL SCREEN

Figure 15-9 shows another example of a video display of a well's interior. In this example, the stainless steel well screen at the bottom of a well is plugged with a biofilm. The person who works at the abandonment of the well needs to remove the screen to ensure the filling material will properly allow for the return of the natural groundwater flow at the well site and the biofilm will not react with the filling materials or abandonment barrier.

Best Management Practice – Conducting On-site or Laboratory Testing and Analysis of Well Water

It is important to conduct on-site or laboratory testing and analysis of the well water to further understand the hydrogeological environment around the well and to determine if the well water may react with the plugging materials or abandonment barriers. A *Professional Engineer* or *Professional Geoscientist* may be needed to interpret the laboratory or field results.

2) DETERMINING EXPERTISE REQUIRED

Another initial factor to consider is who will be abandoning (plugging and sealing) the well. A well owner needs to assess the well and determine if it is feasible for the owner to plug the well or if a professional is required. Regardless of who abandons the well, the requirements of the **Wells Regulation** must always be met.

Although the *Ontario Water Resources Act* and the **Wells Regulation** allow residential well owners to abandon their own wells without a licence, the equipment, materials and expertise needed to comply with the requirements under the **Wells Regulation** far exceed the average well owner's abilities and resources. Well owners need to understand how to measure water levels, well depths and be able to calculate volumes of well water, chemical mixtures and material mixtures. For instance, if residential well owners cannot properly calculate and mix chemicals, do not have the necessary equipment, or cannot employ proper safety procedures, licensed professionals must be retained to abandon the well.

Residential land owners and their families can work on wells on their own property as long as no remuneration or financial exchange occurs. If remuneration takes place, or if the land owner is a business corporation, partnership, sole proprietor or a government agency, the land owner must retain a licenced well contractor to plug and seal the well. For further information, licensing requirements are detailed in Chapter 3: *Well Construction Licences: Obtaining, Maintaining & Exemptions*. Contact numbers for the Ministry are also listed in the Glossary and Resources sections at the end of this manual.

Best Management Practice – Retain Licensed Well Contractor and, if Necessary, Qualified Persons

Due to the need for specialized equipment and technical difficulties which are likely beyond the capabilities of an individual well owner, it is important that wells with one or more complicating factors be plugged by a licensed well contractor who employs licensed well technicians. It may also be advisable that *Professional Geoscientists* or *Professional Engineers* be retained. Complicating factors include:

- Freely flowing artesian wells where groundwater is discharging from the well at or close to land surface
- Flowing, heaving and/or running formations (e.g. sands or gravels) are encountered
- Wells greater than 9 metres (30′) deep
- Wells where surface water runoff, insects or other vermin are entering the well through the well casing
- Wells which produce poisonous or explosive gas, salty or sulphate-rich water
- Wells with well water that may be impacted by on or off-site contaminants (e.g. gasoline, fuel oil, pesticides or agricultural activities)
- Wells where the casing has collapsed or the casing is difficult or not reasonably possible to remove without proper equipment
- Wells where the pumping equipment is difficult to remove
- Wells located in residential, agricultural, commercial or industrial buildings (occupied or vacant)
- Wells located in close proximity to other operating wells
- Wells located in close proximity to surface water
- Improperly Abandoned wells (i.e. plugged with logs or other materials)

There may be additional conditions, other than the above list, that will require licensed professionals to plug and seal a well.

In some cases, driven and shallow dug wells can be plugged by land owners with a minimal amount of special equipment. However, land owners who improperly plug wells may face enforcement actions and additional legal liabilities (e.g. property and environmental damage, personal injury). Re-drilling, re-excavating, and having to plug and seal the well a second time creates a significant increase in costs that could have been avoided if the original plugging and sealing was properly completed.

3) Selecting Plugging Materials

A) Filling Materials

Clean, washed sand or gravel is placed in large voids, bedrock fracture areas or adjacent to water producing zones to:

- Support the abandonment barrier
- Prevent leakage of the abandonment barrier into the groundwater resource or formation, and
- Restore natural groundwater flow at the well site

Clean gravel, sand, silt or clay is placed in large diameter wells (>65cm (2.1′)) to reduce the quantity of abandonment barrier required to seal the well and to provide increased load bearing strength.

Table 15-2: Particle Sizes for Fill Materials

Material	Particle Diameter	Characteristics
Clay	Smaller than 0.002 mm (1/10000 of an inch)	• Particle too small to be seen with the naked eye • Forms putty when wet • Feels smooth between fingers • Cohesive • Low permeability
Silt	Between .002 mm and .08 mm in size (approx 1/10000 of an inch)	• Particle too small to be seen with the naked eye • Can form putty when wet • Generally feels smooth between fingers • Less cohesive than clay • Low permeability
Sand	Smaller than 6 mm (¼″) but large enough to be visible to the naked eye	• Particle can generally be seen with the naked eye • Feels gritty between fingers • Commonly associated with beaches • Medium to high permeability
Gravel	Smaller than 75 mm (3″) but larger than 6 mm (¼″)	• If about the size of a pea, referred to as “pea gravel” • High permeability

These filling materials are mined at local pits and quarries and either sold at the pit or quarry or at building and material supply stores.

Clean, with respect to gravel, sand, silt or clay, means that it should at least:

- Be washed with clean water to remove finer textured material in the case of gravel or coarse sand
- Not cause an impairment of the well-water]

Best Management Practice – Use Table 1 in Soil, Groundwater and Sediment Standards to Meet Parameter Concentrations in Filling Materials

To ensure gravel, sand, silt or clay placed in an abandoned well is clean, the person who works at the abandonment of the well should consider having all gravel, sand, silt or clay meet the parameter concentrations of Table 1 in *Soil, Groundwater and Sediment Standards for Use under Part XV.1 of the Environmental Protection Act* July 27, 2009. The Table is located at the following website: http://www.ene.gov.on.ca/envision/env_reg/er/documents/2009/010-4642%20Standards.pdf

It is up to the person abandoning the well to ensure that the filling materials are clean prior to their installation into the well.

B) Abandonment Barriers

The abandonment barrier must be a slurry consisting of:

- Clean water and at least 20% bentonite solids by weight;
- Clean water, Portland cement and not more than 5% bentonite;
- Clean water and Portland cement;
- Clean water, Portland cement and clean sand;
- Equal weights of Portland cement and clean gravel, mixed with clean water; or
- Clean water, Portland cement, clean sand and clean gravel (sometimes called a concrete slurry).

The abandonment barrier can also be either:

- Bentonite chips or pellets that have been screened and placed in accordance with the manufacturer's specifications, or
- Other material approved in writing by the Director, if the Director is of the opinion that the performance of the other material is the equivalent of the performance of a slurry referred to above.

Cement

Neat cement is a mixture of one 43 kilogram (94 pound) bag of Portland cement (Type I or IA) to not more than 19.7 litres (4.3 Imperial gallons) of clean water. The person adding the water needs to ensure all lumps of solids are removed in the mixture for proper setting. Adding more than 19.7 litres (4.3 Imperial gallons) of water per bag will create a thinner mixture. Thinner mixtures will have reduced strength and may cause shrinkage and open crack issues. Portland cement is readily available at building supply stores. Other grades of Portland cement used in the industry are American Petroleum Institute (API) cements classified as B, C, G, H, K, M and S which may be used depending on the sulphate concentrations, shrinkage compensation or when there is a need for retarders/retardants or accelerators with the cement. Further information on cement can be found at the following website titled Cement and Concrete Basics - http://www.cement.org/basics/concretebasics_history.asp

Concrete

Concrete grout is a mixture of neat cement (see above) with 0.03 cubic metres (1 cubic foot) of sand and/or gravel added per bag of cement. Concrete is readily available or can be made on-site by mixing one 43 kilogram (94 pound) bag of Portland cement, sand or gravel and not more than 19.7 litres (4.3 Imperial gallons) of water.

See the section titled: "Mixing Cement or Concrete Grout (Sealant)," in Chapter 6: *Annular Space & Sealing*, for further information on mixing cement and concrete with water.

Bentonite

Sodium bentonite is a manufactured product that is made from volcanic deposits of sodium montmorillonite clays. The product comes in a powder form for mixing with water. The product also comes in chip, pellet and granular forms that may be added directly into the well water or that may be hydrated prior to adding to the well. When water is properly mixed with the sodium bentonite, the mixture should look like oatmeal. When it hydrates a peanut butter looking material will form. A proper mixture of 20% solids by weight should be a mixture of 91 litres (20 Imperial gallons) of clean water to 23 kilograms (50 pounds) of dry sodium bentonite powder. The mixture will generate a material volume of about 100 litres (or 22 Imperial gallons).

See the section titled: "Mixing Cement or Concrete Grout (Sealant)," in Chapter 6: *Annular Space & Sealing*, for further information on mixing cement and concrete with water.

Sodium Bentonite with Cement

In some cases 3 to 5 percent of bentonite is used as an additive to cement or concrete to improve the workability, slurry weight and density of the cement slurry. However, bentonite is chemically incompatible with cement causing bentonite's swelling ability to reduce. The bentonite additive also reduces the set strength of the seal and lengthens set time.

Table 15-3 (below) provides some general information on advantages and disadvantages of cement and bentonite based abandonment barriers.

Table 15-3: Some General Abandonment Barrier Advantages and Disadvantages

	Advantages	Disadvantages
Bentonite Based **Abandonme nt Barriers**	• Suitable low permeability with high solids by weight grouts • Generally non–shrinking and self–healing • No heat generated during hydration • Low density • Sodium bentonite products expand to about 12 to 15 times their original dry volume allowing for less material to be required • No long curing time required before proceeding with further well drilling. To achieve full gel strength bentonite takes 8 to 48 hours. • Properties such as density can be altered with additives	• For some grout mixtures with significantly high bentonite solids content (>35%), rapid swelling rate and high viscosity result in difficult pumping through grout pumps and tremie pipes • Mineralized groundwater (eg. >5,000 mg/L of total dissolved solids or >8,000 mg/L chlorides) may inhibit its hydration process and its effectiveness as a sealant. This includes source water used in mixing bentonite for a grout. • Flowing well environments will likely diminish its effectiveness • Bentonite grouts can leak out into open fractures in bedrock environments due to its weak strength • May have an impact on the groundwater chemistry near the well because it can trade off cations such as sodium, aluminium, iron and manganese • Additives that may be added to the bentonite slurry (organic and inorganic polymers) may affect groundwater chemistry near the well • Not suitable for arid climates due to potential for dehydration causing cracking and thus, will not perform as a long term effective seal

	Advantages	Disadvantages
Cement Based Abandonment Barriers	• Suitable low permeability • Easily mixed and pumped • Hard–positive seal provides structural integrity (good gel strength) and will not erode or wash-out with water movement • Supports and adheres to casing • Any remaining casing is rendered permanent and non–movable • Adheres well to bedrock • Properties can be altered with additives to reduce hydration time (calcium chloride), to make it stronger (aluminum powder), or have a higher resistance to sulphate rich environments (fly ash). • Expanding Portland cements, Types K, M and S, have characteristics and shrinkage-compensating additives that work well as abandonment barriers • Air-entrained cements work well in cold weather climates because cement with air-entraining agents has water tightness and freeze thaw resistance. • Provides weight and strength to overcome pressures associated with flowing wells	• Possible shrinkage if extra water is used, if improper additives are used or if the person is not using shrinkage compensated cements • Settling problems occur if not properly mixed or placed • Long curing time (minimum 12 hours) increases time to complete well and install equipment in well • Produces high heat levels during hydration process that can distort some plastic casings. The high heat of hydration in combination with weight of grout also increases the potential for plastic casing to distort or collapse. • High density results in loss of grout to some permeable overburden and bedrock formations • If prompt equipment clean–up does not occur, equipment damage may result • In order to properly set, mixing water needs to be cool, clean and fresh. Water also needs to be free of oil soluble chemicals, organic material, alkalies, sulphates and other contaminants • In order to properly set, mixing water needs to have a total dissolved solids concentration of less than 500 mg/L • Using water that has a high pH may increase setting time. • Equipment such as a tremie pipe needs to be kept cool to prevent flash set problems to pumps and tremie pipes • If too much water is used in the mixture, the extra water cannot chemically bind with cement (called bleed water), becomes highly alkaline and then can percolate through the cement. Voids in the cement created by this bleed water can also be subject to chemical attack and thus, will not perform as a long term effective sealing material • Prolonged mixing can interrupt heat of hydration process and reduces strength and cement quality • Neat cement mixtures increase the pH in the subsurface formations.

C) When Contaminants or Naturally Occurring Mineralized Water are Present

In choosing an abandonment barrier, the material must:

- Be compatible with the quality of the water found in the well. In some cases, sulphate rich waters will react and destabilize Type I Portland cement. In some salt rich waters, sodium bentonite will not set properly and destabilize.
- Not contain any materials that may impair the integrity of the abandonment barrier, including soil or drill cuttings.
- Be stable in the presence of any contaminants. If contaminants such as gasoline, fuel oil or nutrients are present in the groundwater or formation, the person abandoning the well will need to ensure that a proper plugging material is chosen. Unstable materials may not properly set and may affect the integrity of the structure.

When in doubt, a small sample batch of the intended abandonment barrier should be mixed and placed in container with a sample of the well water. Observe any reactions.

D) Alternate Abandonment Barrier Products (Director's Written Approval)

The **Wells Regulation** allows for the use of seven types of abandonment barrier materials which are described in section 3) b) on page 23 of this chapter. In some cases, approved abandonment barrier materials may not be suitable for the environment or available for the plugging and sealing operation, therefore, other materials will be required, and may be used if written consent is provided by the Director.

Prior to well abandonment, the person abandoning the well (often the well owner) may apply and seek the written consent of the Director to use a type of abandonment barrier material other than the seven listed abandonment barriers as long as the performance of the material is equivalent to the performance of the listed abandonment barriers.

How Can the Person Abandoning a Well Request and Obtain a Written Consent From the Director?

The person abandoning a well (often the well owner) may contact the Water Well Help Desk:

- in writing to Water Well Help Desk, Ministry of the Environment, 125 Resources Road, Etobicoke ON M9P 3V6;
- by telephone (Toll Free) at 1-888-396-9355 (for Ontario residents only);
- by fax at: 416-235-5960; or
- by e-mail at helpdesk@waterwellontario.ca

The person abandoning a well (often the well owner) should provide a written request with the following information:

- the name of the individual(s)/entity that owns the well;
- the location of the well;
- an indication as to whether or not the well in question is new or an existing well;
- the purpose and use of the well;
- the reason for the alternate abandonment barrier request (e.g. contaminant(s) of concern encountered or trying to stop a flowing well); and
- if applicable, written certification for the use of an alternate barrier material by the manufacturer or a *Professional Engineer*.

The person abandoning a well may be required to retain a *Professional Engineer* or *Professional Geoscientist* who would have to prepare a scientific report showing the appropriate scientific rationale to support the application. The person abandoning a well would have to submit the report along with the request for written consent to the Ministry for its consideration.

Depending on the case and as part of the Director's consideration, the Director may ask other regulators and interested parties to comment on the application.

How Does the Director's Decision Process Work?

The request for written consent must be submitted to the Director along with any and all supporting documents such as a hydrogeological, well plugging design and/or abandonment barrier design report(s). The person abandoning the well and others should be aware that obtaining a written consent will not be a simple and automatic process since the Ministry has to provide for the conservation, protection and management of Ontario's waters and for their efficient and sustainable use, to promote Ontario's long-term environmental, social and economic well-being.

The Director will review the request, supporting information and other information generated from internal and external parties with an interest in the application. Based on the review, the Ministry will contact the person abandoning the well, in writing, indicating the Director has:

- approved the use of an alternate type of abandonment barrier material as per the request;
- refused the request and thus requires the person abandoning the well to immediately abandon the well with one of the other seven listed abandonment barriers; or
- request additional information from the person abandoning the well to continue with the review of the request and render a decision.

4) Estimating Plugging Material Volumes Required

Table 15-4 may be useful to estimate how much cement, concrete or sodium bentonite plugging material is needed to plug a well. Further calculations are provided in Chapter 6: *Annular Space and Sealing,* Calculating Amount of Material Required section.

When plugging wells into bedrock or gravel deposits, large open fractures or open void spaces around the well can cause material to leak out of the well and into the formation. This and other hole irregularities (e.g. Figure 15-6) can increase the volume of plugging material required. Extra material should be available in the event there is an underestimation.

Table 15-4: Estimated Volume of Material for Different Well Diameters

The formula in this table is based on the industry standard well casing diameter in inches for drilled wells and some dug wells. The calculated numbers have then been rounded

Well Diameter		Metres (Feet) of Well Plugged Using One Bag of Material		
Centimetres	**Inches**	**Neat Cement*** 43 kg (94 lbs) bag**	**Concrete** 43 kg (94 lbs) bag**	**Sodium Bentonite* 23 kg (50 lbs) bag**
3	1 ¼	42 m (138 ft)	76 m (250 ft)	126 m (413 ft)
6	2 ¼	13 m (43 ft)	24 m (77 ft)	39 m (127 ft)
8	3 ¼	6 m (20 ft)	11 m (37 ft)	19 m (61 ft)
11	4 ¼	4 m (12 ft)	7 m (22 ft)	11 m (36 ft)
13	5 ¼	2 m (8 ft)	4 m (14 ft)	7 m (23 ft)
16	6 ¼	1.7 m (6 ft)	3 m (10 ft)	5 m (17 ft)
21	8 ¼	1 m (3 ft)	1.7 m (6 ft)	2.9 m (9 ft)
26	10 ¼	0.6 m (2 ft)	1.1 m (4 ft)	1.9 m (6 ft)
31	12 ¼	0.4 m (1.4 ft)	0.8 m (2.6 ft)	1.3 m (4.3 ft)
61	24	0.11 m (0.4 ft)	0.21 m (0.7 ft)	0.34 m (1.1 ft)
91	36	0.05 m (0.2 ft)	0.09 m (0.3 ft)	0.15 m (0.5 ft)

ft = feet m = metres kg = kilograms lbs = pounds

* 91 litres of water and one 23 kilogram bag of sodium bentonite powder will make a volume of about 99.6 litres at 20% solids by weight.

** 19.7 litres of water, one 43 kilogram bag of cement and 0.027 cubic metres of sand or gravel will make a volume of about 60.3 litres.

*** 19.7 litres of water and one 43 kilogram bag of Portland cement will make a volume of about 33.3 litres.

5) Preparing Equipment, Selecting Methods and Obtaining Approvals Needed to Plug the Well

Prior to plugging the well, the following should be determined:

- The type of heavy equipment needed to remove structures, casings, screens and well equipment. This could include a drilling rig, excavator (backhoe or high hoe), water trucks, stake trucks containing extra casing, welding materials, other tools, cement trucks, gravel trucks and pumping equipment.
- The location of nearby pits and quarries that supply filling materials such as gravel. The location of retailers of cement or bentonite will also be important in choosing the materials and methods to plug the well.
- A source of high quality clean water for preparing a slurry.
- The type of specialized equipment such as fishing tools or casing cutters to remove collapsed casing, obstructions or equipment stuck in the well.
- The type and method of installing the plugging materials in the well such as tremie pipes, attachments to casings and grout pumps.
- The location for disposing of any contaminated materials that are removed at the well site.
- Appropriate health and safety precautions. See the *Safety Manual for Well Technicians*. Fleming College School of Continuing Education; supplemental course material, 2008 and the Ministry of Labour's website for additional information: http://www.labour.gov.on.ca/english/.

Any approvals, permits or other instruments that may be necessary before the operation commences. For example:

- If groundwater is anticipated to discharge from a well before abandonment, or is discharging from a well during abandonment, at a rate of more than 50,000 litres per day (about 11,000 imperial gallons per day), a Permit To Take Water under the *Ontario Water Resources Act* must be obtained. More information on Permit To Take Water approvals can be found at following website: http://www.ene.gov.on.ca/envision/water/pttw.htm
- The person abandoning the well must ensure that the location of groundwater, debris and other materials discharging from the well do not cause adverse environmental impacts such as erosion, impairment of surface water courses and/or off-site flooding. This may require the use of settling pits on the property. A sewage works certificate of approval under the *Ontario Water Resources Act* may be required if the person constructing the well discharges the water, drill cuttings or other material and the discharge capacity exceeds 10,000 litres per day. A guide to explain the sewage works process can be found at the following website: http://www.ene.gov.on.ca/envision/gp/4980e.htm

Nine Sequential Step Procedure to Plug and Seal a Well

The person abandoning the well must ensure the following nine steps are taken in sequence unless otherwise specified.

Best Management Practice – Work Efficiently and Cover Abandoned Well

To protect against safety concerns and the well acting as a pathway for contaminants, the person abandoning the well should ensure the person working on the well:

- Manages equipment, time and resources to complete the plugging and sealing steps in one day or less.
- Covers the well in a manner that prevents the entry of surface water and other foreign materials if the person working on the abandoned well leaves the site before completing the plugging and sealing steps.

1) Safeguarding and Returning the Well Tag

If the well has a well tag, it must be removed and returned to the Director within 30 days after its removal.

Since August 2003, persons constructing wells have been required to affix Ministry issued well tags onto new and altered wells.

If the well has a well tag attached to the well casing or near the well, the well tag must be removed at the beginning of the plugging operation and safeguarded throughout the process.

The well tag must be returned within 30 days after completion of abandonment and its removal to Water Well Help Desk, Ministry of the Environment, 125 Resources Road, Toronto, Ontario, M9P 3V6 (1-888-396-9355).

Figure 15-10: Well Tag on Drilled Well

2) REMOVING EQUIPMENT, STRUCTURES, DEBRIS AND ANY COLLAPSED WELL CASING AND/OR WELL SCREEN

A) Structures and Slabs

In some cases, wells are housed in well pits or pump houses to protect the well head from the winter environment or to house pumping and electrical equipment near the well. There are also cases where wells are housed in buildings.

Best Management Practice – Remove Concrete Slabs or Pump House As Soon As Possible

If there are slabs of concrete or tiles surrounding the well casing at or near the land surface or the well is located within a pump house, the concrete slabs or the pump house should be removed prior to the commencement of the abandonment and plugging operation on the well. The well should be properly covered and maintained up to the time the well is deemed abandoned and properly plugged and sealed.

FIGURE 15-11: DRILLED WELL INSIDE A PUMP HOUSE

Figure 15-11 shows a drilled well, waterline, and pump located within a pump house. The pump house floor is a concrete slab.

In cases where wells are housed in residential dwellings or other types of buildings and there is continued use of the building, see Step 7 (page 53) for additional details.

B) Removing equipment

The person abandoning the well must ensure the person working at the abandonment of the well removes all pumping equipment, waterlines (drop pipes), electrical equipment, connections, pipes, and other equipment from the well.

FIGURE 15-12: ELECTRICAL WIRES

FIGURE 15-13: ELECTRICAL WIRES - CLOSE UP

Electrical wires going into drilled wells to submersible pump, as shown in Figures 15-12 and 15-13, are a safety hazard if they are damaged or not properly disconnected and removed.

FIGURE 15-14: EQUIPMENT REQUIRED TO BE REMOVED

Figure 15-16 shows pumping equipment (drop pipe) extending out of the well without a watertight seal on the top of the casing. Removal of pumping equipment, including the drop pipe, from the drilled well is necessary prior to the installation of the abandonment barrier material. The removal of the equipment will help ensure that the entire well is properly plugged.

C) Removing Collapsed Well Casing and Well Screen

Over time, steel well casing can corrode or plastic well casing can degrade or crack. Corrosion, degradation or cracks create openings and allow the migration of contaminants.

If possible, broken well casing or well screen should also be removed from the well. There are a variety of drilling tools that can be used to remove broken casing and well screen. For example a backhoe or highhoe can remove casing in overburden environments up to about 9 metres (30′) below the land surface.

FIGURE 15-15: REMOVAL OF WELL CASING

Figure 15-15 shows the removal of well casing using a drilling rig with a chain attached to the rig's winch.

FIGURE 15-16: REMOVAL OF WELL CASING

The drilling rig raises the chain and casing out of the ground leaving the well open. The rig has removed the casing shown in Figure 15-17 from the well.

FIGURE 15-17: REMOVAL OF WELL CASING

The upper portion of casing is attached to the casing rotator. The casing is being raised up the drilling mast.

FIGURE 15-18: TAPERED TAP

A tapered tap, such as the one shown in Figure 15-18, is used to spear the broken casing. The device is lowered from the drilling rig. Once attached into the casing, the drilling rig can raise the casing out of the well. Other similar attachments that can be used are a sandlock or trip spear.

FIGURE 15-19: CASING CUTTER

This red coloured casing cutter shown in Figure 15-19 is attached to drill rods on the drilling rig. The cutter and drilling rods are lowered into the hole to the desired elevation by the drilling rig and operator. The cutter and drilling rods are rotated by the rotation mechanism on the rig. During the rotation the cutter (the grey coloured steel in centre of the red coloured cutter) will cut the steel well casing.

FIGURE 15-20: CORRODED CASING FROM INSIDE

FIGURE 15-21: CORRODED CASING FROM OUTSIDE

Figures 15-20 and 15-21 show the interior and exterior of a drilled well with casing corroded to a point that a significant hole has formed through the well casing. The hole is seen on the right side of Figure 15-20 and can also be seen in Figure 15-21. The open hole acts as a pathway for surface water and other foreign materials to enter and contaminate the well water.

During the removal process of large diameter concrete well casing, reasonable efforts must be made to remove any broken concrete tiles from the well before proceeding with further plugging and sealing steps.

Best Management Practice – Collapsed Well Casing

When abandoning a well that has a collapsed well casing, or one in which specialized equipment needs to be installed, the person abandoning the well should retain a *Professional Engineer* or *Professional Geoscientist*. The professional should assess the well. The casing and equipment should be removed by experienced licensed well contractors and well technicians. A video camera assessment of the well can assist in the identification and location (depth) of problems in the casing, obstructions and equipment. Solutions may include using fishing tools, re-drilling, overdrilling or excavating the well.

The person working at the abandonment of the well can remove intact well casing before Step 3 if the person working at the abandonment of the well uses an overdrill method to rip out the well casing.

D) Removing Obstructions

If obstructions are not removed from abandoned wells before plugging, the lower portion of the well below the obstruction will not be effectively plugged, resulting in an open conduit for contaminant migration.

Obstructions may include any of the following:

- Pumping equipment
- Devices to measure water levels, water quantity or well water quality such as flow meters, piezometers or pressure transducers
- Materials that have inadvertently or naturally entered the well
- Inflatable packers used to stop well water from discharging out of a flowing well
- Pitless adapters, grounding devices, well seals and caps

FIGURE 15-22: DRILLED WELL PARTIALLY FILLED WITH CONCRETE

Figure 15-22 shows the view inside a drilled well that has only been partially filled with concrete. There is an unsealed portion of the well below the concrete plug (not visible). The concrete needs to be carefully drilled out by an experienced well driller prior to properly plugging and sealing the well.

FIGURE 15-23: EXTERIOR OF PITLESS ADAPTER

Figure 15-23 shows the exterior of a pitless adapter attached to the outer side of the well casing with a horizontal waterline extending from the well. The pitless adapter needs to be removed from this well casing prior to plugging and sealing. Also, the photograph shows a large opening on the outside of the well that will need to be filled.

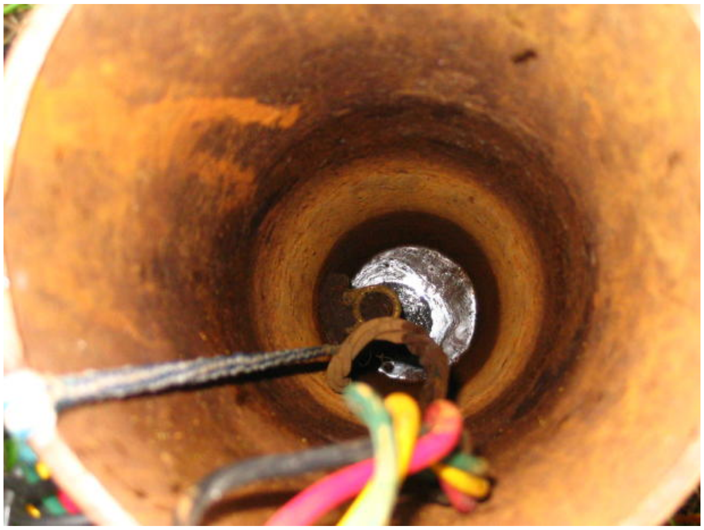


FIGURE 15-24: INTERIOR OF PITLESS ADAPTER

The interior of a pitless adapter, shown in Figure 15-24, is located just above the water level extending through the left side of the drilled well casing. The pitless adapter needs to be removed along with the drop pipe, the submersible pump's three coloured electrical wires, the cable and the rope.

FIGURE 15-25: WATERLINES, AIR VENT AND SEAL TO BE REMOVED

Figure 15-25 shows two waterlines, an air vent and a sanitary well seal which need to be removed from the top of well casing located on the floor of this well pit. The person also needs to ensure the concrete tiles and the fungus in the well pit are removed.

E) Removing Debris

All debris, including biofilm must be removed from the well to ensure that it will not interfere with the setting of the plugging material and not impair the groundwater.

FIGURE 15-26: DEBRIS TO BE REMOVED

The debris shown in the dug well in Figure 15-26 consists of wood, pipe, sticks and leaves which may interfere with the plugging material's (abandonment barrier's) performance.

EXAMPLES OF METHODS FOR REMOVING DEBRIS AND BIOFILMS

SUBMERSIBLE PUMP METHOD

One method of removing debris involves the installation of a clean submersible pump and drop pipe in the well. The pump, wires and drop pipe should be soaked in a solution of fresh unscented bleach and clean water prior to installation.

Best Management Practice – Removal of Well Water Column as Part of Debris

As part of the removal of debris and biofilm from the well, it is recommended that, where feasible, at least twenty volumes[2] of the water column in the well be removed. The volume of the water column in the well should be calculated by measuring the top of the water level (static water level) and well depth. The difference between the two measurements provides the height of the water column in the well. If the well is not very deep an example of a measuring device that may be used is a calibrated tape measure. For accurate measurements in deep wells, a calibrated electrical water level meter should be used.

[2] Schnieders, John H. 2003. *Chemical Cleaning, Disinfection and Decontamination of Water Wells*. Johnson Screens Inc., St. Paul, MN. ISBN 0-9726750-0-0-0

The well water removal process will also remove some of the organic biofilm such as iron bacteria that may have built up on the sides of the well hole. Biofilm can spread through an aquifer to other wells and inhibit chlorination processes. See the "Other Chemical Treatment" section in the Best Management Practice titled "Shock Chlorination" (page 43 in this chapter).

As an example, if a 16 cm (6¼ ′) diameter drilled well contained a column of 10 metres of water, the well would hold about 200 litres (or 44 Imperial gallons) of water. Thus, at least 4,000 litres (or 880 Imperial Gallons) should be pumped from the well.

A pail and timer (e.g. an accurate watch or stop watch) can be used to measure the pumping rate. The pump must be kept at a constant rate using a dole valve, globe valve or ball valve.

For example if a person needed to pump 4,000 litres (880 Imperial Gallons) of water and has a 20 litre (4.4 Imperial Gallons) pail, the person can observe the seconds it takes for the pumped well water to fill up the pail. If it takes 1 minute for the 20 litre pail to completely fill, then at least 200 minutes of pumping would be needed to remove 4,000 litres of water from the well.

To protect against water quantity and quality problems and to determine if approvals are required, see Chapter 10: *Yield Test,* Conducting the Yield Test section (Permit To Take Water note) and Handling Water Discharge section. If approvals are necessary, obtain them before starting to remove (pumping) the well water.

Table 15-5 provides different well diameters and the estimated volume of water per metre (or foot) in the well. Multiplying the height of the water column by the estimated volume per metre (or foot) will provide the estimated volume of water in the well column.

Table 15-5: Estimated Volume of Water for Different Well Diameters

The formula in this table is based on the industry standard well casing diameter in inches for drilled wells and some dug wells. The calculated numbers have then been rounded

Well Casing Inner Diameter		Volumes of Water	
Centimetres	**Inches**	**Litres per metre**	**Imperial Gallons per Foot**
3	1 ¼	0.8	0.05
6	2 ¼	2.6	0.17
8	3 ¼	5.4	0.36
11	4 ¼	9.2	0.61
13	5 ¼	13.9	0.94
16	6 ¼	19.9	1.33
21	8 ¼	34.6	2.31
26	10 ¼	53.1	3.57
31	12 ¼	76.0	5.09
61	24	292.2	19.55
91	36	656.1	43.99

FIGURE 15-27: PREPARING TO INSTALL SUBMERSIBLE PUMP

The person in Figure 15-27 is working on a well and preparing to install a submersible pump into the well. Green waterline and electrical wires are being attached to operate the pump that will discharge the water at land surface. The person will have to clean the pump, wires and lines prior to installation into the well.

Compressed Air Method

In some cases, drilling machines blowing air are used to remove water with the debris and a portion of biofilm from the well (see the above note on page 40 of this section for water discharge).

FIGURE 15-28: COMPRESSED AIR REMOVAL OF DEBRIS

The person operating the rotary rig in Figure 15-28 is using a compressor to blow air under high pressure and a high rate through drill rods into the well. The air forces well water and debris up the well to the ground surface.

Best Management Practice – "Shock" Chlorination

To ensure potential disease causing organisms in the well water or groundwater near the well do not move with groundwater flow to other area wells, well water should be "shock" chlorinated prior to the plugging and sealing of a well (see Chapter 8: *Well Disinfection* for further information). If biofilm from organisms such as iron bacteria or sulphate reducing bacteria is present, mechanical and chemical cleaning are recommended prior to chlorinating the well.

Sodium hypochlorite (unscented bleach) is commonly used in the chlorination process. Bleaches are available at local grocery and hardware stores. Other products may be used to chlorinate water such as calcium hypochlorite and lithium hypochlorite. Commercial bleach at 12% available chlorine is also used by many well contractors. Correct calculations must be made when using this product to ensure proper operating concentrations. Proper safety procedures need to be employed when handling sodium hypochlorite or the other oxidization agents since they are harmful to humans (see Chapter 8: *Well Disinfection* for further information).

Chlorinating the Well

"Shock" chlorination requires a free chlorine residual in the range of 50 to 200 milligrams per litre to remove pathogens from well water (see Chapter 8: *Well Disinfection*). To obtain the correct concentration range in the well (see the formulas, tables and dosing sections in Chapter 8: *Well Disinfection*).

The formulas do not consider metals and organics that will consume the solution prior to creating the oxidizers in the water. As such, free chlorine residual test equipment should be used to verify a free chlorine residual in the well water. Common methods to measure the free chlorine residual such as a colour-wheel test kit and digital colorimeters are shown in Chapter 8: *Well Disinfection*.

Best Management Practice – "Shock" Chlorination (Continued)

Discharging Chlorinated Well Water

It is important, that at the end of treatment period the chlorinated well water be pumped from the well to a suitable storage tank, neutralized, and then discharged to a location that will not cause an adverse effect on the natural environment. It is also important that the chlorinated water from the well be pumped to ensure it does not move through the aquifer and impair nearby wells or surface water (see Chapter 8: *Well Disinfection* for further information).

If Chlorination of Well Water Presents a Hazard

Where the chlorinated water may cause an adverse health reaction or hazard with other chemicals in the well water and groundwater, the contractor and well owner should not chlorinate the well.

Some situations where well chlorination treatment should not occur may be a groundwater resource contaminated with arsenic from naturally occurring sources in the bedrock or by industrial processes. The addition of sodium hypochlorite may elevate arsenic in the groundwater near the well.

In other cases, a nearby well may be hydraulically connected to the well being chlorinated. The chlorinated water may move from the abandoned well to a nearby well and impair the quality of the well water. As such, chlorinating the well before plugging should either not occur or proceed with monitoring of the nearby well. A contingency plan that is ready to be activated to prevent any adverse effects should be in place.

Other Chemical Treatment

In some cases, acid blends using specific biodispersants or other chemical treatments are used to dislodge the biofilm and other encrustations from the sides of the well. The biofilm may then be mechanically cleaned (e.g. pumping) and then removed from the well using pumping or compressed air methods. Only qualified and licensed professionals should conduct these specialized methods and treatments (see Chapter 11: *Maintenance & Repair* for additional information).

3) Plugging and Sealing Within Two Metres of Ground Surface

The **Wells Regulation** identifies different methods for placing plugging materials into wells depending on the diameter of the well.

A) Well Diameter Greater Than 6.5 cm (2.6″) – Typically Drilled Wells

These smaller diameter sized wells are typically drilled and are typically deeper than 9 metres (30′) below the ground surface. Larger diameter dug and bored wells can follow this option or the alternative option listed in Step 3 (c) (page 50).

Neat cement, concrete and sodium bentonite slurries, sodium bentonite chips or pellets, mixtures of not more than 5% sodium bentonite with neat cement or a plugging material approved by the Director are used to plug the well (See Selection of Plugging Materials, page 22).

Best Management Practice – Taking Precautions when Using Dry Bentonite Products

If sodium bentonite pellets or chips are used, the material needs to be screened and placed in accordance with the manufacturer's specifications. Precautions when plugging a well with dry bentonite products include:

- Ensuring sealing material does not bridge when placing material,
- Pouring the products at a rate no faster than 3 minutes per 22 kilogram (50 lb) bag,
- Halting the pouring process occasionally and lower a weighted measuring tape into the well until it reaches the top of the products to confirm that bridging has not occurred,
- Using a tamping device to break any bridges that form, and
- Making sure bentonite is continually hydrated, where necessary, by periodically adding clean water to the bentonite that has been placed in the well.

If sand or gravel is used to fill the water producing zones or open fractures in bedrock, similar precautions to those used for sodium bentonite pellets or chips should be followed.

If a slurry abandonment barrier is used, the best abandonment barrier material that will properly plug and seal the well should be chosen (See Selection of Plugging Materials, page 22).

Any wet abandonment barriers (i.e. slurries) must be placed in the well (including the annular space) from the bottom of the well using a tremie pipe with the bottom of the pipe immersed in the rising accumulation of the abandonment barrier. Care needs to be taken to ensure that the tremie pipe does not become stuck in the abandonment barrier within the well. This will include raising the tremie pipe during the operation.

The tremie pipe typically extends from a grout mixing machine and pump at land surface to the bottom of the well as shown in Figure 15-31. As an alternative, a pipe is sometimes attached from the grout mixing machine and pump to the top of the well casing. The casing is then used as the tremie pipe as shown in Figure 15-32.

If well water, and any material displaced during this operation is contaminated (e.g. contains gasoline), the water must be collected and disposed of in an approved manner. If the displaced water is not contaminated, it should be directed away from the well site to minimize the likelihood of the water flowing into the well opening (see the section titled: "Handling Water Discharge," in Chapter 10: *Yield Test,* for further information).

FIGURE 15-29: GROUT MIXING MACHINE

Figure 15-29 shows a grout mixing machine. Material is placed and mixed in an upper tray and lowered into a lower tray. Material is pumped from the lower tray through a tremie pipe (not shown) to the well behind the drilling rig. It is not recommended to use dual tank grout mixing units with bentonite based grout because separation of the product and water can occur when grout is not agitated in the pumping tank. This results in a flash setting of grout in the tremie line or non-uniform grout consistency.

FIGURE 15-30: ANOTHER GROUT MIXING MACHINE

Figure 15-30 shows another grout mixing machine. In this case the person working at the abandonment of the well is placing and mixing sodium bentonite powder and water in the grout mixing machine. The mixture will be pumped from the machine through a tremie pipe placed into the well.

FIGURE 15-31: TREMIE PIPE INSTALLED INTO DRILLED WELL

In the foreground of Figure 15-31 is a drilled well steel casing. A black tremie pipe has been installed through the top of the well casing to the well's bottom. A hole has been excavated 2 metres (6.6′) below the ground surface around the well casing. In the background, sodium bentonite and clean water are mixed in a grout mixing machine in the back of a pickup truck to achieve a mixture of 20% solids by weight.

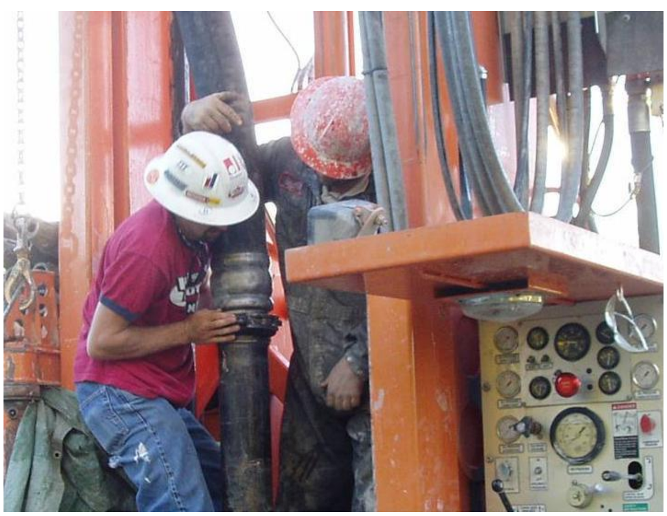


FIGURE 15-32: USE OF DRILLED WELL STEEL CASING AS TREMIE PIPE

Figure 15-32 shows the attachment of a large hose on to the well casing. Both the large hose and casing will be used as the tremie pipe. In this example, cement will be pumped under pressure from a concrete pump truck through the hose and into the top of the well casing. The cement will move down the casing and into the formation below the casing. Due to the pressure exerted in the pumping operation, the cement at the bottom of the casing will push up into any open annular space located near the bottom of the well casing.

FIGURE 15-33: PLUGGING MATERIAL DISPLACING UNCONTAMINATED WATER

In Figure 15-33 and Figure 15-34 (below), a proper slurry mixture of sodium bentonite powder and water are being pumped into a drilled well before the mixture fully cures. In the initial phase, shown in Figure 15-33, the plugging material is rising from the bottom of the well and displaces the well water. The plugging material is placed using the tremie pipe from the bottom of the well to the top of the well casing.

FIGURE 15-34: PLUGGING MATERIAL COMING OUT OF CASING

In Figure 15-34, the fluid coming out of the top of the well is the sodium bentonite plugging material (abandonment barrier). Pumping will stop and the person working at the abandonment of the well will wait in case the abandonment barrier settles out into other parts of the formation around the well. If settling occurs, the person working at the abandonment of the well will pump more plugging material into the well.

The intent of plugging the entire well including the annular space with a tremie pipe is to ensure that bridging and material segregation will not occur during grouting.

Bridging usually occurs when the plugging material is added from the ground surface into a small diameter deep drilled well at a high rate and begins to clog the hole or well casing at an elevation above the bottom of the well. This happens more frequently with dry plugging materials. As a result the material fails to properly fall to the bottom of the well creating open gaps in the well. Open gaps, due to bridging, can potentially allow contaminants to travel vertically in the open portion of well when the casing has been pulled, destabilize the structure of well and impede the effectiveness of the plugging materials.

Material segregation may occur when the different components of a grout (e.g. concrete) vary in weight and the grout (i.e. abandonment barrier) is poured slowly from the top of the well. This segregation reduces the effectiveness of the plugging material. As with bridging, the use of a tremie pipe can eliminate the potential of any material segregation.

Ontario

The abandonment barrier must be placed in manner described in this section until a depth of about 2 metres (6.6′) below the ground surface is reached.

B) Wells with a Diameter Less Than or equal to 6.5 cm (2.6″) – Driven Wells

These wells are typically shallow driven point wells or possibly deep diamond drilled wells. Diamond drilled wells are typically used in mining exploration but are used as domestic wells in certain communities in Ontario. Driven point wells are typically used for domestic water takings from shallow groundwater resources.

When determining the diameter of a single casing well, the initial hole diameter at the time of construction must be taken into account in addition to the outer diameter of the casing.

If the well casing and well screen have been removed, the abandonment barrier must be either:

- A slurry consisting of clean water, Portland cement and not more than 5% bentonite solids by weight; or
- A slurry consisting of clean water and at least 20% bentonite solids by weight.

The above also applies, with necessary modifications, to an uncased well that is less than or equal to 6.5 cm (2.6″) in diameter.

If the well casing and well screen have not been removed the abandonment barrier must be either:

- A slurry consisting of clean water, Portland cement and not more than 5% bentonite solids by weight, or
- Bentonite chips or pellets that have been screened and placed in accordance with the manufacturer's specifications.

The abandonment barrier and filling materials must be installed from the bottom of the well to a depth of approximately 2 metres (6.6′) below the land surface.

Where the abandonment barrier is a slurry consisting of clean water and at least 20% bentonite solids by weight, it must be placed using a tremie pipe. The bottom of the tremie pipe must be immersed in the rising accumulation of the abandonment barrier until the required level has been reached.

In situations where a tremie pipe is not used (e.g. for placement of the cement mixture with no more than 5% bentonite solids by weight or bentonite chips or pellets), there is a potential for the neat cement and bentonite chips or pellets to bridge due to the small diameter of the well. Extreme caution should be exercised for wells greater than 9 metres (30′) deep so that the volume of plugging materials added to the well is equivalent to the volume of the well being plugged. Procedures such as pouring slowly, measuring the material level and measuring the quantity of the material added to the well should be followed (see Step 3A, page 45).

C) Well Diameter Greater than 65 cm (2.1′) – Dug and Bored Wells

These wells are typically considered shallow dug or deeper bored wells that have large diameter concrete tiles, galvanized steel, hand-lain stone walls or fibreglass casing to support the sides of the well.

As an alternative to Step 3A on page 45, a person can plug and seal a well up to approximately 2 metres (6.6′) below the ground surface using the following sequential method:

1) Filling Materials in Well Screen and Water-Producing Zone

Ontario

The **Wells Regulation** requires that clean sand or pea gravel be placed from the bottom of the well to the top of the deepest formation supplying groundwater to the well (water-producing zone) or to the top of the well screen. The deepest one of the two options must be chosen.

For example:

1. A well record for a deep bored well shows the well was bored through a sand deposit, underlain by a clay deposit and then underlain by a gravel deposit. Both the upper sand and lower gravel deposits supply groundwater to the well. The deepest formation supplying groundwater to the well is the gravel deposit. The clean sand or pea gravel must fill the well from the bottom of the well to the top of the gravel deposit.
2. A water intake zone on a bored well is located at the very bottom of the well's interior. The open bottom of the well allows a large volume of groundwater to enter into the well from the formation. However, the bored well also allows groundwater to enter through the joints between concrete tiles. Unsealed joints in concrete tiles that allow groundwater to enter the well are considered to be well screen (See Chapter 2: *Definitions and Clarifications*, Table 2-1). In this example, the upper open joint between concrete tiles that is allowing groundwater to enter the well should be considered the top of the well screen. The clean sand or pea gravel must fill the well from the bottom of the well to the top of the joint between the concrete tiles that allows groundwater to enter the well.
3. Where a well screen and a water producing zone are present, the top of the water producing formation is compared to the top of the well screen and the deeper of the two measurements must be used for the location of the top of the clean sand or pea gravel.

If technical information is unavailable for a well such as a deep bored well, further field work or site assessment may be required that could include any of the following:

- Pumping the water level to the bottom of the well and observing where groundwater is entering the well
- Installing a down-hole video camera and viewing the display to observe the interior of the well
- Drilling near the well and making observations
- Conducting a geophysical survey within the well to determine groundwater yielding formations and the location of well screen

2) Placement of Plugging Materials

The placement of plugging materials above the clean sand or pea gravel is required in the well, including the annular space outside any remaining well casing.

Pouring dry plugging material from ground surface is usually sufficient to properly place it in these types of large diameter wells. Any type of slurry materials must be placed using a tremie pipe.

Bentonite Chips and Pellets

A 0.1 metre (4″) thick layer of sodium bentonite chips or pellets must be placed on top of the sand or pea gravel. The sodium bentonite chips or pellets will begin to hydrate in the water and form a seal.

Well Water Level At or Below the Top of Bentonite Chips or Pellets

In some cases, the well water level will be at or below the top of the bentonite chips or pellets that have been placed in the well. If well water is remaining above the bentonite chips or pellets placed in the well, an attempt must be made to pump the well water down to the top of the chips or pellets. If the water level can be pumped down to the top of the chips or pellets or if the water level is already at or below the required level, the following must be done:

- Sodium bentonite powder is mixed with water to create a 20% by weight bentonite slurry as described in Table 15-4 on page 29
- A layer of at least 0.3 metres (12″) of this sodium bentonite slurry mixture is placed on top of the bentonite chips or pellets
- More bentonite slurry is placed into the well. It should be noted that this material, by itself, does not have sufficient strength to support the weight of humans, animals and vehicles
- Clean gravel, sand, silt or clay are poured evenly over the sodium bentonite slurry surface to displace the bentonite slurry. The method will allow the materials to mix together
- If the gravel, sand, silt or clay material rises to within 0.3 m (12″) below the top of the bentonite slurry then additional sodium bentonite slurry must be added to ensure that there is always 0.3 m (12″) of bentonite slurry at the top
- The process is followed until the well is filled to approximately 2 metres (6.6′) below the ground surface

When not able to Pump Well Water Down to Bentonite Chips and Pellets

In some deeper bored well cases, attempts to pump the well water level down to the top of the bentonite chips and pellets may be unsuccessful. In these cases, the **Wells Regulation** requires sodium bentonite, neat cement or concrete slurries, bentonite pellets or chips, or other materials approved by the Director to be poured or pumped into the well up to about 2 metres (6.6′) below the ground surface. Clean sand or pea gravel layers can be placed in any water producing zones.

Strength of Material

The plugging abandonment barrier material installed in the well must have sufficient strength to hold the weight of humans, animals and vehicles that may move over the area for this alternate method.

4) Removing Entire Casing and Well Screen During Sealing

Ontario

If reasonably possible, the casing and the well screen must be removed (if not already removed in the previous steps) while the bottom of the casing is immersed in the rising accumulation of abandonment barrier material.

5) Casing Removal

Ontario

If reasonably possible, at least two metres (6.6′) of casing below the ground surface must be removed (if not already removed in the previous steps) after the abandonment barrier material has been placed in the well. The abandonment barrier material must be placed up to a depth of about 2 metres (6.6′) below the ground surface (see Step 3, page 45).

In some cases a well opening needs to be created to expose the well casing to a minimum depth of two metres below the ground surface prior to its removal. When using an excavator, such as a backhoe or highhoe, a significant hole is created around the well casing. After the hole has been created the person working at the abandonment of the well must take necessary safety measures to cut and remove at least two metres of casing below the ground surface.

Figure 15-35: Removing 2 Metres of Well Casing

Figure 15-35 shows a contractor removing at least 2 metres (6.6′) of well casing from the abandoned well after filling the well with plugging material. Proper safety procedures including shoring and/or sloping the sides of the well opening excavation need to be followed.

Figure 15-36: Cut Casing with Abandonment Barrier

Figure 15-36, the top of the casing is cut off and the abandonment barrier material is shown inside the remaining casing and also in the well opening (excavated hole) around the well.

Another method of removing casing is to use a casing cutting device. The device is attached to drilling tools and lowered by the drilling machine into the well (see Figure 15-19). The cutting device can easily cut the well casing from the inside at a depth of at least 2 metres (6.6′) below the ground surface. Both the casing and the cutting device can be pulled from the well using the drilling machine.

For dug and bored wells, a large excavator is usually needed to lift and remove large concrete tile or galvanized steel casing. During the removal process of large diameter concrete well casing, any broken concrete tiles must be removed from the well before proceeding with further plugging and sealing steps.

In other cases, the upper portion of the well casing may be sealed into bedrock or within a building. In these cases, where removal of the upper two metres of the casing below the ground surface is not reasonably possible, the upper portion of the well casing may be left intact.

Best Management Practice – Removing the Casing

In all cases, the complete removal of casing prior is the preferred option.

6) When Cement or Concrete are Used (This step is only followed if these materials are used)

If the abandonment barrier contains cement, it must set until firm and, if necessary, it must be topped up to approximately 2 metres (6.6′) below the ground surface.

7) Removing Below Ground Concrete Structures and Slabs

Typically, well pits, structures and slabs are removed before the well is plugged. However, this can also be done during the abandonment process at any time before the sealing of the upper 2 metres (6.6′) of the well opening. Any below ground concrete structures, foundations and slabs must be removed unless the removal may cause remaining structures (e.g. a building) to become destabilized, damaged or unsafe.

The structures must be removed to at least a depth adequate to accommodate the sealing measures.

Best Management Practice – Sealing and Decommissioning any Waterlines and Related Equipment

It is important to properly seal and decommission any waterline and related equipment (e.g. a large diameter conduit that surrounds the waterline) that extend underground from a well to a building. If not properly decommissioned, the underground waterline and related equipment may act as horizontal pathways for surface water and other foreign materials to gain access to the building, or to flow toward the area of the abandoned well.

8) Plugging and Sealing the Upper 2 Metres (6.6′) of the Well Opening

Ontario

To prevent inadvertent or unauthorized access, the well and the well opening (which includes any excavation) must be sealed up to the ground surface by:

- Placing 50 cm (1.6′) to 150 cm (5′) in vertical thickness of bentonite chips, pellets, granules or powder in accordance with the manufacturer's specifications, and
- Filling the remaining well and well opening above the layer of bentonite and up to the ground surface with soil cover or other material that is more in keeping with the existing material immediately adjacent to the well opening.

Best Management Practice – Placing Bentonite Chips, Pellets, Granules or Powder

When placing bentonite chips, pellets, granules or powder in the well opening, they should be fully hydrated to ensure bentonite is fully expanded and prevent any future up-heaving of the ground surface. Care should be taken to estimate the depth of bentonite needed in the well opening by taking into account the significant expansion of bentonite after hydration.

As each environment is unique, the thickness and type of bentonite and the placement method used to fill the well opening should be determined on a case by case basis to ensure that the thickness remains in the required range after filling the well opening. These considerations are important to prevent any collapse at the well opening if a vehicle, animal or human passes over the abandoned well and to offer the best protection to the environment.

Figure 15-37: Placing Bentonite Pellets on Top of Abandonment Barrier

Figure 15-37 shows bentonite pellets being placed in the well opening (excavation) on top of abandonment barrier material (bentonite) in a drilled well (see Figure 15-36). The bentonite pellet layer needs to fill the entire well opening and be at least 50 cm (1.6′) to 150 cm (5′) thick.

9) Stabilizing Disturbed Area

The area of the land surface where the well is located must be covered and stabilized to prevent any erosion.

Best Management Practice – Filling and Stabilizing Well Opening

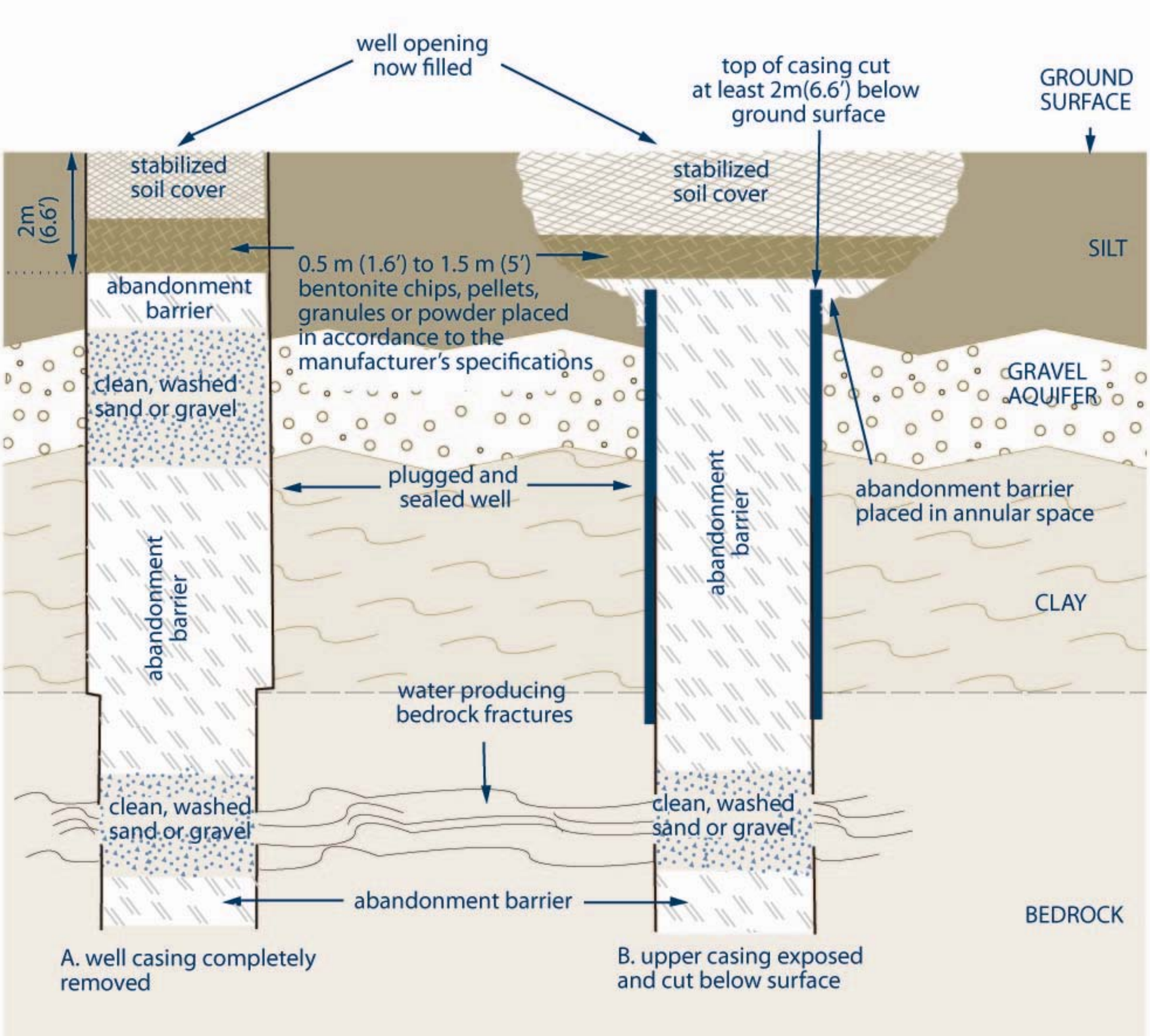
It is important to make sure the material placed in the well opening has sufficient strength to hold the weight of humans, animals and vehicles.

Diagrams of Plugged and Sealed Wells

Figures 15-38 to 15-40 (on pages 56 - 59) and Figure 15-47 (on page 66) provide examples of various well types that have been plugged and sealed based on the nine step sequential process.

All figures and diagrams are for illustrative purposes only and do not necessarily represent full compliance with other requirements found in the **Wells Regulation**.

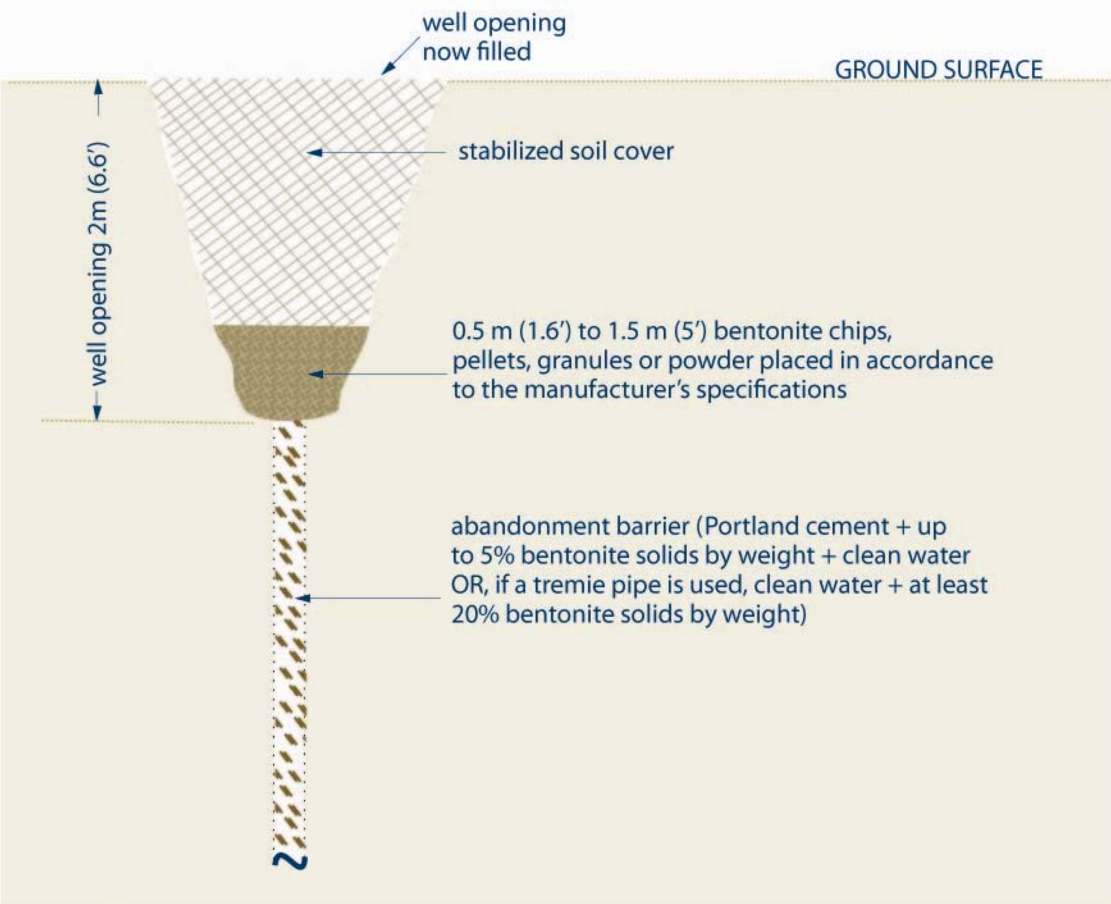
FIGURE 15-38: PLUGGING AND SEALING WELLS > 6.5 CM (2.5″)



- This is typically done for drilled wells and is permitted for any type of well with a diamter greater than 6.5 cm (2.5").
- Abandonment barrier slurries must be placed using a tremie pipe.
- Abandonment barrier must prevent any movement of water, natural gas, contaminants or other materials between subsurface formations (including aquifers) and between a subsurface formation (including an aquifer) and the top of the abandonment barrier.
- Water should be added to the bentonite chips, pellets, granules or powder to start hydration.
- Soil cover can be other material in keeping with existing adjacent surface material. The soil cover must prevent inadvertent and unauthorized access.
- Well opening is typically excavated to remove the top portion of the well casing.

The diagram above is not to scale and is for illustrative purposes for this Chapter only.

FIGURE 15-39: PLUGGING AND SEALING NARROW DIAMETER WELLS < 6.5 CM (2.5″)

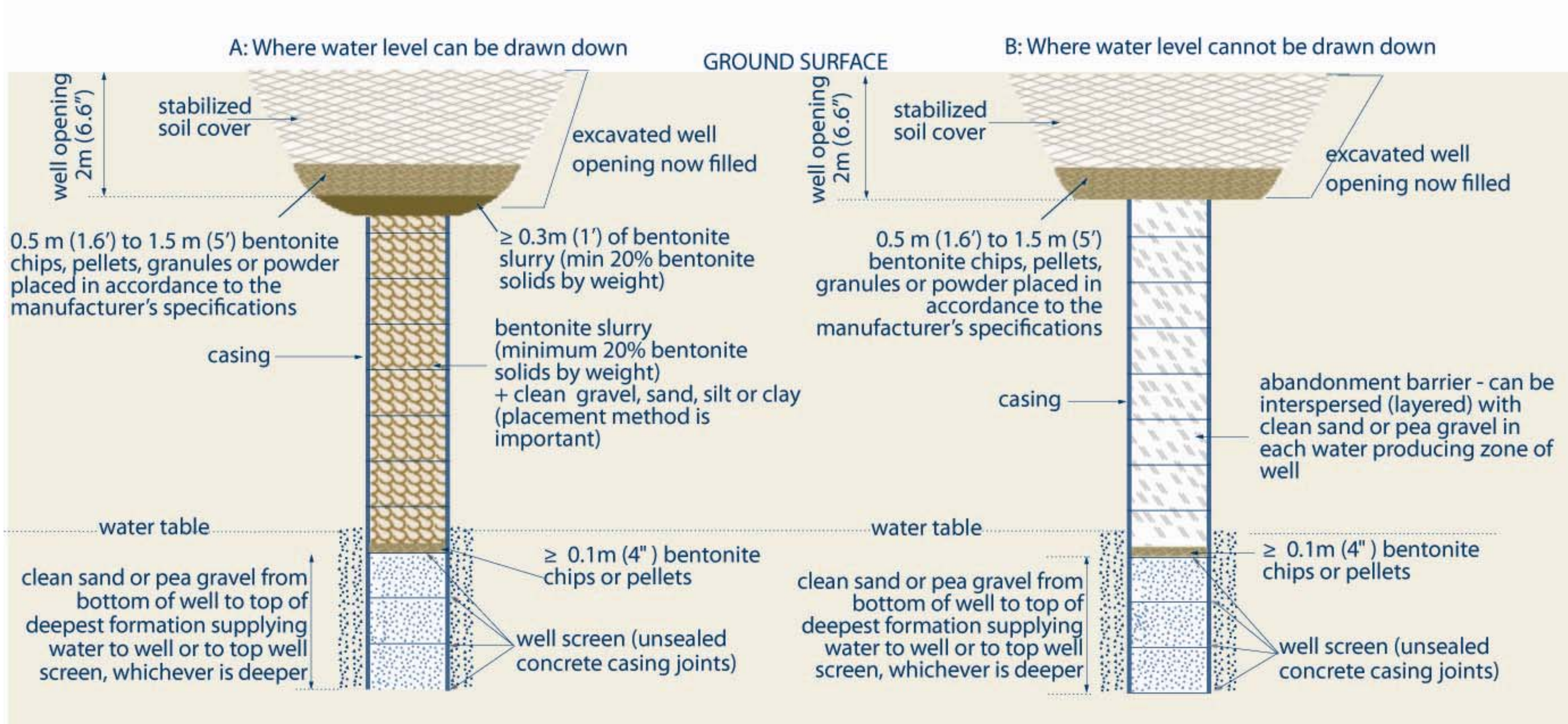


- This is for situations where well casing and well screen are being removed or are absent.
- This is typically for narrow diameter drilled, jetted and driven point wells
- Abandonment barrier must prevent any movement of water, natural gas, contaminants or other materials between subsurface formations (including aquifers), and between a subsurface formations (including an aquifer), and the top of the abandonement barrier
- Water should be added to the bentonite chips, pellets, granules or powder to start hydration
- If well casing and screen are not being removed, the abandonment barrier must be:
  - a slurry of clean water and Portland cement + up to 5% bentonite solids by weight, OR
  - bentonite chips or pellets that have been screened and placed in accordance with manufacturer's specifications.

  At least the top 2 m (6.6') of the casing must be removed, if reasonably possible.
- Well opening is typically excavated to remove the top portion of the well casing.

The diagram above is not to scale and is for illustrative purposes for this Chapter only.

FIGURE 15-40: PLUGGING AND SEALING LARGE DIAMETER WELLS > 65 CM (2.5′) – ALTERNATE METHODS



- This alternate method is for large diameter dug or bored wells [i.e. diameter > 65cm (2.5′)].
- Abandonment barrier slurries must be placed using a tremie pipe.
- Soil cover can be other material in keeping with existing adjacent surface material. The soil cover must prevent inadvertent and unauthorized access.
- Abandonment barrier must prevent any movement of water, natural gas, contaminants or other materials between subsurface formations (including aquifers), and between a subsuface formation (including an aquifer), and the top of the abandonment barrier.
- Water should be added to the bentonite chips, pellets, granules or powder to start hydration.
- Well opening is typically excavated to remove the top portion of the well casing.

The well in Diagram 'A' of Figure 15-40, above, is filled with a bentonite slurry (minimum 20% bentonite solids by weight) + clean gravel, sand, silt or clay. Here the placement method is important. See the placement method 3 C on page 50 of this Chapter.

The diagram above is not to scale and is for illustrative purposes for this Chapter only.

Abandonment of Flowing Wells

Where flowing wells cannot be properly controlled or stopped during well construction, they must be properly abandoned. In these cases, the person abandoning the well must ensure that the person who works at the abandonment of the well properly plugs and seals the well to prevent the movement of the free flowing water. Properly plugging and sealing the well should restore the aquifer to its original condition (i.e. prior to the construction of the well).

The cost associated with the abandonment is to be absorbed by the well contractor unless a previously established written contract expressly releases the well contractor from the cost.

Only licensed well contractors and well technicians with experience in flowing wells should attempt to plug flowing wells.

If Flow at Surface Can Be Controlled Using Weighted Grouts

If the flow at the surface from the aquifer can be controlled using weighted grouts (abandonment barriers), the abandonment (plugging and sealing) can usually be successfully carried out using a high specific gravity cement based grout, (e.g. neat cement or concrete). In many cases, the casing needs to be removed to expose the upper portion of the water producing zone. This will allow for the concrete or cement to more effectively seal the hole and fill any cavities that may have formed around the outside of the well casing, and restore the aquifer to its original condition.

The downhole hydrostatic head pressure and downward grout pressure need to be calculated to determine the density and type of material (e.g. concrete) needed to stop the flow of groundwater from the aquifer (see Chapter 12: *Flowing Wells* for additional information). This abandonment barrier must be placed upward from the bottom of the well using a tremie pipe.

If Flow at Surface Cannot Be Controlled Using Weighted Grouts

If it is not possible to control the flow using weighted grouts, then it may be necessary to offset and drill a properly constructed depressurization (relief) well or wells. These relief wells must be constructed and pumped to reduce the flowing head conditions at the encountered well. Once the flowing conditions are controlled, proper abandonment of the flowing well can proceed. However, extreme caution must be used when constructing the relief wells as there have been many cases where the relief wells did not work or became problem flowing wells themselves. The relief wells would then have to be properly abandoned.

Other techniques such as freezing with liquid nitrogen have been successfully used to temporarily seal the aquifer around the well and allow for the placement of abandonment material.

If the well is a flowing well, commercially manufactured drilling mud that does not impair the quality of the water that it comes into contact with may be used to assist with drilling or the placement of an abandonment barrier, however, drilling mud is not allowed to be used as an abandonment barrier.

Best Management Practice – Retaining Professional Expertise

The person abandoning the well should consider retaining a *Professional Geoscientist* or *Professional Engineer* to determine the type of abandonment barrier materials to use in the abandonment of the flowing well and to prepare a design to plug the flowing well.

Figures 15-41 to 15-46 (below) show the specialized equipment and materials necessary to seal a high pressure flowing well to protect property, surface water and prevent adverse effects on the natural environment.

FIGURE 15-41: FLOWING WELL AT BACK OF DRILLING RIG

Figure 15-41 shows the casing of the drilled well extending just above the ground surface behind the drilling rig. The drill rods are attached to the drilling rig and extend down into the well casing. In this case, the well is approximately 21 m (69′) deep. Groundwater and drilling mud are flowing from the working casing to a horizontal pipe and discharging into a tank. Flowing water from the well cannot be stopped and is freely flowing into the tank with the drilling mud sediment. The discharged material and water are directed into a prepared and approved sediment discharge and settling area on the site. In this case, the well driller could not stop the high pressure of the flowing groundwater out of the well with a weighted drilling mud and had to abandon the well (see Figures 15-46 to 15-50).

FIGURE 15-42: ATTACHING TREMIE PIPE TO TRUCK

In Figure 15-42 and Figure 15-43, the consultants and drillers determined the best way to seal this high pressure flowing well was to remove nearly all of the well casing in the well. The consultant calculated that 3.5 m (11.5′) of concrete would supply sufficient weight to overcome the downhole hydrostatic head pressure and stop the flow. The consultant also determined a high pressure specialized cement pump truck would be necessary to pump the concrete at a high rate into the hole to ensure the material's weight would quickly overcome the groundwater's downhole hydrostatic head pressure. Figure 15-42 shows the persons working on the abandoned well attaching the top of the tremie pipe to the cement pump truck (on left side of photograph).

FIGURE 15-43: TREMIE PIPE GOING INTO FLOWING WELL

Figure 15-43 shows the tremie pipe going into the flowing well behind the drilling rig. The bottom of the tremie pipe was installed near the bottom of the well. In the background a cement truck with more than the calculated volume of concrete and cement pump truck are standing by to start the pumping operation.

FIGURE 15-44: CONCRETE PUMPING OPERATION

Figure 15-44 shows the cement pump truck with its boom in the air and over the drilling rig almost prepared for the pumping of concrete into the flowing well. The cement truck is backing up to the cement pump truck to begin the plugging operation.

FIGURE 15-45: PUMPING CONCRETE

Figure 15-45 shows the concrete being pumped at a high rate into the flowing well. The concrete is displacing the remaining water in the well. The water is discharging from the well onto the surface and into a controlled sediment settling area. The consultant and well owner had obtained a Permit to Take Water since the flowing well was discharging at a rate greater than 50,000 litres per day.

FIGURE 15-46: FLOW STOPPED

Figure 15-46 shows that the placement of 3.5 cubic metres (123.6 cubic feet) of concrete within a few minutes has stopped the flow of water out of the well. The aquifer has been sealed and restored to its original state. The concrete will cure and act as a permanent seal. The entire well casing was removed exposing the open hole at surface. The upper portion of the well opening will be properly plugged.

WELLS WITHIN LARGER DIAMETER WELLS OR WELL PITS

When a well is to be abandoned, the **Wells Regulation** requires the filling, plugging and sealing of the entire well. Different materials and filling procedures apply to wells of different diameters.

In some cases existing wells consist of drilled wells that were installed through dug or bored wells. The drilled wells are typically small diameter wells and the dug or bored wells have diameters greater than 65 cm (26″).

In other cases, drilled wells are installed in well pits. For the purpose of well abandonment, well pits are considered wells and must be properly plugged and sealed as outlined in this chapter. When considering the type of abandonment barrier to be installed in the well, the:

- Drilled well portion of the well (less than or equal to 65 cm (26″)) should be sealed in accordance with step 3 (A) on page 45 up to about two metres below the land surface; and
- Large diameter portion of the dug well or well pit must be sealed in accordance with step 3 (A) or as an alternative Step 3 (C) on page 50.

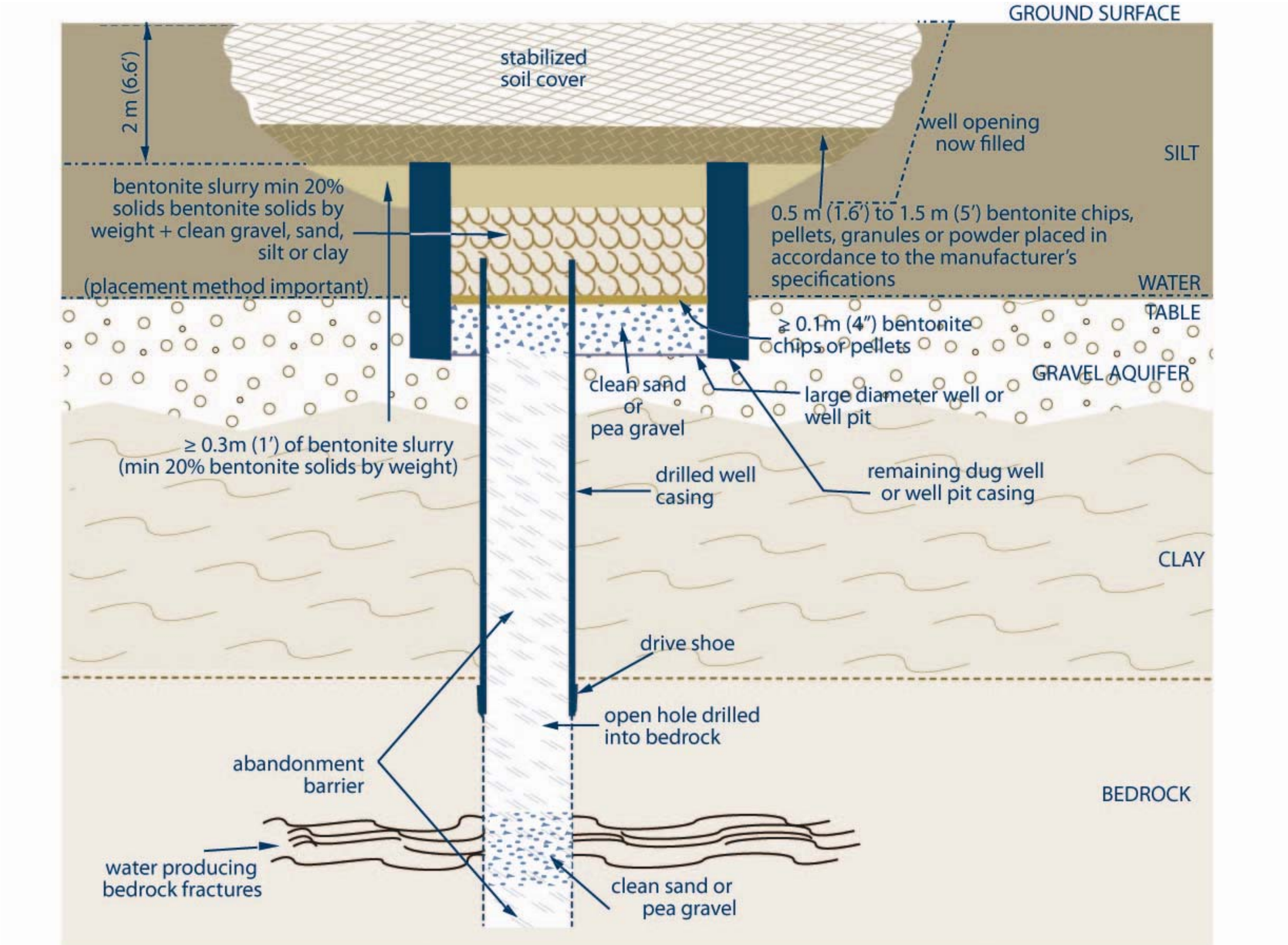
With respect to the removal of both large and small diameter casings, a person must follow Steps 2, 4 and 5 of the nine sequential steps to plug and seal a well (pages 32 and 52).

The person abandoning the well must then ensure the remaining steps in the filling, plugging and sealing of the abandoned well are completed.

There are many cases of existing drilled wells housed in well pits. For improved maintenance and sanitary protection, many of these wells are being altered to extend the top of the drilled well casing above the ground surface and the well pits are being plugged and sealed. If the well owner decides to continue to use the drilled well, with the new casing extension, and to abandon the well pit:

- the person abandoning the well pit portion of the well (often the well owner) must ensure the well pit is abandoned, with necessary modifications, as if it were a well, and
- the person constructing (altering) the well and the well owner should review the information found in the section titled: “Extension of Well Casing for a Well in a Well Pit,” in Chapter 11: *Maintenance & Repair*.

FIGURE 15-47: PLUGGING AND SEALING A DRILLED WELL THROUGH A LARGE DIAMETER DUG WELL OR WELL PIT



- Requirements for wells >6.5 cm (2.5″) apply to the drilled portion of the well, and alternate method for wells >65cm (2.5') could be used from the bottom of the dug well or well pit up to the ground surface.
- Abandonment barrier slurries must be placed using a tremie pipe.
- Soil cover can be other material in keeping with existing adjacent surface material. The soil cover must prevent any movement of water, natural gas, contaminants or other materials between subsurface formations (including aquifers), and between a subsurface formation (including an aquifer), and the top of the abandonment barrier
- Water should be added to the bentonite chips, pellets, granules or powder to start hydration
- Well opening is typically excavated to remove the top portion of well casing.

If water cannot be pumped down to the top of the 0.1 m (4″) of bentonite chips or pellets see Figure 15-42 and Step 3 (C) (page 50 of this chapter) for material placement method.

The diagram above is not to scale and is for illustrative purposes for this chapter only.

EXCAVATING THE ENTIRE WELL

Ontario

The person who abandons a well by excavating the entire well in the course of work carried out for another purpose does not need to meet the nine step sequential process but must do each of the following:

- Ensure the contract with the well contractor requires the person working on the excavation possesses a valid well technician licence of the prescribed class and is employed by a licensed contractor unless exempt by the **Wells Regulation**
- If a well tag is present, return the well tag to the Director within 30 days after its removal
- Complete a well record and submit the record to the owner of the land and Ministry (see Chapter 13: *Well Records, Documentation, Reporting and Tagging* for further information and see the section titled *After the Well is Plugged and Sealed* in this Chapter for further information)

Work carried out for another purpose that involves the entire removal of the well by excavation could include any of the following:

- Installing a new building foundation
- Excavating elevator shafts
- Removing overburden and other materials that are on a contaminated site
- Excavating to create a pond, trench or lagoon
- Excavating in an open pit mine, quarry or sand and gravel pit

A plan for development at a site that may excavate an entire well in the future does not exempt the well owner from the requirement to immediately abandon a well that is not being used or maintained for future use as a well. In these cases, the person abandoning the well must follow the nine (9) sequential steps to plug and seal the well and not wait until the future excavation occurs.

Unless exempt, the person abandoning the well must retain the services of a holder of a well contractor licence and ensure that the contract between them requires that a well technician licensed to construct the type of well that is being abandoned is used to abandon the well. For more information on this issue see Chapter 3: *Well Construction Licences: Obtaining, Maintaining & Exemptions*.

After the Well is Plugged and Sealed

1) Complete and Submit a Well Record

The person abandoning the well (often the well owner) must obtain a blank well record form from the Ministry of the Environment if the person does not already have a record.

The person abandoning the well must fully complete the well record form by following the directions on the back of the well record form and any other instruction sheet that may come with the well record.

After the well construction equipment has been removed from the site, the person abandoning the well has a maximum of 14 days to provide the owner of the land with a copy of the well record and a maximum of 30 days to forward the well record to the Ministry of the Environment. Instructions on how to deliver the well record form to the Ministry are provided on the back of the well record.

The person working at the abandonment of a well can assist the person abandoning the well (often the well owner) in completing the well record and delivering the well record to the Ministry (see Chapter 13: *Well Records, Documentation, Reporting & Tagging* for additional information on the well record).

Best Management Practice – Attaching Written Approval to Well Record

If an alternative abandonment barrier has been approved by the Director and installed in the well, the person abandoning the well should attach the original written approval to the Ministry's copy of the well record and submit a copy of both the record and written approval to the Ministry within the required timeframe. A copy of the written approval should be submitted to the owner of the land along with the well record. The person abandoning the well should retain a copy of the written approval with the well record for future reference.

2) Important Information for the Well Owner

After the well has been plugged and sealed the following key information should be provided to the well owner by the person who worked at the abandonment of the well:

- Additional maintenance (e.g. landscaping) may be required because the top soil layer or other material at the surface might settle immediately after the abandonment or later
- Relevant safety issues, such as avoiding any digging on or around the plugged and sealed well. For example, if the plugging material in a flowing well is accidentally hit by a large excavating machine, the seal may be compromised and allow water to flow up to the ground surface potentially creating adverse effects (e.g. flooding, property damage)
- The importance of the well abandonment information on the well record for future reference (e.g. location, abandonment details)

Best Management Practice – Maintaining Area to Prevent Erosion

It is important that the owner of the land maintain the ground surface around the plugged and sealed well to prevent any erosion.

Best Management Practice – Recommending that the Well Owner Make Extra Copies of Well Record

It is recommended that the well owner make additional copies of the well record and keep the copies in a location where they can be easily found such as one or more of the following:

- Beside the pumping equipment
- With mortgage papers
- Land property survey
- In a safety deposit box

The well owner should provide all well records for wells including the abandoned wells when the property is transferred to a new owner. The new well owner will then have knowledge of the location and status of the wells on the property to prevent:

- Well damage from any new excavations or building on the property, and
- Well contamination from any new source of contaminants constructed near a well.

Who Can Be Contacted For Information Or Assistance?

The local Ministry of the Environment office can be found in the telephone book. The local environmental officer should be able to answer questions or provide other contacts with Ministry experts on wells. The Ministry's website: www.ene.gov.on.ca also provides information on water and water wells.

Licensed well contractors (e.g. drilling, excavating and pump installation) can be found in the telephone book or on the internet under water well drilling and services. The Ministry maintains an online database of licensed well contractor at www.wellwater.ca.

Professional Geoscientists or *Professional Engineers* can be found in the telephone book or on the internet under Environmental Consultants or on the associations' web sites at www.apgo.net or www.peo.on.ca.

Is There Funding Available for Private Well Owners?

In some cases, provincial funding may be available to pay for a portion of the well abandonment costs. If funding is available, it is usually distributed through the local conservation authority. A local conservation authority can be found in the blue pages of the telephone book or on the internet at http://www.svca.on.ca/calinks.htm.