WATER SUPPLY WELL GUIDELINES



for use in DEVELOPING COUNTRIES

THIRD EDITION

"More people die from unsafe water than from all forms of violence, including war."

– UN Secretary-General Ban Ki-moon

“Drinking water supply well drilling & pump installer services, when properly performed, do more to extend the average life expectancy and improve the quality of life in developing countries than all the medical doctors.”

- *Anonymous*

WATER SUPPLY WELL GUIDELINES for use in DEVELOPING COUNTRIES

Third Edition

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PREFACE

Presentations by individuals working in developing countries prompted further discussion at the 2008 National Ground Water Association (NGWA) Expo about the need for standards. That discussion resulted in the creation of draft guidelines (originally referred to as standards) related to water supply wells and their well head appurtenances for use in developing countries.

The initial draft was first presented for comment at the June 2009 Groundwater for the Americas conference in Panama City, Panama where the concept and draft document attracted significant attention.

Subsequent drafts were presented for review and comment at the:

- October 2009 International WaTER Conference, University of Oklahoma, Norman, OK
- December 2009 NGWA Expo in New Orleans, LA
- November 2010 American Water Resources Association (AWRA) Annual Conference in Philadelphia, PA.

Considerable national and international input resulted from these conferences and via e-mail list circulations, web postings and other discussion/reviews. The document came to fruition and the first edition was published in October 2011 and initially presented at the 2011 International WaTER Conference in Norman, OK.

The first edition was enthusiastically received. Many constructive comments were subsequently provided resulting in the second edition (2012). Further comments and insight, especially from the 36th WEDC International Conference in Nakuru, Kenya in 2013, prompted this third edition. It is hoped and expected that comments and suggestions will continue to be provided, which will result in further refinements.

These well guidelines are intended to support those working with groundwater systems in developing countries. The document is a teaching, reference and administrative tool, designed especially for those intimately involved in improving the quality and quantity of water in developing countries.

Endorsements by government and non-government organizations (NGOs), especially those involved in improving the quality and quantity of drinking water in developing countries, are encouraged.

TABLE OF CONTENTS

1 PURPOSE & USE

These guidelines are considered minimum requirements for basic protection of the groundwater resource and for the health and safety of those that develop and use the resource. These guidelines are intended to address basic water supply well construction, pumping equipment, and maintenance issues. Water supply wells include wells designed for domestic, municipal, community, industrial, commercial, irrigation and/or livestock water supply use in addition to aquifer storage (injection) and recovery wells.

These guidelines are encouraged to be used as an education and training tool as well as an everyday field guide for those performing the work. These guidelines may also be used as a basis in establishing national, regional or local standards in regions where there are no standards or very limited standards. Reference No. 4, page 54, is an example of a well standard. These guidelines may also be useful for establishing specifications in procurement or construction documents and hydrophilanthropic agreements.

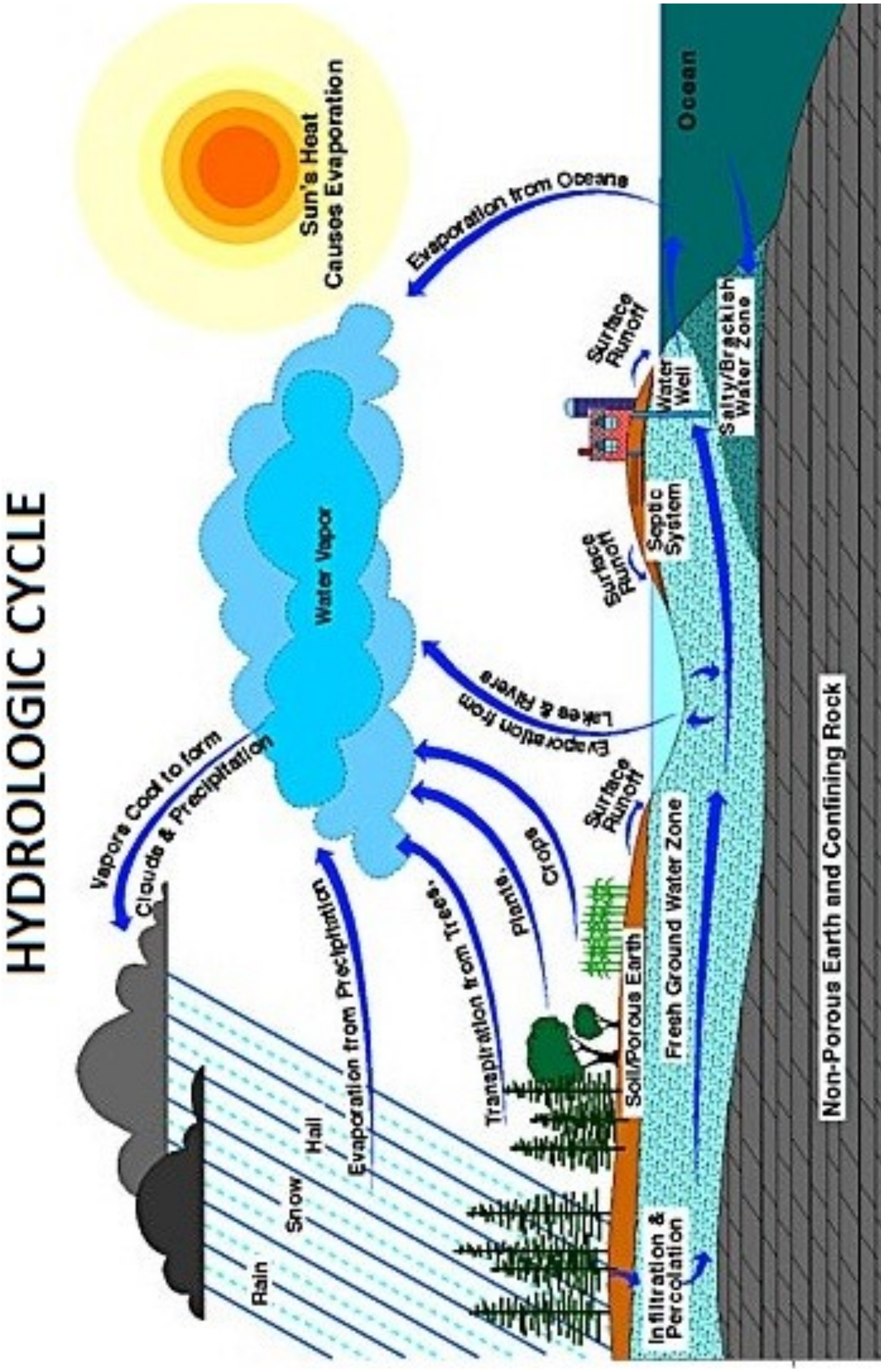
This document is not intended to include or limit the countless means, methods and designs for the work except in unique situations where appropriate. It is up to those responsible for the construction to determine the appropriate means, methods and design. Regardless, hand dug or excavated wells are not encouraged by these guidelines given that there is not a strong consensus as to the appropriateness of this type of well construction. Hand dug or excavated wells pose significant concern for the safety of those constructing, maintaining and using such wells. In addition, the difficulty of constructing and maintaining a sanitary supply that is free of harmful pathogens using the dug well technique argue against the practice except where there is no reasonable alternative. In those situations, it should be considered a preliminary or temporary practice unless such wells are constructed in conformance to this document.

Water well construction is not for amateurs. It is always recommended that whenever possible, appropriately skilled and reputable local individuals, companies or agencies be encouraged to perform the work addressed herein. However, when those individuals or entities are not available, these guidelines can be used to assist in the training of local citizens toward becoming skilled service providers. They should also be made available to those using the groundwater supply systems as a guide to facilitate in the long-term, safe, sanitary use and protection of the groundwater resource.

If there are standards, rules or laws in effect and applicable by other authorities, the more restrictive criteria for each requirement should be followed. These guidelines are not intended to replace any local, municipal, provincial, national or other laws or standards; these guidelines are meant to supplement such laws or standards, or in the absence thereof, to be considered the minimum standard. Respect should be afforded all licensing, permitting, construction, and other applicable laws in each area of each country.

These guidelines are written utilizing wording that suggests more of a recommendation than a mandate. For example, you will notice the use of the word "should" for most requirements. This is done because, in many rural undeveloped areas, the availability of materials specified herein or the cost of compliance may be inappropriate when considering the lives at stake. If it is desired to use these guidelines as a mandatory requirement, substitute the word "shall" or "must" for "should". Refer to the definitions in section 4, pages 7 and 8. For a publication using the mandatory language, contact the principal author.

FIGURE 1

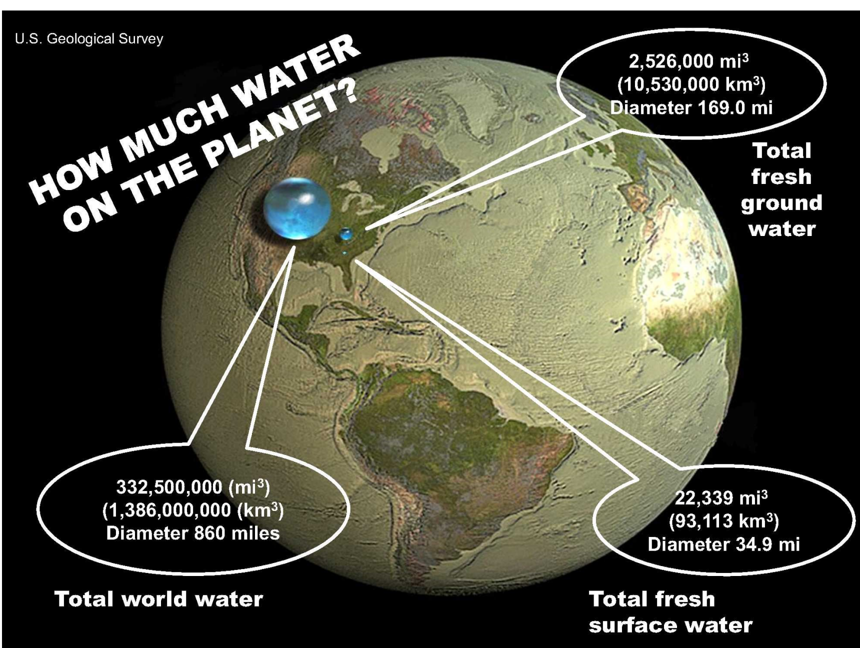

HYDROLOGIC CYCLE
Sun's Heat Causes Evaporation
Evaporation from Oceans
Ocean
Water Vapor
Vapors Cool to form Clouds & Precipitation
Rain
Snow
Hail
Evaporation from Precipitation
Transpiration from Trees,
Plants,
Crops
Evaporation from Lakes & Rivers
Surface Runoff
Surface Runoff
Surface Runoff
Septic System
Water Well
Salty/Brackish Water Zone
Soil/Porous Earth
Fresh Ground Water Zone
Infiltration & Percolation
Non-Porous Earth and Confining Rock

2 GROUNDWATER AVAILABILITY

Water is in perennial motion as exhibited by the Hydrologic Cycle (Figure 1). Our planet has the same amount of water today as we did yesterday and will have tomorrow. Water is being naturally recycled by nature even with man's constant diversion, use and quality alterations. The earth often acts as a natural filter for much of the earth's fresh water, especially in filtering out most harmful pathogens.

Most of the liquid water on earth is saline; less than 1% of all water on the planet is considered fresh water (Figure 2). However, of all the fresh water on earth, it may be surprising to find that there is over 100 times more fresh groundwater than there is fresh surface water. With the depletion of available supplies of surface water, which often contains harmful pathogens or chemicals, groundwater holds the promise as the source for much our future safe drinking water supplies.

FIGURE 2



3 COST BENEFIT

J. Whinnery in 2012 (Reference No. 6, page 54) developed a Cost-Benefit Analysis (CBA) that compared the costs and benefits of properly completed wells versus inferior completed wells. The CBA revealed the following:

- Almost 40 times more benefit, than cost, is provided with a properly constructed, operated and maintained well system.
- There is approximately 5 times more net value realized solely as a result of the implementation of an operation and maintenance (O&M) program.
- Wells providing localized poor water quality should not be considered acceptable.

  Construction of such a well results in a negative net present value; that is, there is more cost than benefit (a benefit-cost ratio less than 1).
- A properly constructed well will have at least 3 times more net value than an inferior well.

  The multiplier approaches infinity if water quality has also been compromised in the inferior well.
- Inferior construction that results in groundwater contamination or aquifer damage should not be considered acceptable.

  Although it is not specifically analyzed in the CBA, it can be inferred that well construction which compromises aquifer quality or results in loss of aquifer head (e.g. commingling of aquifers or uncontrolled artesian pressure), will have negative impacts in the form of reduced large-scale benefits in addition to added costs of remediation or mitigation. These negative impacts will most certainly result in a negative net present value.

4 DEFINITIONS

Aquifer — A geologic formation, group of formations, or part of a formation that contains saturated and permeable material capable of transmitting water in sufficient quantity to supply wells or springs and that contains water that is similar throughout in characteristics such as potentiometric surface head, chemistry, and temperature.

Annulus — The space between the outside diameter of a casing or liner and the borehole wall or the inside diameter of another casing or liner. It is synonymous with annular space.

Artesian aquifer — A confined aquifer in which groundwater rises above the level at which it was first encountered, whether or not the water flows at land surface.

Backfill — Inorganic material placed or left in a part of the well or its annulus that is not sealant, filter pack or formation stabilizer. It may be used to provide temporary or permanent support for a well intake assembly, for a liner or casing, for filter pack or formation stabilizer, or for sealant. Backfill may also be used as a barrier to prevent undesirable migration of a fluid sealant prior to it taking solid form.

Casing — The pipe that is a permanent part of the well, which extends above the ground surface, and around which an annular seal is placed. Casing in a well may be of multiple diameters and connected at size changes by welding, threading, grouting or with a minimum 2 meter [6 feet] overlap if the overlap is above the static water level.

Commingling — Flow or leakage of groundwater within a well (e.g. within the casing, liner, screen, borehole and/or annulus) from one aquifer to another aquifer, resulting from gravity flow or artesian pressure.

Consolidated formation — Materials that have become firm and coherent through natural rock-forming processes. These include, but are not limited to, basalt, sandstone, claystone, shale, limestone, dolomite and granite.

Drill fluid — Water, air, or mud (with or without additives) used down the borehole during well construction. Drill fluid functions may include: hole stabilization, carrying or temporarily supporting cuttings, cooling of the drill bit.

Filter pack — Sand, gravel or a manufactured material (e.g. glass beads) placed in the annulus of the well between the borehole wall and the well intake assembly to control formation material from entering the well through the well intake. Filter pack should be clean, well rounded, uniform siliceous material. See Appendix I.

Formation stabilizer — Sand or gravel placed in the annulus of the well between the borehole wall and the well intake to provide temporary or long-term support for the borehole. Formation stabilizer is not designed to control formation material from entering the well through the well intake.

Gravel pack — A term that is becoming less commonly used. It is sometimes used synonymously with filter pack or considered a type of filter pack. It also has been used to describe gravel used as formation stabilizer and/or backfill.

Head — The elevation to which water rises to as a result of pressure. Head is usually expressed in meters [feet].

Liner — Pipe in the well that is not part of a pump but is used to line the borehole wall to prevent collapse. An annular seal is never placed around a liner.

May — Means the statement in which it is used expresses a specification that is suggestive, optional and is not mandatory.

Must — Means the statement in which it is used expresses a mandatory requirement or obligation that allows no exceptions.

Permeability — The ability of a formation to transmit water.

Potable water — Water that is safe enough to be consumed by humans with low risk of immediate or long term harm.

Potentiometric surface — An imaginary surface representing the level to which water will rise in a well as a result of pressure under which it is confined in an aquifer.

Shall — Means the statement in which it is used expresses a mandatory requirement or obligation that allows no exceptions.

Should — Means the statement expresses a requirement or an obligation that allows an exception only if extreme conditions warrant otherwise.

Unconsolidated formation — Sediment that is naturally occurring, loosely cemented, or poorly indurated including clay, sand, silt and gravel.

Static Water Level (SWL) —The level of water in a well that is not being affected by withdrawal of groundwater. Affects of withdrawal include withdrawal from other wells, flowing artesian, and recovery after withdrawal has stopped. SWL is usually expressed in meters [feet] below a specified point such as top of casing or ground surface. For flowing artesian wells, it may be expressed as pressure (kPa [psi]) or in head of water at the surface.

Transmissivity — The rate at which water is transmitted through a unit width of aquifer under a unit hydraulic gradient.

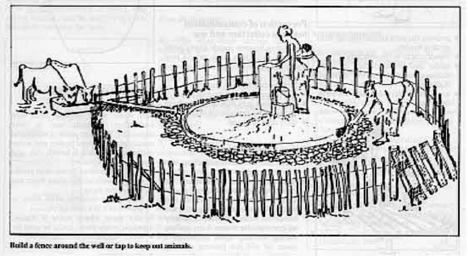
Well — Any artificial opening or any artificially altered natural opening, however made, by which groundwater is sought or through which groundwater flows under natural pressure, or is artificially withdrawn or injected.

Well intake — The screen or perforated interval of a well that is designed to allow water to enter into the well.

5 WELL LOCATION

Every well should be located in an area that is:

- at least 30 meters [98 feet] from any part of a human waste disposal area (e.g. septic drainfield, latrine),
- at least 15 meters [49 feet] from any food or related wastewater disposal area (e.g. kitchen and/or laundry wash water disposal areas),
- at least 30 meters [98 feet] from any confined animal feeding areas, animal housing or manure storage, and



- at least 150 meters [492 feet] from any solid waste landfill (dump) or chemical or industrial waste disposal area.

See Figure 3, page 10.

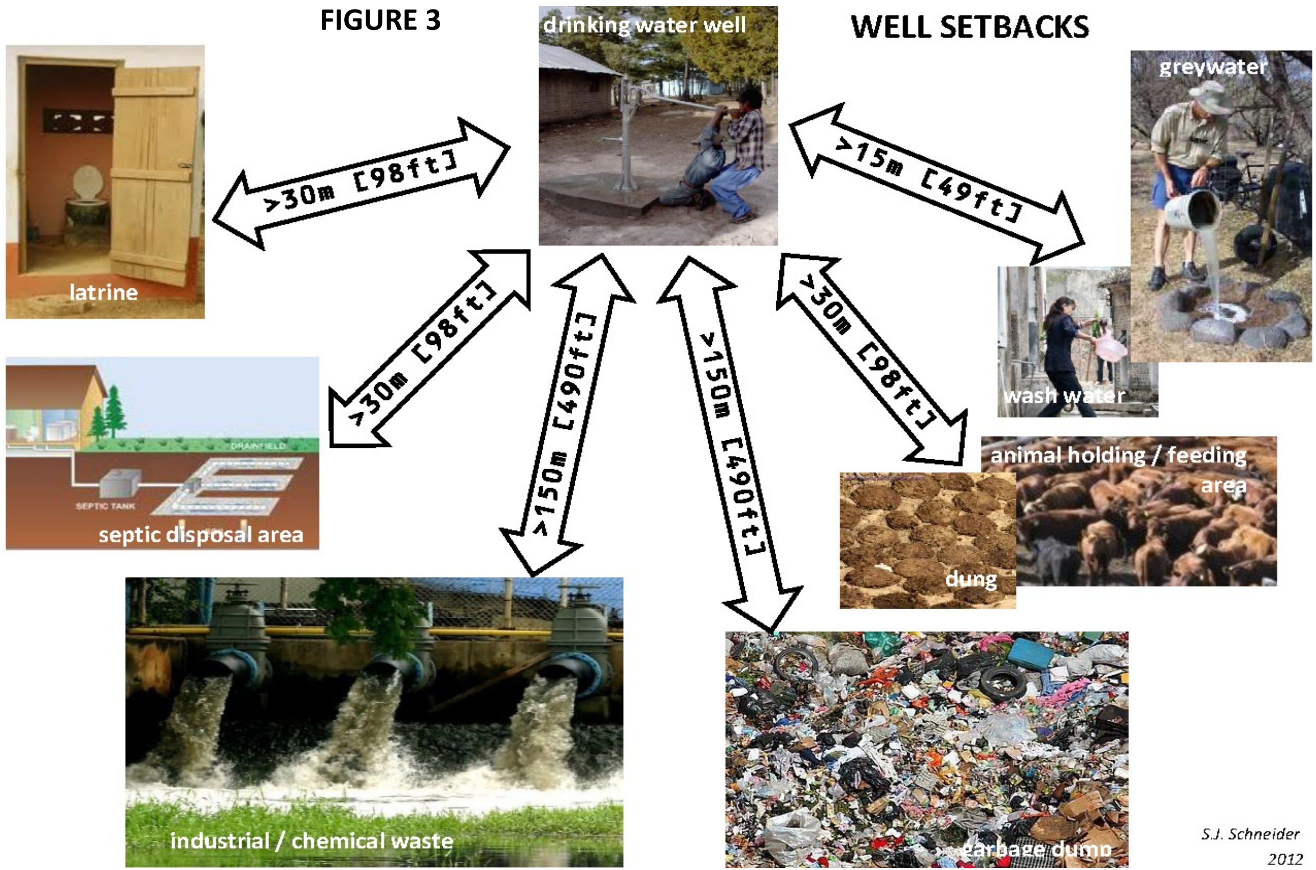
In addition, every well should be located in an area that is:

- up-gradient of the preceding identified areas whenever possible (i.e. at a higher land surface elevation, or if the groundwater flow direction is known, then at a location of higher groundwater head),

Surface water entering a well.

FIGURE 3

WELL SETBACKS



- reasonably accessible to the beneficiaries if it is also the point of water distribution for individuals,
- protected from contamination from wild and open-range animals and livestock,
- outside of floodplains and areas prone to regular flooding from surface rainwater drainage (e.g. if established, outside of 100 year floodplain without other criteria specified herein) unless the well has a more extensive annular surface seal than specified herein and its casing is extended above the highest known flood level,
- close to power if the well is to be connected to an electric pump,
- reasonably available for future servicing of the well, and
- protected from vandalism.

6 DRILLING METHODS

There is a variety of well construction techniques available. The method used must take into consideration the available equipment, personnel skills, well design, and geology. For more details on this, a professional (e.g. a licensed or otherwise credentialed well driller or a hydrogeologist or engineer trained and experienced in well construction techniques and design) should be utilized to assist in determining well design, construction methods, and equipment selection. Again, **this is not an area for amateurs.** Common drilling methods utilized today include:

- Cable tool (percussion) - Air rotary -Mud rotary

- Auger - Reverse circulation rotary

Variations and combinations of these methods are often used in constructing a well.

Most methods use machine powered rigs; however, manual drilling techniques applying one or more of the aforementioned methods are sometimes used for shallow well construction in mostly favorable unconsolidated formations. Manual drilling should not be confused with hand digging or excavation of wells. Manual drilling is any drilling process wherein the drilling action (e.g. rotating or raising & lowering an auger or bit) is performed by individuals rather than being powered by a machine. Manual drilling requires the workers to be in excellent physical condition and to be well trained in the technique used.

7 DRILLING PRODUCTS

Introduction of contaminants during well construction is always a concern.

Water utilized in the constructing of wells should be potable. If a potable supply is not available, construction water should be

disinfected prior to being utilized. The well should be protected from allowing surface runoff from entering the well during construction.

Organic materials of any kind should not be used as part of a drilling fluid or to assist with lost circulation, etc. This includes but is not limited to:

- animal waste products (e.g. cow dung),
- compost or soil containing roots or other vegetation,
- nuts or hulls,
- wood products, and
- petroleum based products.

If undesirable lost circulation is encountered, inert lost circulation materials are commercially available. Inert mineral aggregate may also satisfactorily control a lost circulation zone. Often a change in drilling method is required (e.g. utilizing a method that advances casing while drilling).

8 WELL ANNULAR SURFACE SEAL

Every well **must** have an annular surface seal surrounding the permanent casing to prevent shallow and surface contaminants from entering the well. The seal should extend to at least 5 meters [16.4 feet] below ground surface or to the top of the target aquifer if the top of the aquifer is less than 5 meters [16.4 feet] below ground surface. It is cautioned that aquifers shallower than 5 meters [16.4 feet] are much more prone to contamination and, if available, a deeper source should be sought.

Additional seal depth may be required to:

- **prevent commingling (see Section 9, page 27),**
- **satisfactorily control leaking artesian aquifer conditions within a well or at the surface, or**
- **properly exclude contaminants from entering a well.**

In addition to the above, annular surface seals should extend at least 1.5 meters [4.9 feet] into a very low permeability formation (i.e. clay, competent rock) located below 5 meters [16.4 feet], if present. This is especially important if in an area prone to flooding. If a low permeability formation is not present, the seal should meet the aforementioned minimum depth and also extend below the top of the static water level. Proper annular seal depth and design is often dependent on the local geology.

<u>The annular surface seal is one of the most important components of a well.</u> (see Figures 4-9)

SEALANT MATERIALS — Sealant must not contain any organic material. Sealant should have very low permeability. Sealant materials include:

- **CEMENT GROUT**—A mix of Portland cement and water proportioned approximately one part water to two parts cement by weight (e.g. 21.5 kg [47 pounds] or 21.5 liters [5.7 gallons] of water to 43 kg [94 pounds] cement).
- **CHIP BENTONITE**—Commercially packaged sodium bentonite chips designed for sealing wells. The chips should be 1-2 cm [⅜-¾ inch] nominal size.
- **CONCRETE**—A mix of Portland cement, water and aggregate. The aggregate should be clean sand and or gravel. The aggregate should be less than 2.5 cm [1 inch]. Cement content should be at least 15% by weight.

If the above sealants are not available, locally available products should be researched for the best available material to create a low porosity, inorganic material that can be properly placed in the annulus and that will not measurably shrink. Drilling fluid, drill cuttings, or a combination thereof should not be considered an acceptable sealant.

Table 1

MINIMUM BOREHOLE DIAMETERS for ANNULAR SEAL INTERVALS

		Sealant							
		cement grout	cement grout	cement grout	chip bentonite	chip bentonite	chip bentonite	chip bentonite	concrete
Criteria	**Minimum additional borehole diameter** (amount larger than the largest outside diameter of the casing or its coupling, bell, or other circumferential attachment)	>4cm [>1.6in]	>8cm [>3in]	>4cm [>1.6in]	>8cm [>3in]	>8cm [>3in]	>8cm [>3in]	>8cm [>3in]	>20cm [>8in]
	A. Depth of seal interval below ground surface	<30m [98ft]	any	any	<30m [98ft]	<300m [980ft]	<300m [980ft]	<300m [980ft]	any
	B. Water in seal interval	not allowed	allowed	allowed	not allowed	not allowed	<15m [49ft]	<150m [<492ft]	not allowed
	D. Drill fluid (mud) in seal interval	not allowed	allowed	allowed	not allowed	not allowed	not allowed	not allowed	not allowed
	D. Grout pipe used in annulus	no	yes	no	not applicable	not applicable	not applicable	not applicable	no
	E. Grout placed through casing via cementing plugs or grout pipe	no	no	yes	not applicable	not applicable	not applicable	not applicable	no
	F. Coupling, bell or other circumferential device used on casing	allowed	allowed	allowed	allowed	not allowed	allowed	not allowed	allowed

The additional diameter of the seal interval must be compatible with the selected sealant and criteria A through F.

S.J. Schneider - 2012

PLACEMENT OF SEALANT — An oversized borehole must be constructed to contain the sealant. The casing should be centered in the borehole to assure the sealant totally surrounds the casing throughout the seal interval. Types and locations of centering devices vary with the seal material being used, the depth of the seal interval and the method of seal placement. The size of the annulus is dependent on the sealant material, the depth of the seal, how the sealant is placed, casing size and type of casing connection (see Table 1, page 15):

- **CEMENT GROUT Placement** — (see Figures 4-9)

  ⇒ Cement grout may be placed by pouring from the surface if:

  ♦ it will not be placed through standing water or a liquid drill fluid such as silty water or mud,

  ♦ the oversized borehole diameter is at least 4 cm [1.6 inches] larger than the outside diameter of the casing or its coupling, bell or similar circumferential device, whichever is greater, <u>and</u>

  ♦ it is placed at depths less than 30 meters [98 feet].

  ⇒ Cement grout may be placed in standing water or a drill fluid, or at depths greater than 30 meters [98 feet] when it is placed by pumping through a grout (tremie) pipe from the bottom of the seal interval back to surface. The following two methods are available:

  1. <u>Grout pipe placed in the annulus</u>. The pipe should be submerged in the grout at all times during pumping. The grout pipe should be completely removed from the annulus after completion of grout placement. The oversize borehole diameter should be at least 8 cm [3 inches] larger than the outside diameter of the casing or its coupling, bell or other circumferential device, whichever is greater.

2. <u>Grout pipe placed inside the casing</u>. This method forces cement back up the outside of the casing. There are several methods that utilize this approach and it should **only be used with proper training** and allowances for consequences that might occur (e.g. if grout does not return to surface prior to setting up). The oversize borehole diameter in the portion of the well sealed in this manner should be at least 4 cm [1.6 inches] larger than the outside diameter of the casing or its coupling, bell or other circumferential device, whichever is greater.

- **CHIP BENTONITE Placement**— (see Figures 4-9)

  ⇒If there is **no standing water or liquid drill fluid** in the annulus, chip bentonite should be placed as follows:

  a. Drill an oversized borehole diameter that is at least 8 cm [3 inches] larger than the outside diameter of the casing or its coupling, bell or other circumferential attachment, whichever is greater,

  b. Pour the chip bentonite from the surface at a controlled rate not exceeding 50 kg [110 pounds] per minute,

  c. Sound the top of the sealant periodically during placement to assure that it is not bridging,

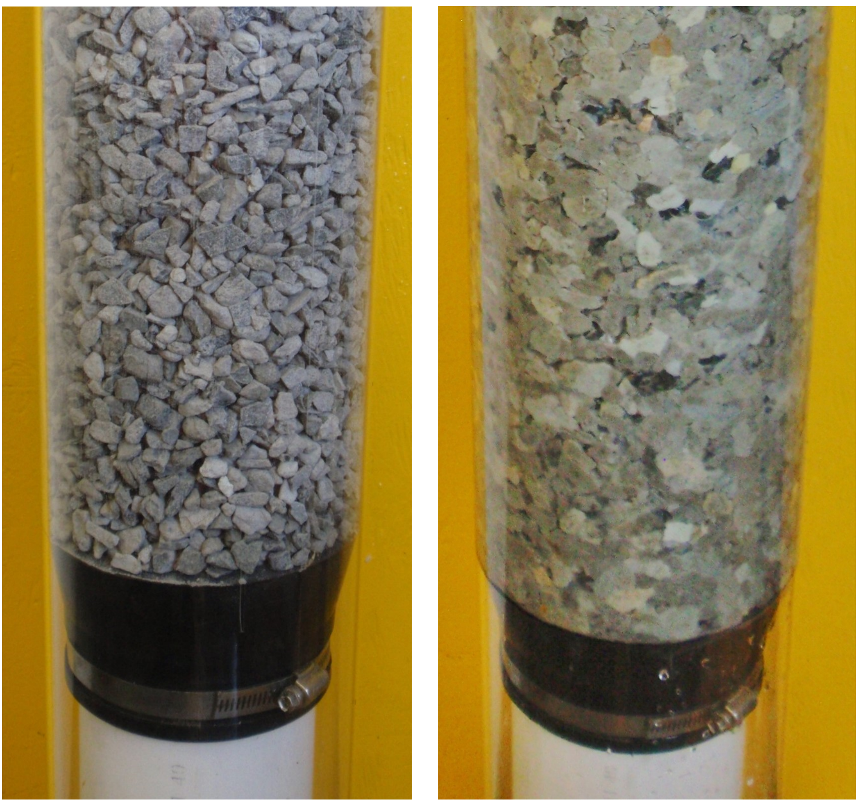
  d. If the casing has a coupling, bell or other circumferential device, do not place at a depth greater than 30 meters [98 feet], and

  e. If using flush connected casing with no circumferential devices, do not place at a depth the depth greater than 300 meters [980 feet].

  ⇒If there is **standing water and no drilling mud**, chip bentonite should be placed as follows:

a. Drill an oversized borehole diameter that is at least 8 cm [3 inches] larger than the outside diameter of the casing or its coupling, bell or other circumferential device, whichever is greater,

b. Screen the chip bentonite during placement to remove dust and fine material that promote bridging by running the chips across an approximately 6 mm [¼ inch] mesh screen formed into a semi-circle and angled toward the well



Chip bentonite before (left) and after (right) initial hydration. The chip bentonite surrounds a white PVC casing positioned inside a clear plastic pipe (for demonstration purposes).
The chips are supported by a shale trap [see Figure 5, page 22].

annulus at an angle to control the pour rate such that the chips are placed at not more than 11 kg [24 pounds] per minute,

c. If using casing that has a coupling, bell or other circumferential device, do not place through more than 15 meters [49 feet] of water, and

d. If using flush connected casing with no circumferential devices, do not place through more than 150 meters [492 feet] of water.

⇒ In arid environments, chip bentonite placed within 5 meters [16 feet] of land surface should be hydrated with clean, uncontaminated water shortly after placement.

⇒ Chip bentonite should not be placed in water having a total dissolved solids (TDS) above 800 milligrams per liter [parts per million] without permission from the manufacturer.

- **CONCRETE Placement**— (see Figures 4-9)
  ⇒ Concrete should never be placed through standing water unless it can be placed through a submerged grout (tremie) pipe, which is often difficult to do.

  ⇒ If there is no water or other fluid in the seal interval and concrete is poured from the surface, the oversized borehole diameter should be at least 20 cm [8 inches] larger than the outside diameter of the casing or its coupling, bell or other circumferential device, whichever is greater.

In all cases of annular seal placement, the amount of sealant actually used should be verified as being adequate to fill the volume of the annulus being sealed (see Table 2).

TABLE 2 - ANNULAR VOLUMES

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ISO UNITS (METRIC)

Neat cement: 1205 kg dry cement/m^3 of slurry

Bentonite chips: 1080 kg/m^3

CASING OUTSIDE DIAMETER (cm)

Bore Hole Dia (cm)	5	10	12	15	20	25	30	35	40	45	50	60
5												
10	0.06											
12	0.09	0.03										
15	0.16	0.10	0.06									
20	0.29	0.24	0.20	0.14								
25	0.47	0.41	0.38	0.31	0.18							
30	0.69	0.63	0.59	0.53	0.39	0.22						
35	0.94	0.88	0.85	0.79	0.65	0.47	0.26					
40	1.24	1.18	1.14	1.08	0.94	0.77	0.55	0.29				
45	1.57	1.51	1.48	1.41	1.28	1.10	0.88	0.63	0.33			
50	1.94	1.88	1.85	1.79	1.65	1.47	1.26	1.00	0.71	0.37		
60	2.81	2.75	2.71	2.65	2.51	2.34	2.12	1.87	1.57	1.24	0.86	
75	4.40	4.34	4.30	4.24	4.10	3.93	3.71	3.46	3.16	2.83	2.45	1.59
90	6.34	6.28	6.25	6.19	6.05	5.87	5.65	5.40	5.11	4.77	4.40	3.53

VOLUME OF ANNULUS
(Cubic Meters / Meter of Depth)

ENGLISH UNITS

Neat cement: 76 lb dry cement/ft^3 of slurry

Bentonite chips: 68 lb/ft^3

CASING OUTSIDE DIAMETER (in)

Bore Hole Dia (in)	2	4	5	6	8	10	12	14	16	18	20	24
2												
4	0.07											
5	0.11	0.05										
6	0.17	0.11	0.06									
8	0.33	0.26	0.21	0.15								
10	0.52	0.46	0.41	0.35	0.20							
12	0.76	0.70	0.65	0.59	0.44	0.24						
14	1.05	0.98	0.93	0.87	0.72	0.52	0.28					
16	1.37	1.31	1.26	1.20	1.05	0.85	0.61	0.33				
18	1.75	1.68	1.63	1.57	1.42	1.22	0.98	0.70	0.37			
20	2.16	2.09	2.05	1.99	1.83	1.64	1.40	1.11	0.79	0.41		
24	3.12	3.05	3.01	2.95	2.79	2.60	2.36	2.07	1.75	1.37	0.96	
30	4.89	4.82	4.77	4.71	4.56	4.36	4.12	3.84	3.51	3.14	2.73	1.77
36	7.05	6.98	6.93	6.87	6.72	6.52	6.28	6.00	5.67	5.30	4.89	3.93

VOLUME OF ANNULUS
(Cubic Feet / Feet of Depth)

FIGURE 4

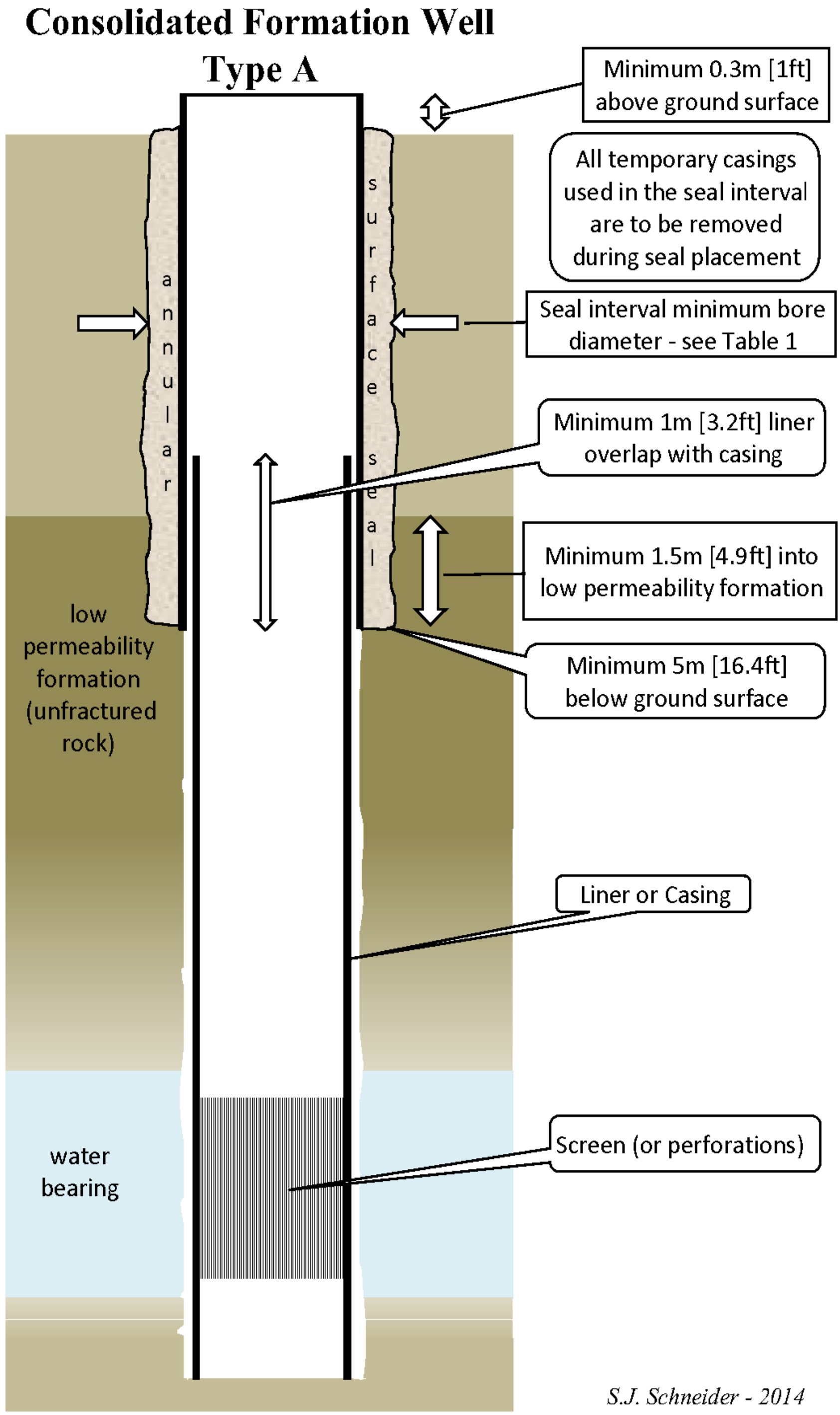

Consolidated Formation Well
Type A
Minimum 0.3m [1ft] above ground surface
All temporary casings used in the seal interval are to be removed during seal placement
Seal interval minimum bore diameter - see Table 1
annular
surface seal
Minimum 1m [3.2ft] liner overlap with casing
Minimum 1.5m [4.9ft] into low permeability formation
Minimum 5m [16.4ft] below ground surface
low permeability formation (unfractured rock)
Liner or Casing
water bearing
Screen (or perforations)
S.J. Schneider - 2014

FIGURE 5

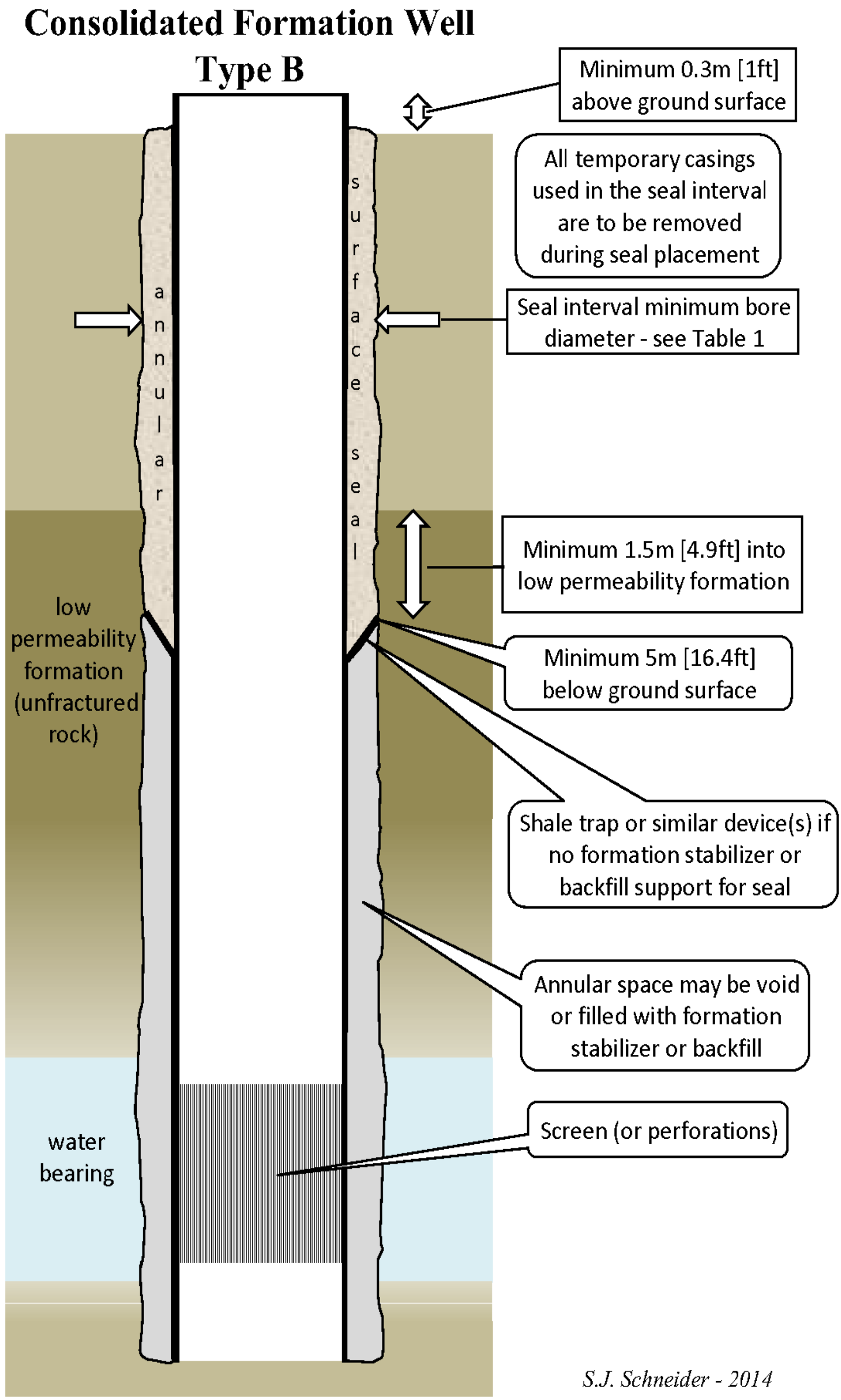
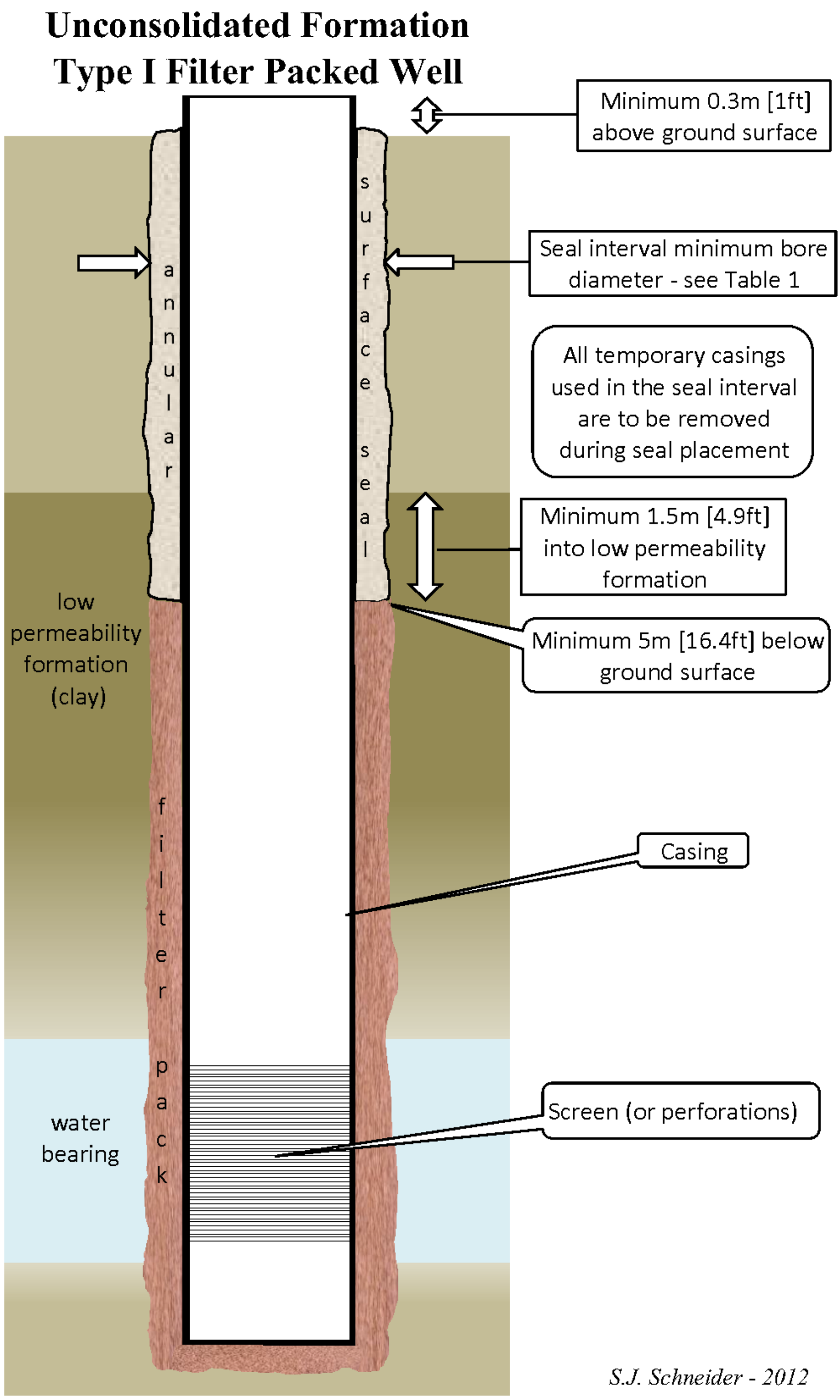

Consolidated Formation Well
Type B
Minimum 0.3m [1ft] above ground surface
All temporary casings used in the seal interval are to be removed during seal placement
Seal interval minimum bore diameter - see Table 1
annular
surface seal
Minimum 1.5m [4.9ft] into low permeability formation
low permeability formation (unfractured rock)
Minimum 5m [16.4ft] below ground surface
Shale trap or similar device(s) if no formation stabilizer or backfill support for seal
Annular space may be void or filled with formation stabilizer or backfill
water bearing
Screen (or perforations)
S.J. Schneider - 2014

FIGURE 6



Unconsolidated Formation
Type I Filter Packed Well
Minimum 0.3m [1ft] above ground surface
Seal interval minimum bore diameter - see Table 1
All temporary casings used in the seal interval are to be removed during seal placement
Minimum 1.5m [4.9ft] into low permeability formation
Minimum 5m [16.4ft] below ground surface
annular
surface seal
low permeability formation (clay)
filter pack
Casing
water bearing
Screen (or perforations)
S.J. Schneider - 2012

FIGURE 7

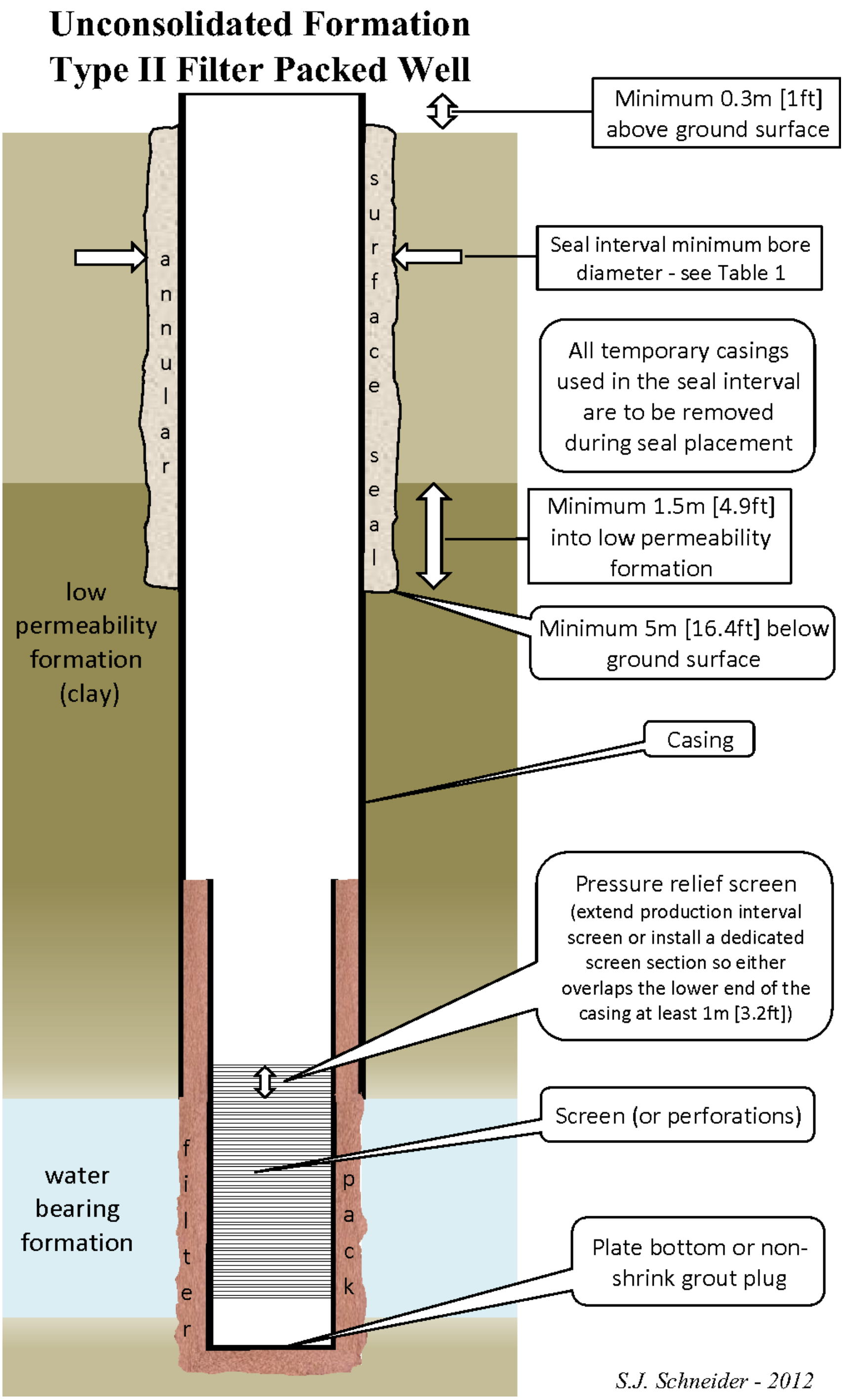
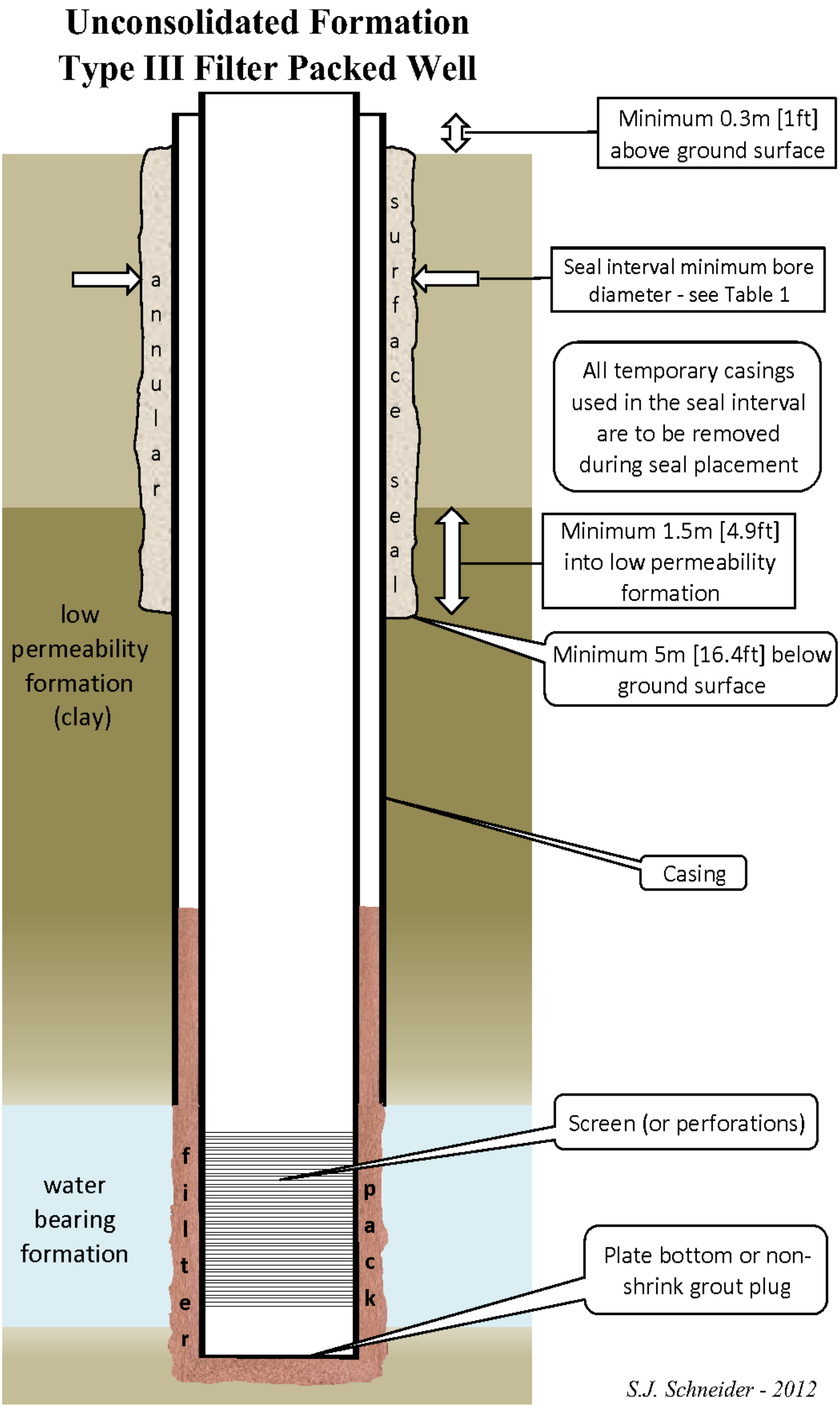
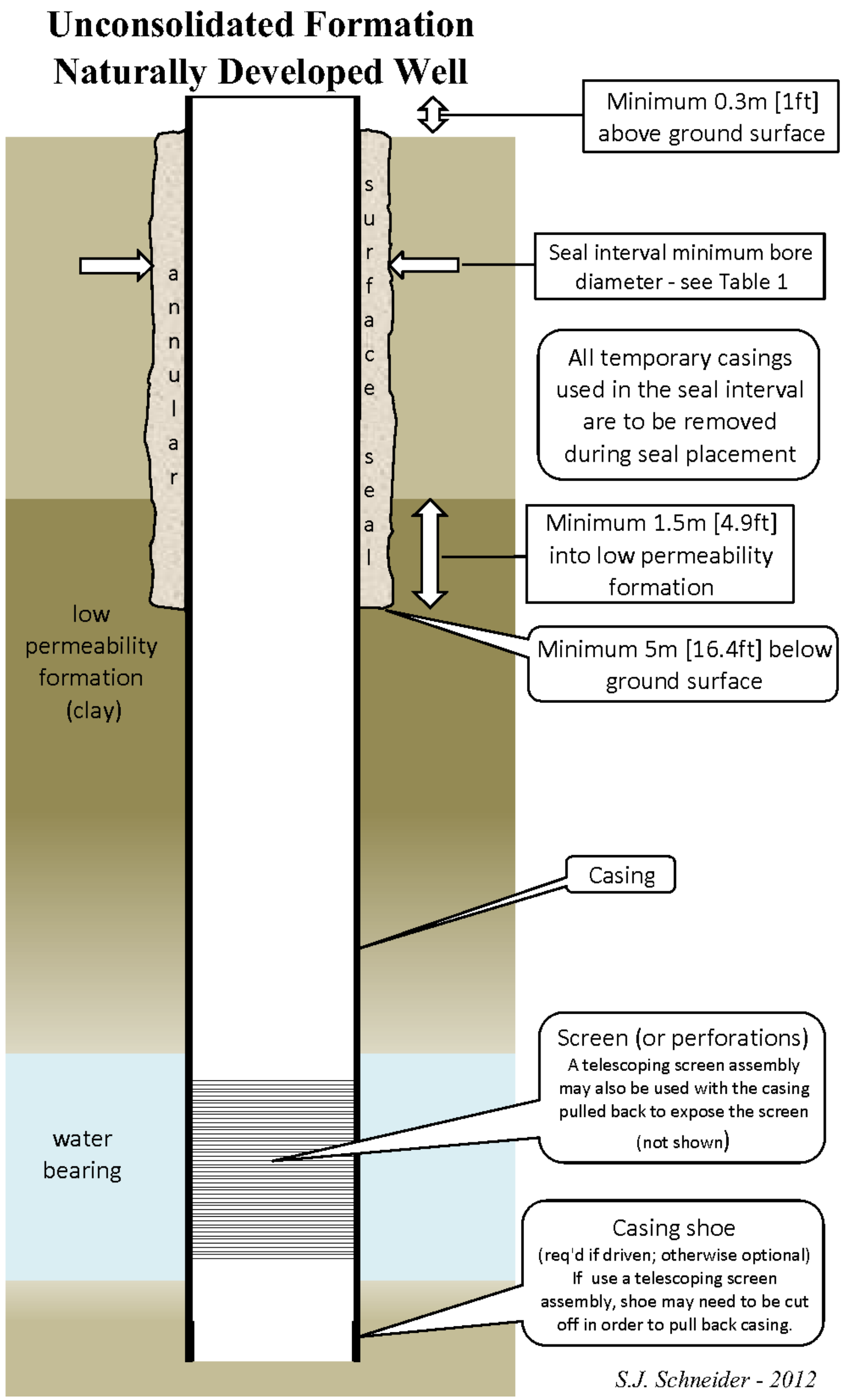

Unconsolidated Formation
Type II Filter Packed Well
Minimum 0.3m [1ft] above ground surface
Seal interval minimum bore diameter - see Table 1
All temporary casings used in the seal interval are to be removed during seal placement
Minimum 1.5m [4.9ft] into low permeability formation
Minimum 5m [16.4ft] below ground surface
Casing
Pressure relief screen (extend production interval screen or install a dedicated screen section so either overlaps the lower end of the casing at least 1m [3.2ft])
Screen (or perforations)
Plate bottom or non-shrink grout plug
annular
surface seal
low permeability formation (clay)
water bearing formation
filter
pack
S.J. Schneider - 2012

FIGURE 8



Unconsolidated Formation
Type III Filter Packed Well
Minimum 0.3m [1ft] above ground surface
Seal interval minimum bore diameter - see Table 1
All temporary casings used in the seal interval are to be removed during seal placement
Minimum 1.5m [4.9ft] into low permeability formation
Minimum 5m [16.4ft] below ground surface
Casing
Screen (or perforations)
Plate bottom or non-shrink grout plug
annular
surface seal
low permeability formation (clay)
water bearing formation
filter
pack
S.J. Schneider - 2012

FIGURE 9



Unconsolidated Formation
Naturally Developed Well
Minimum 0.3m [1ft] above ground surface
annular
surface seal
Seal interval minimum bore diameter - see Table 1
All temporary casings used in the seal interval are to be removed during seal placement
Minimum 1.5m [4.9ft] into low permeability formation
Minimum 5m [16.4ft] below ground surface
low permeability formation (clay)
Casing
Screen (or perforations)
A telescoping screen assembly may also be used with the casing pulled back to expose the screen (not shown)
water bearing
Casing shoe
(req'd if driven; otherwise optional)
If use a telescoping screen assembly, shoe may need to be cut off in order to pull back casing.
S.J. Schneider - 2012

9 COMMINGLING AND LEAKAGE

See Section 4, pages 6 and 7, for definitions of aquifer, artesian aquifer, commingling and head.

If multiple aquifers are encountered in a well, the well should be constructed to prevent commingling and leakage of groundwater by gravity flow or artesian pressure from an aquifer to another aquifer or to an unsaturated zone that is capable of long term acceptance of the water. This will prevent the spread of contaminates or poor quality water to other formations and prevent loss of aquifer head within an aquifer. There should be no water moving up or down the well, either inside or outside the casing or liner when the well is in a completely static (non-pumping) and recovered condition. Prevention may be accomplished by placement of additional surface seal depth or utilizing an additional lower annular seal. (see Figures 11 and 12, pages 31 and 32).

10 CASING AND LINER

See Section 4, pages 6 and 7, for definitions of casing and liner.

Casings and liners should be PVC (polyvinyl chloride) or black steel pipe meeting the specifications of Table 3, page 30.

PVC casing should be protected from long term exposure to sunlight (ultraviolet light). Protection may include an outer steel protector casing, a concrete tile (or masonry box) and lid or cover, a building, a pump, etc.

All casing should be new or like new. It should be cleaned of any contaminants and inspected for any mechanical damage, holes, pitting, etc.

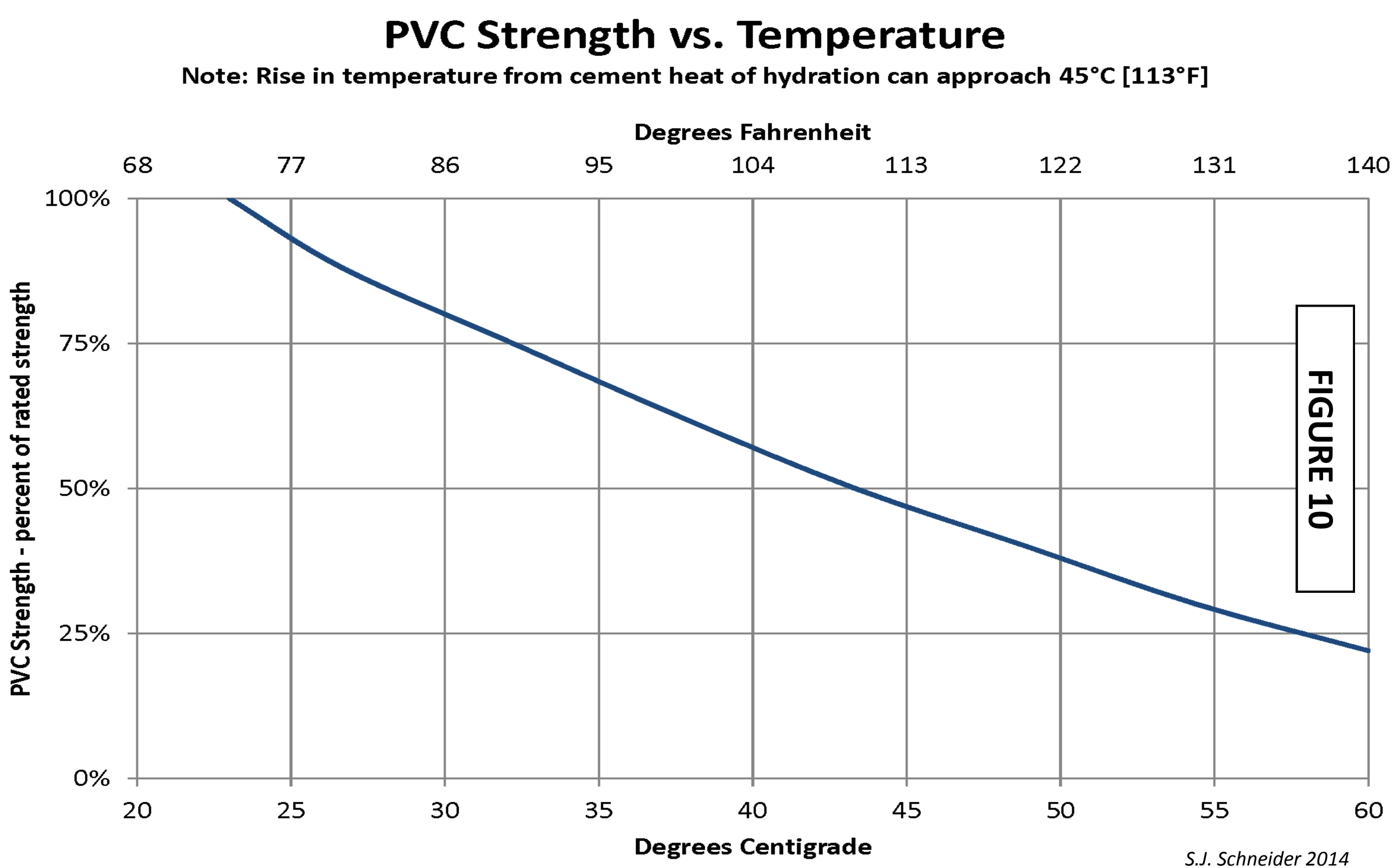
PVC casing should never be driven. If driving steel casing, a drive shoe is recommended.

The casing and or liner diameter should be sized to allow easy placement of the pumping equipment. Typically, the inside diameter of the casing and liner in the pump placement interval of the well should be at least 1 cm [½ inch] larger in diameter than the largest part of the in-well pump components if the pump components are less than 10 cm [3.9 inches]. Larger clearances are always better and should be used with larger pump systems.

CAUTION: If cement grout sealant is used around PVC casing, care should be taken to prevent PVC exposure to excess heat of hydration from cement curing that can permanently deform the pipe. Cement grout placed in excessively large borehole areas (e.g. caverns, voids, wash-outs) will result in a significant increase in heat that will likely cause this to happen which could make the well unusable, requiring its proper decommissioning. If PVC casing is sealed using cement, cold water may be circulated in the well bore during the early curing process (recommend at least 24 hours) to attempt to prevent damage to the casing.

PVC collapsed from excessive heat.
PVC rapidly loses strength with increasing temperature (see Figure 10, page 29).

Nevertheless, it is better to use steel casing (if available) when sealing with cement.



PVC Strength vs. Temperature
Note: Rise in temperature from cement heat of hydration can approach 45°C [113°F]
Degrees Fahrenheit
68
77
86
95
104
113
122
131
140
100%
75%
50%
25%
0%
PVC Strength - percent of rated strength
FIGURE 10
20
25
30
35
40
45
50
55
60
Degrees Centigrade
S.J. Schneider 2014

TABLE 3 - CASING & LINER MATERIALS

diameter mm [in]	maximum depth	material	minimum wall thickness	suggested material standards
< 127 [5]	Note A	low carbon steel	schedule 40	ASTM A53B, API 5L, AS 1395, A120
≤ 355 [14]	Note A	low carbon steel	6.35 mm [.25 in]	ASTM A53B, API 5L, AS 1396
> 355 [14]	Note A	low carbon steel	9.53 mm [.375 in]	ASTM A53B, API 5L, AS 1397
any	30m [98ft]	PVC	SDR 26 (Note B)	ASTM F480, ASTM D2241, ASTM D1785, AS/NZS 1477
any	60m [196ft]	PVC	SDR 21 (Note B)	ASTM F480, ASTM D2241, ASTM D1785, AS/NZS 1478

Note A: Maximum depth and wall thicknesses should be considered based on hydrostatic pressures the casing or liner may see naturally during grouting and during pumping. Wall thickness may also need to be increased based on drilling methods (e.g. driving casing), depth, and other factors that may increase the column and/or collapse loading. Consult technical professionals in these situations.

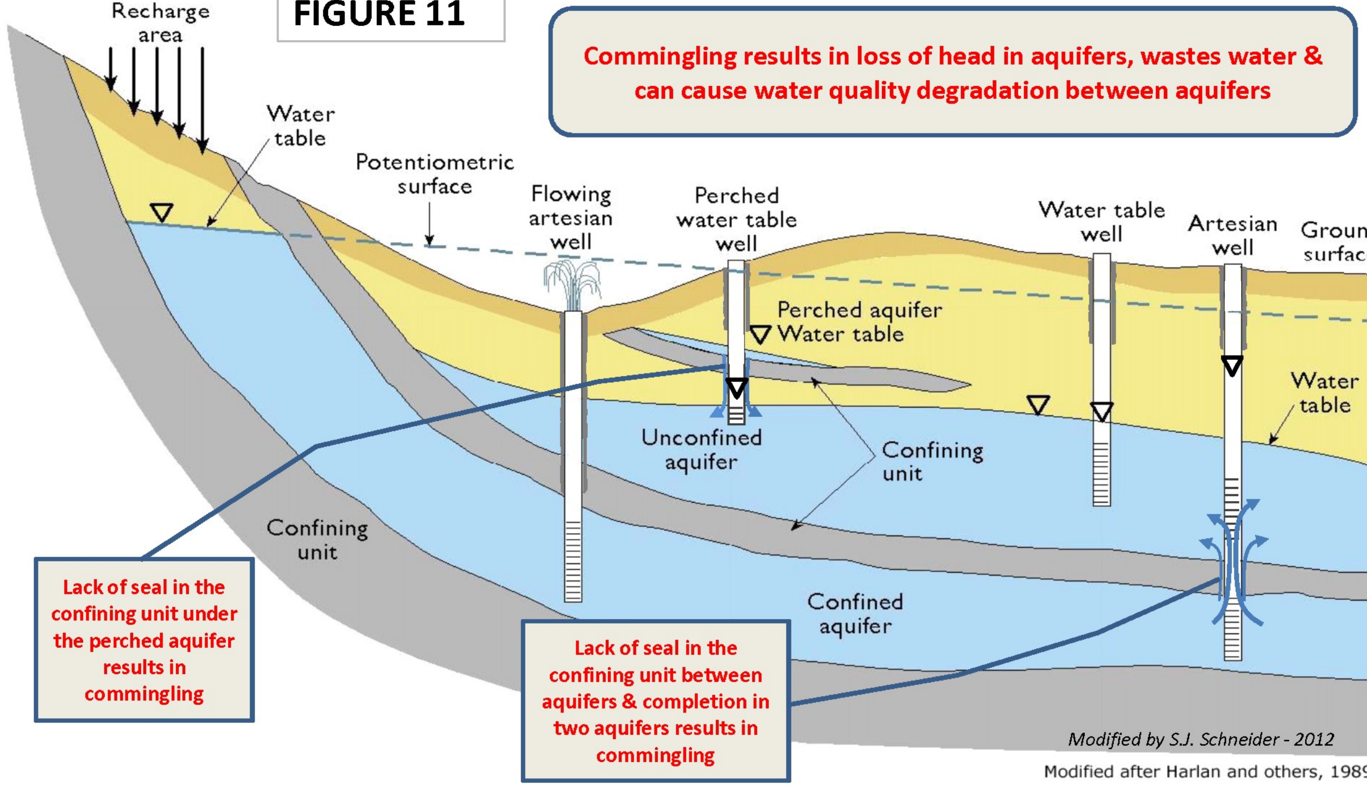
Note B: SDR = Standard Dimension Ratio = pipe outside diameter / pipe wall thickness. If used only as a liner in consolidated formations, depth limit does not apply to SDR 21.

Stainless steel is usually too costly to consider but may be desired for ASR applications or other unique situations. Wall thickness tolerance is often used to the fullest extent possible (minus 10%) on this material. In no event should the resulting wall thickness be less than 4.77 mm [.188 in]. Note A especially applies to these applications.

Fiberglass has less strength than PVC, is normally less available and more costly, hence no specifications are provided herein as it is unlikely it would be selected as a casing or liner material.

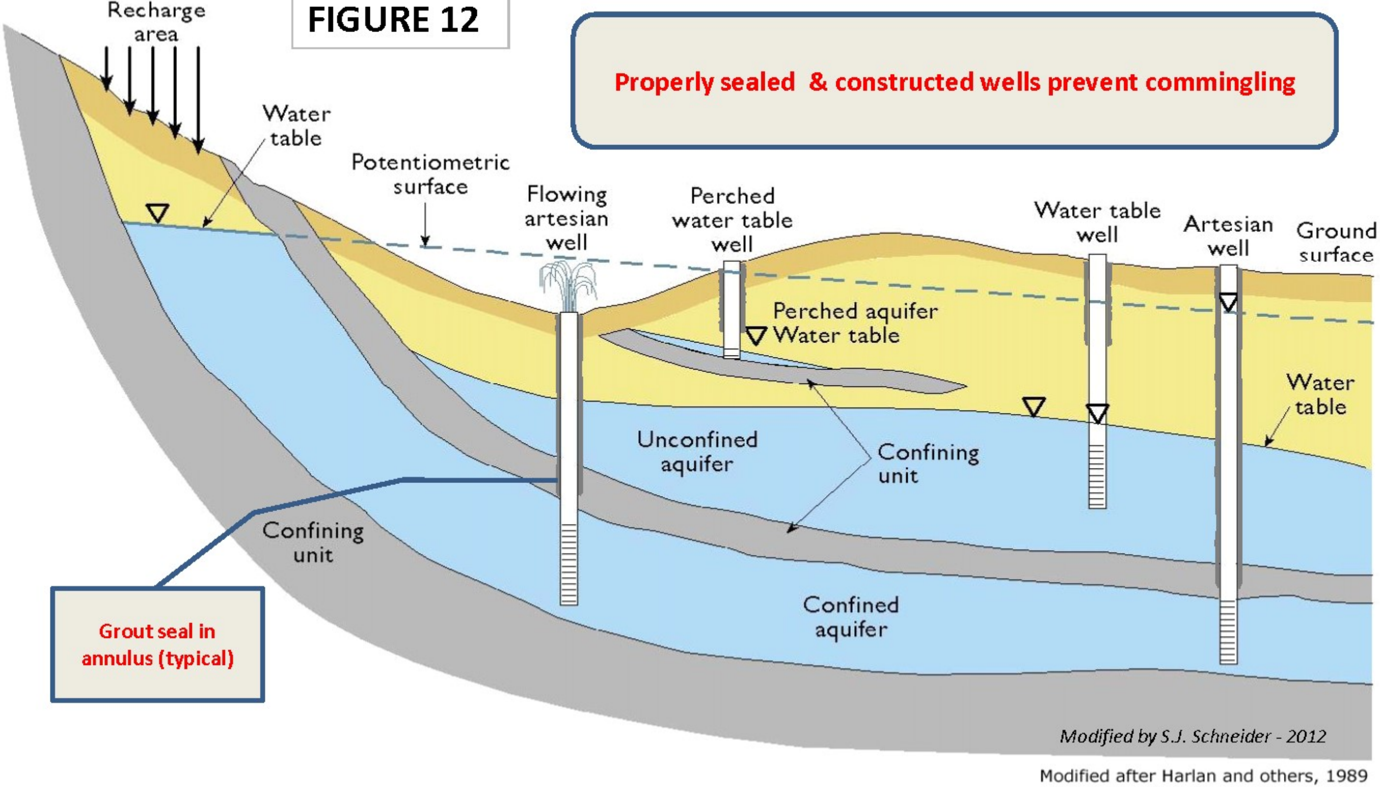
S.J. Schneider - 2012

FIGURE 11



Commingling results in loss of head in aquifers, wastes water & can cause water quality degradation between aquifers
Recharge area
Water table
Potentiometric surface
Flowing artesian well
Perched water table well
Water table well
Artesian well
Ground surface
Perched aquifer
Water table
Unconfined aquifer
Confining unit
Water table
Confining unit
Confined aquifer
Lack of seal in the confining unit under the perched aquifer results in commingling
Lack of seal in the confining unit between aquifers & completion in two aquifers results in commingling
Modified by S.J. Schneider - 2012
Modified after Harlan and others, 1989

FIGURE 12



Properly sealed & constructed wells prevent commingling
Recharge area
Water table
Potentiometric surface
Flowing artesian well
Perched water table well
Perched aquifer
Water table
Water table well
Artesian well
Ground surface
Water table
Unconfined aquifer
Confining unit
Confining unit
Confined aquifer
Grout seal in annulus (typical)
Modified by S.J. Schneider - 2012
Modified after Harlan and others, 1989

11 OTHER WELL MATERIALS

Other well materials, including but not limited to gravel or filter pack media, annular backfill or filler, screens, packers, plugs and shale traps should be clean and free of organic material prior to placement in the well. Proper design, material selection and skilled installation will ensure a satisfactory well completion for its intended use. **Improper screen or filter pack design is the most common cause of a sand producing well.** Such wells result in premature pump failure, degradation of surface seals from subsidence, casing shifting or breaking and poor water quality. These wells are often abandoned without proper decommissioning. There are many publications available to assist with the correct design and selection of screens, filter packs and other unique well materials (see Appendix I, page 48, and Reference No. 3, page 54).

12 PLUMBNESS AND ALIGNMENT

Water supply well plumbness (drift) and alignment is extremely important since wells are usually equipped with down-hole pumps or pumping equipment. Acceptable plumbness and alignment also facilitates well completion and maintenance.

Unless otherwise specified, the well should be plumb within one percent of true vertical. In other words, it should not drift from vertical more than 0.3 meter in 30 meters [1 foot in 100 feet].

There should be no noticeable bends or dog-legs, especially in the portion of the well wherein pumps or pumping equipment is to be installed. Excess misalignment makes screen, liner, pump and other material installation and removal difficult or impossible. In addition, it causes excess or premature wear of the pump equipment or well casing or liner. The well alignment shall be such that its screen assembly, liner(s) and pumping equipment can be freely installed.

13 WELL DEVELOPMENT

All water supply wells should be developed to ensure that they do not produce excessive sand that could cause premature pumping equipment failure and/or compromise the structural integrity of the well. Less than 25 milligrams per liter [parts per million] is recommended. Additional filtration on the surface may still be desired, especially for drinking water. Development also improves the efficiency of the well. There are many publications available to assist with the selection of the proper approach, tools to use and when to use them during a well's construction.

14 SURFACE COMPLETION

The area immediately surrounding a well should be sloped away from the well to drain water from the well vicinity.

If the well is equipped with a hand pump, a raised concrete apron should be placed around the well. The apron should extend at least 10 cm [4 inches] above the highest ground around the well. The casing should extend above the concrete apron as far as the pumping equipment will allow. The apron should extend around the well at least 1 meter [3 feet] in all directions. The apron should

Well head with good apron and drainage

be designed to drain any water, whether from rain or spillage, away from the well.

If the well is not equipped with a hand pump, the casing should extend at least 0.3 meter [1 foot] above the highest ground surface around the well.

All wells should be sealed between the pumping equipment and the well casing. If the well is equipped with a hand pump and concrete apron, the pump base in contact with the apron should be sealed to prevent any liquid from entering.

All wells should be equipped with a vent to prevent vacuum drawing contaminants into the well. The vent should be screened to prevent bugs and insects from entering the well. The vent should be positioned at least 0.3 meter [1 foot] above the concrete apron or highest ground around the well, whichever is higher. The vent should be facing downward to prevent any liquid (and contaminants) from running, or being drawn, into the well through the vent. The vent should be of a rugged design to prevent damage from vandalism and the environment.

All wells should be equipped with an access port in order to measure the water level. The access port should be at least 1.5 cm [0.6 inch] diameter. The access port should be securely plugged (e.g. wrench tightened thread or lock) when not being used to prevent access from unauthorized personnel. Deep wells should be equipped with a dedicated probe pipe, normally attached to the pumping equipment, to facilitate water level measurements. Probe pipes should be at least 1.5 cm [0.6 inch] diameter.

15 DISINFECTION

All wells and the equipment installed in them should be disinfected prior to their use. Chlorine is a commonly used disinfectant. A 50 mg/l [ppm] concentration is commonly accepted for disinfection.

Table 4, page 36 provides suggested quantities of chlorine agents to achieve 50 mg/l [ppm] initial concentration. Depending on the well chemistry and other concerns, additional chlorine may be required to fully effect disinfection. Chlorine disinfectant requires contact time to be effective. At least 12 hours of contact should be allowed. Chlorine is heavier than water. Agitation within the well will result in a better disinfection.

TABLE 4
CHLORINE DISINFECTANT REQUIRED
for 50 mg/l [ppm] CONCENTRATION in
30 METER [98 FEET] of WATER in a WELL

Hole Diameter		Hole Volume		65% Dry Weight*		5% Liquid**	
centi meters	inches	liters	gallons	grams	ounces	liters	ounces
5.1	2	62	16	5	0.2	0.1	2
10.2	4	247	65	19	0.7	0.2	8
12.7	5	386	102	30	1.0	0.4	13
15.2	6	556	147	43	1.5	0.6	19
20.3	8	988	261	76	2.7	1.0	33
25.4	10	1544	408	119	4.2	1.5	52
30.5	12	2224	587	171	6.0	2.2	75
35.6	14	3027	800	232	8.2	3.0	102
40.6	16	3953	1044	304	10.7	4.0	134
45.7	18	5003	1322	384	13.6	5.0	169
50.8	20	6177	1632	474	16.7	6.2	209
61.0	24	8894	2350	683	24.1	8.9	301
76.2	30	13898	3672	1067	37.6	13.9	470
91.4	36	20012	5287	1537	54.2	20.0	677

*65% dry weight is often found as granular calcium chloride.

**5% liquid is often found as liquid bleach.

The quantity of other compounds required to obtain the same concentration is proportional to the above percent concentrations.

The quantity of the above compounds required to obtain a concentration other than 50 mg/l [ppm] is proportional to the above quantities.

Every time in-well equipment is installed or re-installed it should be cleaned and disinfected prior to installation and use. If the well is, or even might be, used for human consumption, it should also be tested for E-coli (see section 16, page 37). Equipment removed from a well awaiting repair before re-installation should never be placed directly on the ground and should be protected from exposure to vegetation, rodents and other animals.

Protect pump and drop pipe from direct contact with the ground during installation and maintenance

16 TESTING

Wells should be tested for yield (flow rate) and basic potability. An appropriate down-hole water level measurement device is required for every well construction or well maintenance project. The static water level in the well should be measured near the beginning of a yield test. Typically, yield testing on low capacity, low demand wells is performed with the permanent pump. Often a simple

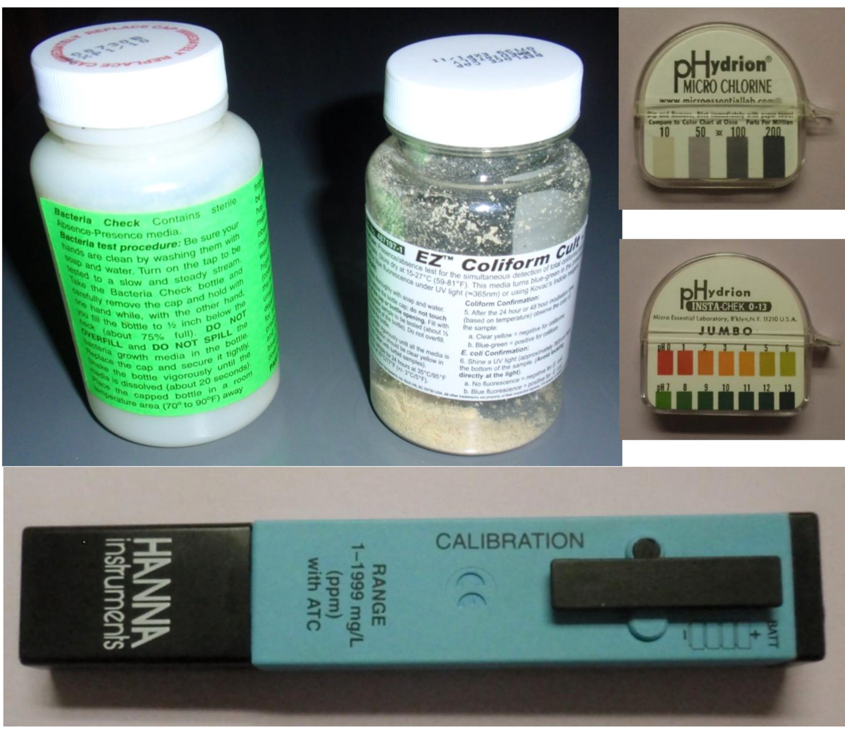
Bucket timing flow from a domestic well

Orifice tube measuring flow from a municipal well

computation using the time it takes to fill a container of known volume is used to determine a flow rate. The duration of the test for small capacity wells should be at least one hour. Large demand wells (e.g. irrigation, community) should be tested longer than an hour, sometimes 24 hours or longer if they will are expected to run continuously for several days. The yield of large demand wells should be measured using more sophisticated measurement devices (e.g. flowmeters or orifice tubes). These devices provide a more accurate determination of the flow rate. In addition, the pumping water level should be taken frequently throughout the yield testing of large demand wells in order to graphically extrapolate the data to forecast long term pumping water level. Such data is also useful for determining well efficiency and aquifer characteristics such as transmissivity.

Each well should be tested for potability after all disinfectant has been thoroughly removed from the well and prior to initial use for human consumption. Potability consists of testing for Escheichia coli (E-coli). **No E-coli shall be present.** A simple method to test for E-coli is to perform a test for coliform bacteria. It there is no coliform bacteria, there is no E-coli; however, a positive coliform test does not necessarily mean that E-coli is present. If a coliform test comes up positive, it is recommend that the well be sampled and tested again (since it is not uncommon to get a false positive) or that it be sampled again and specifically tested for E-coli.

Other tests should be considered depending on the intended use of the well and known or suspected minerals and contaminates in the area. Such other tests include, but are not limited to: nitrates, arsenic, fluoride, salinity, radionuclides.



Basic testers available (CW: coliform, chlorine, PH, TDS)

17 WELL DECOMISSIONING

All wells that are not completed during construction, are damaged beyond repair, or are replaced because they are contaminated should be permanently decommissioned. Permanent decommissioning should restore the boundaries between aquifers and the boundary from ground surface to the first aquifer utilizing sealants specified previously herein. Casing(s) and liner(s) should be removed during decommissioning if possible and feasible.

Chip bentonite for decommissioning should only be used in un-cased and un-lined portions of boreholes. Chip bentonite may be used inside cased portions of a well that has been documented to have been properly annularly sealed as prescribed herein.

If placing cement grout inside a casing or liner, the casing or liner shall be thoroughly perforated to permit the grout to migrate outside of the casing or liner.

Concrete may be used for decommissioning that part of the uncased borehole that is above the water level in the well at the time of placement. It may also be used inside the casing but only if it is used opposite that part of the casing that has been documented to have a proper seal around it. Concrete may also be used to decommission dug wells but only from 1 meter [3 feet] above the static water level and to depths no greater than 15 meters [49 feet].

In all cases of decommissioning, the volume of sealant actually used should be verified as being adequate to fill the volume of the space being sealed (see Table 5, page 41).

If permanent decommissioning is not desired or feasible, all wells shall be properly secured to prohibit children from accessing it and from foreign material or contaminants from entering it.

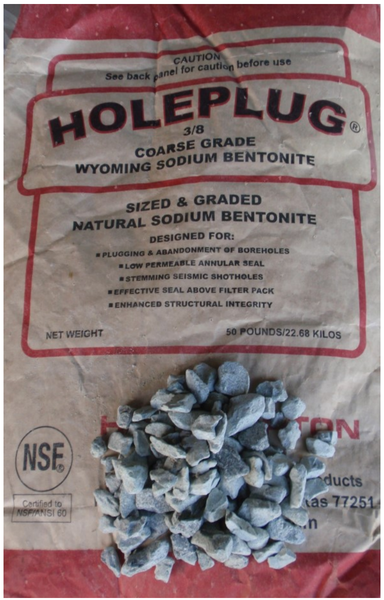


TABLE 5 - WELL VOLUMES & MIMIMUM AMOUNT OF SEALANT REQUIRED FOR DECOMMISSIONING

Hole Diameter		Hole Volume		Bentonite Chips		Neat Cement*	
centi meters	inches	l per m depth	ft^3 per ft depth	kg per m depth	lb per ft. depth	kg per m depth	lb per ft. depth
5.1	2	1.9	0.02	2.0	1.4	3.3	2.3
10.2	4	8.4	0.09	9.2	6.2	15.1	10.1
12.7	5	13.0	0.14	14.2	9.6	23.4	15.8
15.2	6	18.6	0.20	20.3	13.7	33.5	22.5
20.3	8	32.5	0.35	35.6	23.9	58.6	39.4
25.4	10	51.1	0.55	55.9	37.6	92.1	61.9
30.5	12	73.4	0.79	80.3	53.9	132.2	88.9
35.6	14	99.4	1.07	108.7	73.1	179.1	120.4
40.6	16	130.1	1.40	142.2	95.6	234.4	157.5
45.7	18	164.4	1.77	179.8	120.9	296.3	199.1
50.8	20	202.5	2.18	221.5	148.9	364.9	245.3
61.0	24	291.7	3.14	319.0	214.4	525.6	353.3
76.2	30	456.2	4.91	498.9	335.3	821.9	552.4
91.4	36	656.8	7.07	718.3	482.7	1183.5	795.4

*Weight of dry cement mixed with water to form neat cement slurry.
Cement/water slurry ratio is 1.9 kg/l [16 lb/gal or 94 lb sk/6 gallon water]

18 DOCUMENTATION

WELL RECORD

A log or record should be made and maintained on each well (including well decommissioning).

Documentation should include:

- Well location— Two methods should be recorded to minimize error:
    1. GPS (global positioning system), and
    2. Property legal description or other locally used documentable location criteria.

GPS - Essential tool for documenting well location

- Well identification number or nomenclature — The unique number or nomenclature shall be permanently imbedded or attached in/on the concrete apron or the exposed casing (or the pumping equipment if the first two are not an option). The identification number / nomenclature should be recorded on all documents containing the other information specified herein and it should be noted as to where that identification is located on the well.
- Well owner or user — Identify as to whether they are the owner, user or both.
- Well constructor's name and/or organization.
- Depth drilled and depth of completed well.
- Formation description by depth, including: predominant material(s), color, size and hardness or texture.

- Annular seal depth and material used.

- Depth and height above ground of all casings and liners, diameters, types of material (e.g. PVC, steel), and schedules or wall thicknesses.

- Full description (material, size, quantity, etc.) and location by depth of all perforations, screens, pack, and any other component of the well.

- Date and depth to static water level.

- Date and results of yield test.

The log or record of each well's construction details should be filed in accordance with any local regulations. A copy should also be provided to those in charge of operating and maintaining the well

A permanent well identification number or nomenclature should be on every well and in related documentation and it should also be filed in a secure central web based repository that provides public access. (Sample form on next page)

Filings are used to facilitate the operation and maintenance of the well, to aid in the future proper decommissioning of the well, and to identify and quantify the availability of groundwater resources in the area.


SWL measurement with electric probe.

PUMP RECORD

A record should be created by the pump installer, and maintained by the well owner/operator, of the current pump installed in the well. The record should contain the type of pump (e.g. hand, solar submersible, merry-go-round, etc.), drop pipe and rod dimensions as applicable, depth of set, voltage and phase if electric powered, manufacturer, model, serial number and any other pertinent information. (Sample form on page 46)

WATER QUALITY RECORD

Documentation of all water quality tests should be maintained by the owner/operator. Records should include: Dates and results of the chemical tests performed, name of individual obtaining the sample, the source location of the sample, the date that the sample was taken, name of the laboratory or individual performing the analysis, and test method(s) utilized.

WATER SUPPLY WELL REPORT

Well ID # / Name________________________ Location of ID on well______________________

(1) **OWNER**: Land___ User___ Both___

Name

Address

(2) TYPE OF WORK

☐ New Well ☐ Deepening ☐ Alteration (repair/recondition) ☐ Decommissioning

(3) DRILL METHOD:

☐ Rotary Air ☐ Rotary Mud ☐ Cable

☐ Other

(4) PROPOSED USE:

☐ Domestic ☐ Community ☐ Industrial ☐ Irrigation

☐ Thermal ☐ Injection ☐ Livestock ☐ Other

(5) BORE HOLE CONSTRUCTION:

All Depths Are in ____Meters ____Feet Below Ground Surface

Depth of Completed Well __________

HOLE			SEALS			
Diameter	From	To	Material	From	To	Sacks or pounds

How was seal placed:

Backfill placed from______ to______ Material______

Filter pack placed fm ______ to______ Size of pack ______

(6) CASING/LINER:

	Diameter	From	To	Gauge	Steel	Plastic	Welded	Threaded
Casing:					☐	☐	☐	☐
					☐	☐	☐	☐
					☐	☐	☐	☐
					☐	☐	☐	☐
Liner:					☐	☐	☐	☐
					☐	☐	☐	☐

Drive Shoe used ☐ Inside ☐ Outside ☐ None

Final location of shoe(s)

(7) PERFORATIONS/SCREENS:

☐ Perforations Method______

☐ Screens Type______ Material______

From	To	Slot size	Number	Diameter	Tele/pipe size	Casing	Liner
						☐	☐
						☐	☐
						☐	☐
						☐	☐

(8) WELL TESTS: Minimum testing time is 1 hour

☐ Pump ☐ Bailer ☐ Air ☐ Flowing Artesian

Yield gal/min	Drawdown	Drill stem at	Time
			1 hr.

Temperature of water______ Degrees C__ F__

Was a water analysis done? ☐ Yes By whom______

Did any strata contain water not suitable for intended use? ☐ Too little

☐ Salty ☐ Muddy ☐ Odor ☐ Colored ☐ Other______

Depth of strata:______

(9) LOCATION OF WELL GPS:

Latitude______________Longitude______________

Other (legal or locally used documentable location description):

(10) STATIC WATER LEVEL:

________ below land surface. Date ________

Artesian pressure ______ kPa__ PSI__ Date ________

(11) WATER BEARING ZONES:

Depth at which water was first found ______

From	To	Estimated Flow Rate	SWL

(12) WELL LOG:

Ground Elevation ______

Material	From	To	SWL

Date started______________Completed______________

Person or Organization responsible for well's construction:

Name:______________________________

Address______________________________

Phone #______________ E-mail______________

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PUMP INSTALLATION RECORD

Well ID # / nomenclature ____

Owner ____

Type of Owner: Land_____ User_____ Both_____

Date of Installation ____

Type of Pump ____

Manufacturer ____

Model Number ___________________________Serial #__________________

If Electric Powered: Volts_______________Phase____ Amps__________________

Type of Drop Pipe / Column ____

Drop Pipe / Column: Inside Diameter____________Length____________________

Size, type & material of rod / shaft ____

Water Level Access? Probe Tube_____ Plug/Cap______ None______

Water Level Access: Inside Diameter ____________ Material__________________

Well Pump Chamber (e.g. Casing): Inside Diameter_____________Material__________________

Static Water Level ____

Well Depth ____

Installer ____

All Depths Reported Are In: Meters_____ Feet_____ Datum*___________________

All Diameters Reported Are In: Millimeters_____ Inches______

Other Information: ____

____

* Datum is reference from which all depths are reported (e.g. ground surface, top of pad, etc.)

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19 PERSONNEL SAFETY

Well construction and pump installation usually involves operation of power driven equipment with part of the machinery operating over the operators head. Tools and equipment can be heavy and are often dropped. Dust is often created during the drilling operation and sealant materials may give off harmful dust during their use. Personal protection equipment (PPE) should always be used as appropriate for the operation.

PPE required would likely include:

- Hard Hat
- Gloves
- Dust Mask
- Eye Protection
- Leather Shoes
- Hearing Protection

APPENDIX I

Filter (gravel) Pack – Analysis and Selection

<u>Sand Aquifer</u> — Procedures

1. Choose the water bearing zones (WBZs) that will potentially be used.

Balance, shaker and sieves used for sieve analysis

2. Perform a sieve analysis (see figure 13, page 50) on each of the selected WBZs that can visually be identified to potentially have the finest material. A sieve analysis does not need to be performed on every sample taken.

3. Using the sieve analysis, identify the WBZ that will be utilized having the finest material. In some wells, an identified WBZ may have finer material than desired and if there are sufficient coarser WBZs available, the finest WBZ may not be used. In such case, the well design should have no well intake openings near unused fine WBZs; that is, there should be no openings from at least 2 meters (6 feet) below to at least 1 meter (3 feet) above a fine WBZ. An even larger separation length will be cause for an increased assurance that such a WBZ will not contribute sand to the well.

4. Using the formation sieve analyses of the WBZ with the finest material that will be exposed, multiply its 70% retained size by a factor of 4 to 6. The result is the target value range for the 70% retained size of the filter pack.

5. Perform a sieve analysis on any candidate filter pack material that does not already have an analysis provided. Candidate filter pack material should:

a. Be clean,
b. Have well rounded grains,
c. Contain at least 90% quartz or silica, and
d. Be uniform in size. A uniformity coefficient (UC - the ratio of the 40% retained size to the 90% retained size) of less than 2.5 is preferred.

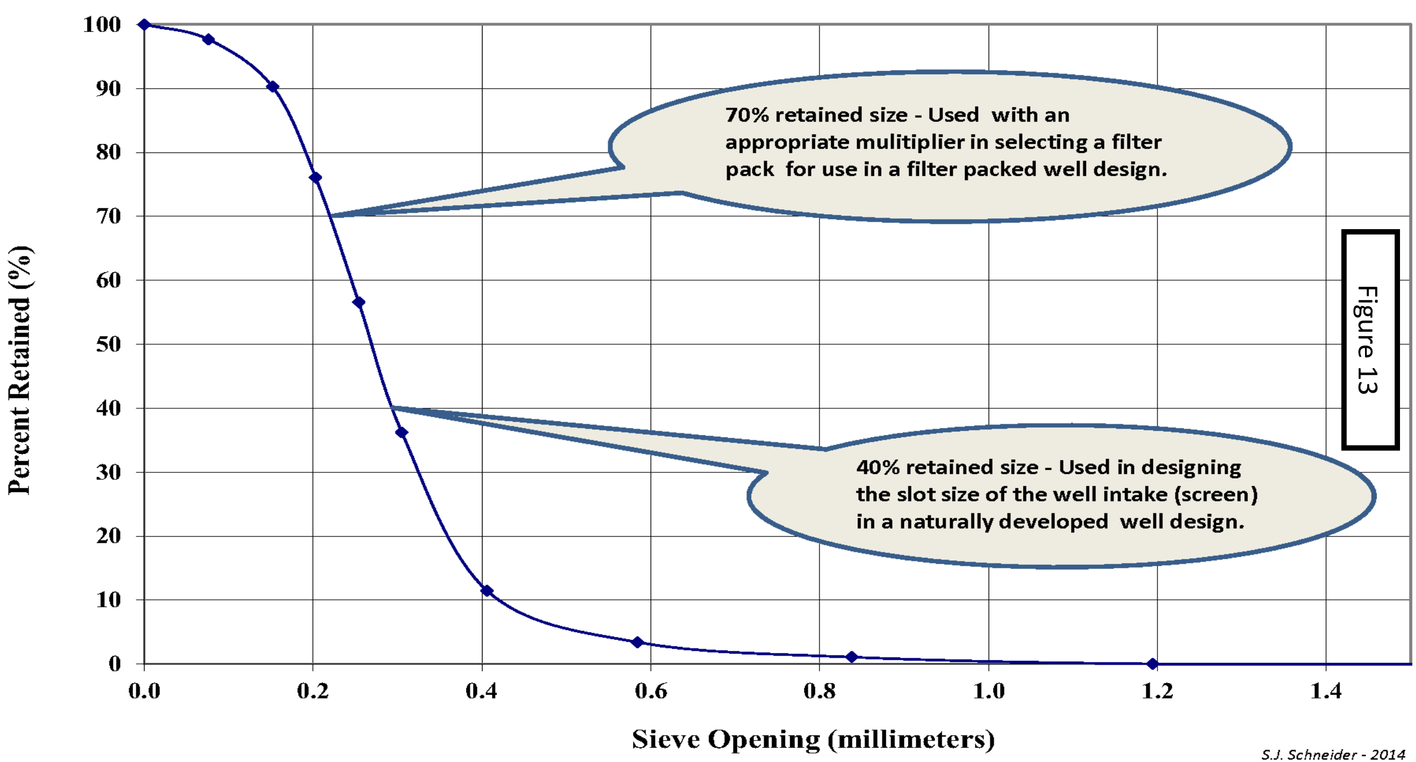
6. From the candidate filter pack materials, select one that has a 70% size within the target value range identified in step 4 above; coarser is preferred if the UC is <2.5.

A sample of filter pack material

7. Select a well intake opening (slot width) that is no larger than the 90% retained size of the selected filter pack material.

8. Construct the well such that the filter pack thickness is no less than 25 mm [1 inch] at any point around the well intake and no more than 100 mm [4 inch]. A thick pack is more difficult to develop and a thin pack is more difficult to properly place (e.g. bridging or particle segregation may occur). The preferred thickness range is 40 mm [1.5 inch] to 70 mm [3 inch].

Sieve Analysis Graph (example)



Sand & Gravel Aquifer

Use the following alterations to the Sand Aquifer procedures:

- If the percent of sand in the formation is estimated to be greater than 50% and the majority of the sand is less than 2 mm [.08 inch], then in the sieve analysis (Sand Aquifer procedure #2, page 48), remove from consideration all material retained on a 10 mm [3/8 inch] and larger sieve.

- If the percent of sand in the formation is estimated to be about equivalent to the amount of gravel, or there is more gravel than sand and the majority of the sand is greater than 0.5 mm [.02 inch], then in Sand Aquifer procedure #4, page 49, make the 70% multiplication factor 6 to 8 in lieu of 4 to 6.

Soil & Aggregate Terminology and Size

Silts and clays	Less than .08mm (.003in)
Fine sand	.08mm (.003in) up to .43mm (.02in)
Medium sand	43mm (.02in) up to 2.0mm (.08in)
Coarse sand	2.0mm (.08in) up to 4.8mm (.19in)
Fine gravel	4.8mm (.19in) up to 19mm (.75in)
Coarse gravel	19mm (.75in) up to 75mm (2.9in)
Cobbles	75mm (2.9in) up to 300mm (11.8in)
Boulders	greater than 300mm (11.8in)

Reference No.2, page 54: Unified Soil Classification System

APPENDIX II

Well Design Pros and Cons

Consolidated Formation Well Design Comparison

Type A

- A liner is optional (although it is recommended).
- The liner may be removed, if required, for future well alteration or rehabilitation work.
- Formation and water bearing zone information should be obtained before installing and sealing the casing to ensure that they are properly located.

Type B

- Accommodates a single diameter borehole from top to bottom which may be beneficial using a fluid stabilized borehole drilling method.
- May cost more than a Type A design.
- Bacteria may accumulate in the annular area between the seal and the well intake; if so, it may be difficult to eliminate them.

Unconsolidated Formation Well Design Comparison

Naturally Developed well

- Requires very accurate sampling, sieve analysis and screen selection in order to prevent excessive sand pumping. Thin layers of fine sand or silt often create a sand production problem.
- May be constructed with a uniform inside diameter for full depth (i.e. screen or perforations are same size as casing) or with a telescoping well intake structure (e.g. pull back casing to expose well intake).
- Usually has a lower initial construction cost than a filter packed design.
- Becoming less commonly used with the higher percentage of long-term successes being experienced using filter pack designs.

Type I Filter Pack

- Least expensive filter pack design.
- Uniform inside diameter for the full depth provides for easier development and future rehabilitation.
- Pump may be easily installed to the very top of the well intake thereby maximizing available drawdown.
- Does not provide for replenishment of filter pack. Not recommended for shallow aquifers or situations where limited height is available for reserve filter pack.
- Annular seal should not be completed until development is complete. May require a temporary casing to be used in the seal interval to maintain borehole integrity until the seal is placed.

Type II Filter Pack

- Can replenish pack (usually requires pump removal).
- Difficult to measure filter pack level, especially with a pump in the well.
- More expensive than a Type I Filter Pack design.
- Non-uniform inside diameter increases the difficulty and cost of development and future rehabilitation.
- Depth of the pump chamber (i.e. the inside diameter of the well that is above the top of the well intake structure) is less than would be available with a Type I or a Type III Filter Pack design.

Type III Filter Pack

- Most expensive design.
- Accommodates monitoring of the filter pack level from the surface without pump removal.
- Accommodates replenishment of the filter pack from the surface without pump removal.
- Uniform inside diameter for the full depth makes for easier development and future rehabilitation.
- A pump can be installed to the very top of well intake thereby maximizing available drawdown.

REFERENCES (listed alphabetically)

1. Anderson, K. E., *Ground Water Handbook*
2. ASTM International, *Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)* ASTM D2487
3. Driscoll, F.G., *Groundwater and Wells* Second Edition
4. National Ground Water Association, *ANSI/NGWA-01-14 Water Well Construction Standard*
5. National Ground Water Association, *Lexicon of Groundwater and Water Well System Terms*
6. Whinery, J., *A Well Construction Cost-Benefit Analysis: For Water Supply Well Guidelines for use in Developing Countries*

RESOURCES

National Ground Water Research and Educational Foundation (NGWREF)
"National Ground Water Research and Educational Foundation, also known as NGWREF, is focused on conducting educational, research, and other charitable activities related to a broader public understanding of groundwater." http://www.ngwa.org/Foundation

Rural Water Supply Network (RWSN)
"RWSN is a global network of professionals and practitioners working to raise standards of knowledge and evidence, technical and professional competence, practice and policy in rural water supply and so fulfil the vision of sustainable rural water services for all." http://www.rural-water-supply.net

Water, Engineering and Development Centre (WEDC) of Loughborough University
"The Water, Engineering and Development Centre is one of the world's leading education and research institutes for developing knowledge and capacity in water and sanitation for sustainable development and emergency relief." http://wedc.lboro.ac.uk

ABOUT THE PRINCIPAL AUTHOR & EDITOR

Stephen J. Schneider (Steve) manages the drilling division at Schneider Water Services of St. Paul, OR, USA a contracting business employing approximately 25 people in water related activities including: drilling, pumps & water systems installations, water treatment and service. Raised in the industry, he continues to work for the same company for over 37 years.

With a BS degree in mechanical engineering from Oregon State University, Steve worked for the US Department of Defense as a civilian engineer, which included writing/editing many technical specifications. He has drilling licenses in the states of Oregon, Washington and Idaho and pump installer licenses in Oregon and Washington. He is a National Ground Water Association (NGWA) Master Ground Water Contractor (MGWC).

Steve has presented educational seminars and workshops via Webinars and in person at NGWA Expos, NGWA Groundwater Summits, Oregon Ground Water Association (OGWA) conventions, WEDC International Conference, and other events. He was the first non-government presenter of required continuing education related to well construction rules in Oregon.

Steve has also served on:

- Oregon Ground Water Advisory Committee, including as Chair
- Oregon well construction Rules Advisory & other committees
- NGWA Standards Development Oversight committee
- NGWA Developing Countries Interest Group, including as Chair
- NGWA Policy & Code committee, including as Chair
- NGWA McEllhiney Lecturer Task Force
- NGWA initial strategic planning session
- NGWA item writing sessions
- OGWA board of directors, including as President
- OGWA government affairs committee, including as Chair

- OGWA meetings/conference committees
- Pacific NW Ground Water Association, including as Vice President
- National Ground Water Research & Education Foundation (NGWREF), 2011-2014 as President

Steve continues to be active in NGWA's Developing Countries Interest Group and has made several trips to, and continues to work with, a mission in Mexico developing groundwater supplies for the indigenous Tarahumara Indians.

PDF version of this book and a related
cost-benefit analysis are available at:

http://www.schneiderwater.com/pdf/
Hydrophilanthropy_Well_Guidelines.pdf

Also available at schneiderwater.com
Click on Hydrophilanthropy
Click on the Well Guidelines book image

"As of January 2012, the National Ground Water Association congratulates this initiative and looks forward to its continuing evolution to capture best practices in groundwater protection and in water well design, construction, and operation and maintenance."

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