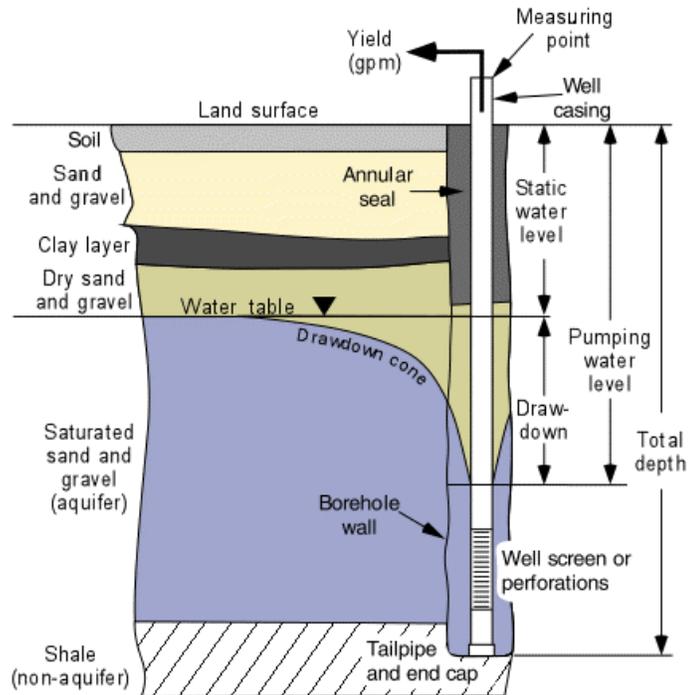


# Water Wells

## Water Well Construction and Terms

The drawing below illustrates some of the terms related to the construction and performance of a typical non-artesian water well.

Although there can be many variations in the details, all wells should contain the features shown and can be described using these terms. Artesian wells differ in that they are constructed so that pressure in the aquifer can be controlled. Under artesian conditions the water table would be above the top of the aquifer, and possibly above land surface.



The left side of the drawing shows the geologic setting for this well. The borehole penetrated soil, a near-surface sand and gravel that is separated from the aquifer by a clay layer, and a second sand and gravel. The lower part of the second sand and gravel is saturated and is an aquifer. Below the aquifer the borehole hit shale which is not an aquifer. The water-well driller describes and records the geologic units at the time a well is drilled. Geologic conditions into which wells are constructed vary widely and although those depicted in the drawing are common, they do not represent all conditions encountered by all wells.

**Annular seal:** The annular seal is the material between the borehole wall and the casing, usually placed near the land surface and is designed to keep surface water and other potential contamination out of the well. Materials commonly used include bentonite (a sticky clay), and neat cement grout (cement and water with no sand).

**Aquifer:** An aquifer is a geologic unit (sand and gravel, sandstone, limestone, or other rock) that will yield usable amounts of water to a well or spring.

**Borehole:** the hole drilled to construct a well. Most boreholes for domestic wells in Montana are only slightly larger than the well casing.

**Casing:** Steel or plastic pipe placed in the borehole to keep it from collapsing. The casing is sealed to the borehole wall near the land surface with the annular seal.

**Drawdown:** The drawdown in a well is the difference between the pumping water level and the static (non-pumping) water level. Drawdown begins when the pump is turned on and increases until the well reaches "*steady state*" sometime later. Therefore, drawdown measurements are usually reported along with the amount of time that has elapsed since pumping began. For example, "*The drawdown was 10 feet, 1 hour after pumping began.*"

**Drawdown cone:** The depression in the water table near the well that is caused by pumping is called the "*drawdown cone*" or sometimes the "*cone of depression*". When the well is pumping, water levels are drawn down most near the well and the amount of drawdown decreases as the distance from the well increases. At some distance from the well at any given time there is a point at which the pumping does not change the water table and the drawdown is zero.

**Measuring point:** Water levels in wells are usually reported as depths below land surface, although the measuring point can be any convenient fixed place near the top of the well. In this drawing the measuring point is the top of the casing. The altitude of the measuring point is commonly recorded so that static water levels can also be reported as altitudes.

**Pumping water level:** The pumping water level is the distance from the land surface (or measuring point) to the water in the well while it is pumping. The time that the pumping water level was measured is usually recorded also. For example, "*The pumping water level was 85 feet below land surface, 1 hour after pumping began.*"

**Screen or perforations:** All wells are open to the aquifer so that water can enter the well. Well completions vary from "*open hole*" in consolidated rock that does not need a casing, to "*open bottom*" where the only way for the water to enter the well is through the end of the casing. However, many wells have some sort of well screen installed or perforations cut into the casing through which water can enter. The openings must be correctly sized so that water will enter, but sand and other aquifer materials do not.

**Static water level:** The static water level is the distance from the land surface (or the measuring point) to the water in the well under non-pumping (static) conditions. Static water levels can be influenced by climatic conditions and pumping of nearby wells and are often measured repeatedly to gain information about how aquifers react to climatic change and development.

**Tailpipe and end cap:** Wells that are completed with well screens may have a tailpipe installed below the screen. The tailpipe provides a place where sand that may enter the well through the

screen can settle away from the pump. The end cap forces all water to enter the well through the well screen. Most wells that are completed with perforations will not have a tailpipe.

**Water table:** The top of the saturated part of a water-table (also known as an unconfined) aquifer. Below the water table, pore spaces (or fractures) in the geologic media are filled with water. Above the water table, the pore spaces are filled with air. An upside-down triangle is often used by hydrologists to indicate the water table.

**Total depth:** The total depth of the well is the distance from land surface to the bottom.

**Yield:** The amount of water measured in gallons per minute a well will produce when pumped.

Your well is more than just a hole in the ground; it is the source of water for you and your family. To ensure a safe and sufficient water supply, your well must be constructed properly.

Wells draw water from aquifers, which are water-saturated layers of soil or rock. A well should be built so that only water from selected depths may enter and only the best available ground water is obtained. Proper well construction also helps prevent ground water contamination. Once your well is built, protection and management of the well and the area around it are necessary to maintain the quality of your water supply.

## **Well Construction Methods**

The type of construction needed depends largely on the required yield and the type of formation. Yield is the rate at which water flows into the well during pumping - for example, 10 gallons per minute. A consolidated formation is one in which the particles are firmly cemented together, such as slate, sandstone, or granite. Unconsolidated formations, such as sands, gravel, or saprolite (soft, disintegrated rock remaining in its original place), lack such cementing.

Construction methods vary across the states. The following are some methods of common construction along with typical size ranges and the soil or rock formations suitable for each:

- **Dug wells** are relatively large in diameter, usually excavated by pick and shovel. They are often lined with brick, rock, concrete, or vitrified clay. These wells were common before World War II.
- **Bored wells** are excavated with earth augers. Bored wells are usually cased with concrete pipe. Bored wells are the modern equivalent of the older dug wells.
- **Driven wells** are built by driving a small diameter pipe, equipped with a drive point and screen, into the earth. Although shallow driven wells are often installed by homeowners or farmers, the individual usually does not have the equipment or expertise to construct the well with proper protection.
- **Jetted well** construction uses high-pressure water to dislodge soil and wash it away. In dense or partially consolidated formations, a chisel bit may be used with the jet to help break up the formation.
- **Drilled wells** use either percussion or rotary methods. Percussion drilling repeatedly drops a heavily weighted chisel bit to break up the formation at the bottom of the borehole.

Rotary drilling uses drag or roller bits attached to the end of a rotating drill stem. In the hydraulic-rotary method, driller's mud, a slurry of water and clay, is circulated in the hole to cool the bits and remove cuttings. The air-rotary method uses compressed air instead of driller's mud. A number of other additives may be used by the driller, depending on the type of conditions encountered during well construction.

The excavation or structure created in the ground by digging, driving, boring or drilling to access groundwater in underground aquifers are called water wells. The well water is drawn by an electric, a trash pump, a vertical turbine pump, a handpump or a mechanical pump (e.g. from a water-pumping windmill). It can also be drawn up using containers, such as buckets that are raised mechanically or by hand.

## Types of water wells

### Dug wells



A dug well in a village in Faryab Province, Afghanistan.

A dug well in a village in [Kerala](#)



Until recent centuries, all artificial wells were pumpless hand-dug wells of varying degrees of formality, and they remain a very important source of potable water in some rural developing areas where they are routinely dug and used today. Their indispensability has produced a number of literary references, literal

and figurative to them.

Hand-dug wells are excavations with diameters large enough to accommodate one or more men with shovels digging down to below the water table. They can be lined with laid stones or brick; extending this lining upwards above the ground surface to form a wall around the well serves to reduce both contamination and injuries by falling into the well. A more modern method called caissoning uses reinforced concrete or plain concrete pre-cast well rings that are Hand dug well cased with concrete rings lowered into the hole. A well-digging team digs under a cutting ring and the well column slowly sinks into the aquifer, whilst protecting the team from collapse of the well bore.

Hand dug wells provide a cheap and low-tech solution to accessing groundwater in rural locations in developing countries, and may be built with a high degree of community participation, or by local entrepreneurs who specialize in hand-dug wells. Hand dug wells have been successfully excavated to 60 metres (200 ft). Hand dug wells are inexpensive and low tech (compared to drilling) as they use mostly hand labour for construction. Hand dug wells have low operational and maintenance costs, in part because water can be extracted by hand bailing, without a pump. Hand dug wells can be easily deepened, which may be necessary if the ground water level drops, by telescoping the lining further down into the aquifer. The yield of existing hand dug wells may be improved by deepening or introducing vertical tunnels or perforated pipes.

Drawbacks to hand-dug wells are numerous. It can be impractical to hand dig wells in areas where hard rock is present, and they can be time-consuming to dig and line even in favourable areas. Because they exploit shallow aquifers, the well may be susceptible to yield fluctuations and possible contamination from surface water, including sewage. Hand dug well construction generally requires the use of a well trained construction team, and the capital investment for

equipment such as concrete ring moulds, heavy lifting equipment, well shaft formwork, motorized de-watering pumps, and fuel can be large for people in developing countries. Construction of hand dug wells can be dangerous due to collapse of the well bore, falling objects and asphyxiation, including from dewatering pump exhaust fumes.

Woodingdean well, hand-dug between 1858 and 1862, is claimed to be the world's deepest hand-dug well at 1,285 feet (392 m). The Big Well in Greensburg, Kansas is billed as the world's largest hand-dug well, at 109 feet (33 m) deep and 32 feet (9.8 m) in diameter. However, the *Well of Joseph* in the Cairo Citadel at 280 feet (85 m) deep and the Pozzo di S. Patrizio (St. Patrick's Well) built in 1527 in Orvieto, Italy, at 61 metres (200 ft) deep by 13 metres (43 ft) wide are both larger by volume.

## **Driven wells**

Driven wells may be very simply created in unconsolidated material with a "well hole structure", which consists of a hardened drive point and a screen (perforated pipe). The point is simply hammered into the ground, usually with a tripod and "driver", with pipe sections added as needed. A driver is a weighted pipe that slides over the pipe being driven and is repeatedly dropped on it. When groundwater is encountered, the well is washed of sediment and a pump installed.

## **Drilled wells**

Drilled wells are typically created using either top-head rotary style, table rotary, or cable tool drilling machines, all of which use drilling stems that are turned to create a cutting action in the formation, hence the term 'drilling'.

Drilled wells can be excavated by simple hand drilling methods (augering, sludging, jetting, driving, hand percussion) or machine drilling (rotary, percussion, down the hole hammer).



Drilled wells can get water from a much deeper level than dug wells can - often up to several hundred metres.

Drilled wells with electric pumps are used throughout the world, typically in rural or sparsely populated areas, though many urban areas are supplied partly by municipal wells. Most shallow well drilling machines are mounted on large trucks,

trailers, or tracked vehicle carriages. Water wells typically range from 3 to 18 m deep, but in some areas can go deeper than 900 m.

Rotary drilling machines use a segmented steel drilling string, typically made up of 6 m sections of galvanized steel tubing that are threaded together, with a bit or other drilling device at the bottom end. Some rotary drilling machines are designed to install (by driving or drilling) a steel casing into the well in conjunction with the drilling of the actual bore hole. Air and/or water is used as a circulation fluid to displace cuttings and cool bits during the drilling. Another form of rotary style drilling, termed 'mud rotary', makes use of a specially made mud, or drilling fluid, which is constantly being altered during the drill so that it can consistently create enough hydraulic pressure to hold the side walls of the bore hole open, regardless of the presence of a casing in the well. Typically, boreholes drilled into solid rock are not cased until after the drilling process is completed, regardless of the machinery used.

The oldest form of drilling machinery is the cable tool, still used today. Specifically designed to raise and lower a bit into the bore hole, the 'spudding' of the drill causes the bit to be raised and

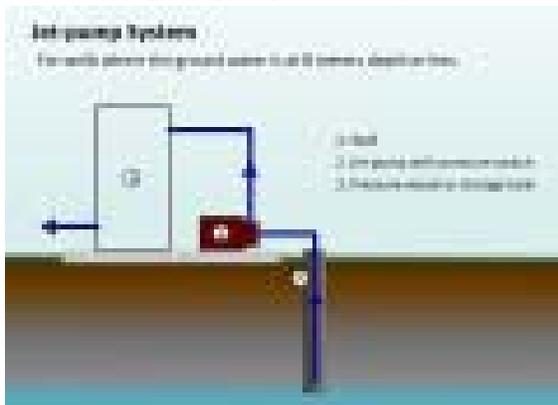
dropped onto the bottom of the hole, and the design of the cable causes the bit to twist at approximately  $\frac{1}{4}$  revolution per drop, thereby creating a drilling action. Unlike rotary drilling, cable tool drilling requires the drilling action to be stopped so that the bore hole can be bailed or emptied of drilled cuttings.

Drilled wells are usually cased with a factory-made pipe, typically steel (in air rotary or cable tool drilling) or plastic/PVC (in mud rotary wells, also present in wells drilled into solid rock). The casing is constructed by welding, either chemically or thermodynamically, segments of casing together. If the casing is installed during the drilling, most drills will drive the casing into the ground as the bore hole advances, while some newer machines will actually allow for the casing to be rotated and drilled into the formation in a similar manner as the bit advancing just below. PVC or plastic is typically welded and then lowered into the drilled well, vertically stacked with their ends nested and either glued or splined together. The sections of casing are usually 6 m or more in length, and 6 to 12 in (15 to 30 cm) in diameter, depending on the intended use of the well and local groundwater conditions.

Surface contamination of wells in the United States is typically controlled by the use of a 'surface seal'. A large hole is drilled to a predetermined depth or to a confining formation (clay or bedrock, for example), and then a smaller hole for the well is completed from that point forward. The well is typically cased from the surface down into the smaller hole with a casing that is the same diameter as that hole. The annular space between the large bore hole and the smaller casing is filled with bentonite clay, concrete, or other sealant material. This creates an impermeable seal from the surface to the next confining layer that keeps contaminants from traveling down the outer sidewalls of the casing or borehole and into the aquifer. In addition, wells are typically

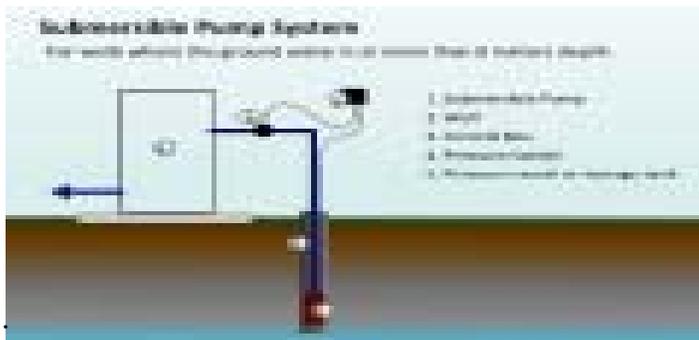
capped with either an engineered well cap or seal that vents air through a screen into the well, but keeps insects, small animals, and unauthorized persons from accessing the well.

At the bottom of wells, based on formation, a screening device, filter pack, slotted casing, or open bore hole is left to allow the flow of water into the well. Constructed screens are typically used in unconsolidated formations (sands, gravels, etc.), allowing water and a percentage of the formation to pass through the screen. Allowing some material to pass through creates a large area filter out of the rest of the formation, as the amount of material present to pass into the well slowly decreases and is removed from the well. Rock wells are typically cased with a PVC liner/casing and screen or slotted casing at the bottom, this is mostly present just to keep rocks from entering the pump assembly. Some wells utilize a 'filter pack' method, where an undersized



screen or slotted casing is placed inside the well and a filter medium is packed around the screen, between the screen and the borehole or casing. This allows the water to be filtered of unwanted materials before entering the well and pumping zone.

An automated water well system powered by a jet-pump.



An automated water well system powered by a submersible pump.



A water well system with a cistern.

## Classification

### Water well types.

There are two broad classes of drilled-well types, based on the type of aquifer the well is in:

- *Shallow or unconfined wells* are completed in the uppermost saturated aquifer at that location (the upper unconfined aquifer).
- *Deep or confined wells* are sunk through an impermeable stratum into an aquifer that is sandwiched between two impermeable strata (aquitards or aquicludes). The majority of deep aquifers are classified as artesian because the hydraulic head in a confined well is higher than the level of the top of the aquifer. If the hydraulic head in a confined well is higher than the land surface it is a "flowing" artesoam well.

Two additional broad classes of well types may be distinguished, based on the use of the well:

- *production or pumping wells*, are large diameter (greater than 15 cm in diameter) cased (metal, plastic, or concrete) water wells, constructed for extracting water from the aquifer by a pump (if the well is not artesian).

- *monitoring wells* or piezometers, are often smaller diameter wells used to monitor the hydraulic head or sample the groundwater for chemical constituents. Piezometers are monitoring wells completed over a very short section of aquifer. Monitoring wells can also be completed at multiple levels, allowing discrete samples or measurements to be made at different vertical elevations at the same map location.

Obviously, a well constructed for pumping groundwater can be used passively as a monitoring well and a small diameter well can be pumped, but this distinction by use is common.

## Siting

Before excavation, information about the geology, water table depth, seasonal fluctuations, recharge area and rate must be found. This work is typically done by a hydrogeologist, or a groundwater surveyor using a variety of tools including electro-seismic surveying any available information from nearby wells, geologic maps sometimes geophysical imaging..

## Contamination



Man cleaning a well

Shallow pumping wells can often supply drinking water at a very low cost, but because impurities from the surface easily reach shallow sources, a greater risk of contamination occurs for these wells

when they are compared to deeper wells. Dug and driven wells are relatively easy to contaminate, and dug wells are unreliable in most of the U.S. The quality of the well water can be significantly increased by lining the well, sealing the well head, fitting a self-priming hand

pump, constructing an apron, ensuring the area is kept clean and free from stagnant water and animals, moving sources of contamination (latrines, garbage pits) and carrying out hygiene education. The well should be cleaned with 1% chlorine solution after construction and -----

## **Microorganisms**

Most of the bacteria, viruses, parasites, and fungi that contaminate well water comes from fecal material from humans and other animals. Common bacterial contaminants include E. coli, Salmonella, Shigella, and Campylobacter jejuni.. Common viral contaminants include norovirus, sapovirus, rotavirus, enteroviruses, and hepatitis A and E. Parasites include Giardia Lamblia.

## **Chemicals**

Chemical contamination is a common problem with groundwater. Nitrates from sewage or fertilizer are a particular problem for children. Pollutant chemicals include pesticides and volatile organic compounds from gasoline, dry-cleaning, the fuel additive methyl tert-butyl ether (MTBE), and perchlorate from rocket fuel, airbag inflators, and other artificial and natural sources.

Several minerals are also contaminants, including lead leached from brass fittings or old lead pipes, chromium VI from electroplating and other sources, naturally occurring arsenic, radon, and uranium—all of which can cause cancer—and naturally occurring fluoride, which is desirable in low quantities to prevent tooth decay, but can cause dental fluorosis in higher concentrations.

Some chemicals are commonly present in water wells at levels that are not toxic, but can cause other problems. Calcium and magnesium cause what is known as hard water, which can precipitate and clog pipes or burn out water heaters. Iron and manganese can appear as dark flecks that stain clothing and plumbing, and can promote the growth of iron and manganese bacteria that can form slimy black colonies that clog pipes.

## **Mitigation**

Cleanup of contaminated groundwater tends to be very costly. Effective remediation of groundwater is generally very difficult.

Contamination of groundwater from surface and subsurface sources can usually be dramatically reduced by correctly centering the casing during construction and filling the casing annulus with an appropriate sealing material. The sealing material (grout) should be placed from immediately above the production zone back to surface, because, in the absence of a correctly constructed casing seal, contaminated fluid can travel into the well through the casing annulus. Centering devices are important (usually 1 per length of casing or at maximum intervals of 9 m) to ensure that the grouted annular space is of even thickness. Upon the construction of a new test well, it is considered best practice to invest in a complete battery of chemical and biological tests on the well water in question. Point-of-use treatment is available for individual properties and treatment plants are often constructed for municipal water supplies that suffer from contamination. Most of these treatment methods involve the filtration of the contaminants of concern, and additional protection may be garnered by installing well-casing screens only at depths where contamination is not present.

Well water for personal use is often filtered with reverse osmosis water processors; this process can remove very small particles. A simple, effective way of killing microorganisms is to bring the water to a full boil for one to three minutes, depending on location. A household well contaminated by microorganisms can initially be treated by shock chlorination using bleach, generating concentrations hundreds of times greater than found in community water systems; however, this will not fix any structural problems that led to the contamination and generally requires some expertise and testing for effective application.

## **Environmental problems**

A risk with the placement of water wells is soil salination. This problem occurs when the watertable of the soil begins to drop and salt begins to accumulate as the soil begins to dry out. Another environmental problem that is very prevalent in water well drilling is the potential for methane to seep through.

## **Soil salination**

The potential for soil salination is a large risk when choosing the placement of water wells. Soil salination is caused when the water table of the soil drops over time and salt begins to accumulate. In turn, the increased amount of salt begins to dry the soil out. This is a very detrimental problem because the increased level of salt in the soil can result in the degradation of soil and can be very harmful to vegetation.

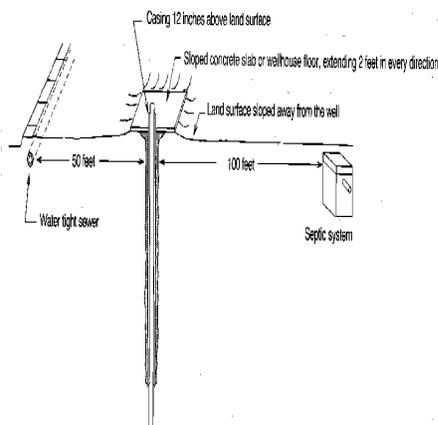
## Methane

Methane, an asphyxiate, is a chemical compound that is the main component of natural gas.

When methane mixes with oxygen, it has the ability to reduce oxygen to harmfully low levels in a small space or to form an explosion. This explosive quality is what poses such a danger in regards to the drilling and placement of water wells.

Low levels of methane in drinking water are not considered toxic. When methane seeps into a water supply, it is commonly referred to as "methane migration." This can be caused by old

Wells should be sited at least 100 feet from any septic system or drainfield and at least 50 feet from any watertight sewer lines. Exceptions may be granted in the case of single-family dwellings on small lots to allow a minimum of 50 feet from a septic system or drainfield and a minimum of 25 feet from a water-tight sewer line.



As a general rule, all piping, wiring, and air vents should enter the well at least 8 inches above land surface. The only exception is for *pitless units*, for which state code sets special conditions. Pitless units are special sections of casing, manufactured with integral connections for piping and wiring below the ground surface. They are available for common casing materials (such as steel, or PVC). *Pitless adapters* are add-on kits that require in-the-field assembly. The practice of finishing the wellhead in a pit is no longer permitted, since well pits tend to collect debris and surface waters, increasing the chances of direct contamination of the well.

If you suspect that your new well does not meet state requirements, you can have it inspected without charge by contacting your regional office of the Ground Water Section of the Division of Environmental Management. If a notice of violation is issued, the driller will be required, at his own expense, either to bring the well up to standards or properly abandon it.

## **Hazardous Materials and the Wellhead Area**

It is particularly dangerous to conduct the following four activities involving hazardous materials near a water supply:

Your contract should specify that the well must meet all state and county regulations in force at the time of construction, then include any agreements on areas such as abandonment and enclosures. Though this may seem a nuisance, especially if the contractor is a friend, it is good business practice for both parties to know exactly what is expected.

The purpose of a well is to tap a supply of clean water and transport that water in a sanitary manner to the point of use. To succeed, the well must be constructed to exclude contaminants. This requires protection of the borehole, wellhead, and the area around it. Wells should be sited at least 100 feet from any septic system or drainfield and at least 50 feet from any watertight sewer lines. Exceptions may be granted in the case of single-family dwellings on small lots to allow a minimum of 50 feet from a septic system or drainfield and a minimum of 25 feet from a water-tight sewer line. (Some counties require greater separations.)

The state code requires that the driller leave at least 12 inches of casing above the land surface. (The practice of cutting the casing off below the ground surface for aesthetic reasons is no longer permitted.) A concrete slab should be poured around the casing, extending at least 2 feet from the

outer casing in all directions and sloped to shed water. This slab helps stabilize the casing and the soil immediately around it. It also prevents surface water from entering the annular space and moving down the outside of the casing.

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If you suspect that your new well does not meet state requirements, you can have it inspected without charge by contacting your regional office of the Ground Water Section of the Division of Environmental Management. If a notice of violation is issued, the driller will be required, at his own expense, either to bring the well up to standards or properly abandon it.

Many possible defects may occur in well construction. Some are fairly obvious; others are not. And, like any mechanical system, the likelihood of failure increases with the age of the well. It is reasonable to assume that there are thousands of defective wells in operation that will never be repaired. Chemical use near any well is risky, but especially if the well is not known to be properly constructed and in good repair.

Large-diameter wells (bored or dug) should be completely filled with cement grout, dry clay, or material excavated during drilling, which must then be compacted in place. Other types of wells that are in unconsolidated formations (such as sands, shells, or clay) must be completely filled with cement grout.

Wells in consolidated rock formations may be filled with cement, sand, gravel, or drill cuttings to within 5 feet of the top of the consolidated rock. The rest of the well must be filled with cement grout. Contracts should specify that the well must meet all state and county regulations in force at the time of construction and include any stipulations on areas such as abandonment and enclosures.