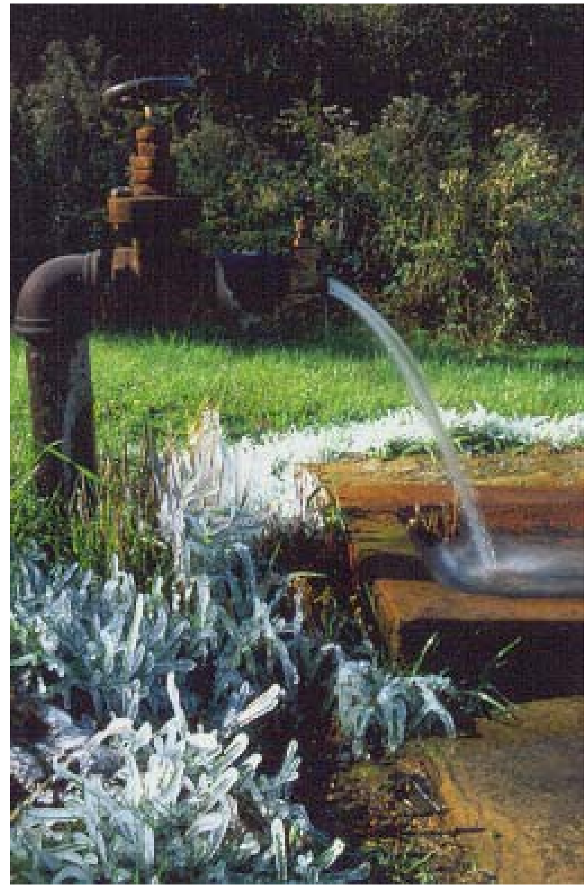
WELLS
GETTING WATER from the GROUND

"The strata penetrated, the depth of water horizons, almost all the facts of use in artesian investigations must be gathered while the boring of any well is in progress, or not at all."

– William Harmon Norton
Artesian Wells of Iowa, 1897



Clay Smith

The internal pressure that causes artesian wells to flow comes from the arrangement of rock layers beneath the ground. (Black Hawk Bluff, Allamakee County)

Water flows from an aquifer into your drinking glass by means of a well. Techniques for well drilling and construction vary with aquifer depth, aquifer rock type, other strata encountered above the aquifer, and the amount of water needed. In Iowa, three major types of wells are used to produce groundwater: sandpoints, bored wells, and drilled wells. Common to most of them is a cylindrical hole excavated into the ground, a column of pipe or *casing* to keep the hole from collapsing, grout to seal the space between the hole and the casing, and a pump to lift the water to the surface.

The oldest method of obtaining groundwater is to dig a hole by hand to some depth below the water table. Historically such dug wells were lined with stones, bricks, or tiles and covered with a cap of wood, stone, or concrete. Modern versions of these dug wells are large-diameter seepage wells that are mechanically bored with power equipment. These wells usually range from 30 to 36 inches in diameter, and they are intended to expose a large surface area to slowly infiltrating groundwater. Such bored wells are useful in tapping shallow water-table conditions, often in fine-grained, slowly permeable materials such as loess (silt) or glacial till (clay).

Sandpoint wells, or "driven wells" as they are sometimes called, are small-diameter pipes (about two inches) pushed into the ground to tap shallow water-bearing sand or gravel. These pipes are usually fitted with a pointed screen at the bottom. Like the dug and bored wells, these shallow wells are typically less than 50 feet deep, and they go dry when the water table drops below the bottom of the well. They are also highly vulnerable to contamination sources originating at the land surface (diagram, p.45).

Most deeper wells today are constructed by truck-mounted, rotary drill rigs (photos, p.46). After a drill hole is completed, permanent steel or plastic casing is inserted. Typically the casing extends from just above ground level through the relatively soft glacial materials and into bedrock, usually several feet into the major water-bearing bedrock aquifer. The drilled hole below the casing is left exposed to provide water to the well (diagram, p.44). Wells drilled into shallower sand and gravel require casing plus an attached well screen to prevent the hole from collapsing and to keep fine sediment from entering the well and damaging the pump or clogging the pipe. When an aquifer consists of very fine sand, a gravel pack is added around the screen to prevent sand from entering the well. This technique allows use of larger slot openings in the screen, thus enabling increased water yields. Wells drilled into loosely cemented sandstone bedrock sometime need screens too. When the aquifer is in carbonate rocks, screens are unnecessary because groundwater movement is along fractures and bedding planes, and usually there is little sand or silt present.

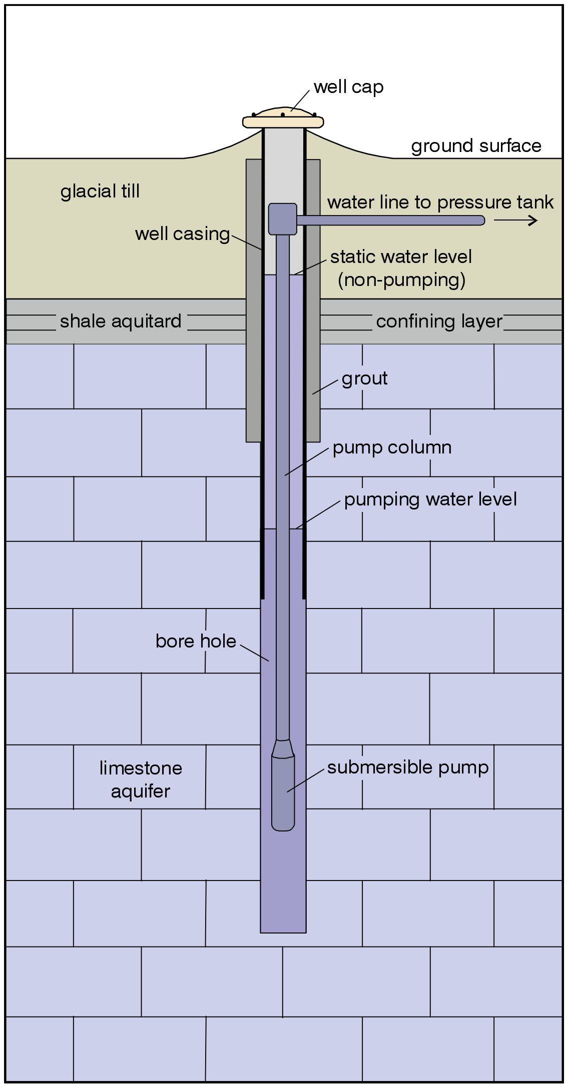
Once the well casing is in place, grout is used to seal the *annular space* between the borehole and well casing. *Grout* is a slurry mixture of cement or *bentonite* and water that sets up to form an effective seal. This prevents surface water from draining down the outside of the casing and into the well and also prevents the movement of water between aquifers. In addition, grout seals off openings to undesirable formations and helps to prevent corrosion of the well casing (diagram, p. 44).

Modern wells are constructed in accordance with rules found in the *Iowa Administrative Code*. These rules fit the various well construction methods used in Iowa – drilled wells in unconsolidated (glacial) materials, drilled wells in bedrock materials, and bored and augered wells in unconsolidated materials (diagram p.45).

Most wells drilled in Iowa are for groundwater supplies. The deepest water well record on file at the Iowa Geological Survey in Iowa City is the 3,467-foot Greenfield Municipal Well #1 in Adair County drilled in 1929. Other wells are drilled to test for water-bearing conditions, to monitor aquifer conditions, and to explore for minerals, oil and gas (or its underground storage), and, historically, to drain wet ground (*ag-drainage wells*). For many years, the deepest well drilled in Iowa for any purpose was a 5,305-foot oil test in Page County completed in 1930. Then in 1987, an exploratory oil test hole in Carroll County near Halbur was drilled to a depth of 17,851 feet. This remains the deepest well drilled in Iowa to date.

Often wells are "developed" by drillers to increase the amount of water produced in a new well or to improve the performance of an older well. *Well development* may be as simple as the vigorous pumping of a new well to remove excess drilling mud and other fine sediments. At other times a solution of dilute hydrochloric acid may be pumped into a new well to enlarge openings in carbonate rock formations (called "acidizing") or into an older well to remove encrusting deposits of lime. The addition of polyphosphates, followed by vigorous surging of a well, is used to disperse silts and clays and remove oxides of iron and manganese.

Components of a Water Well

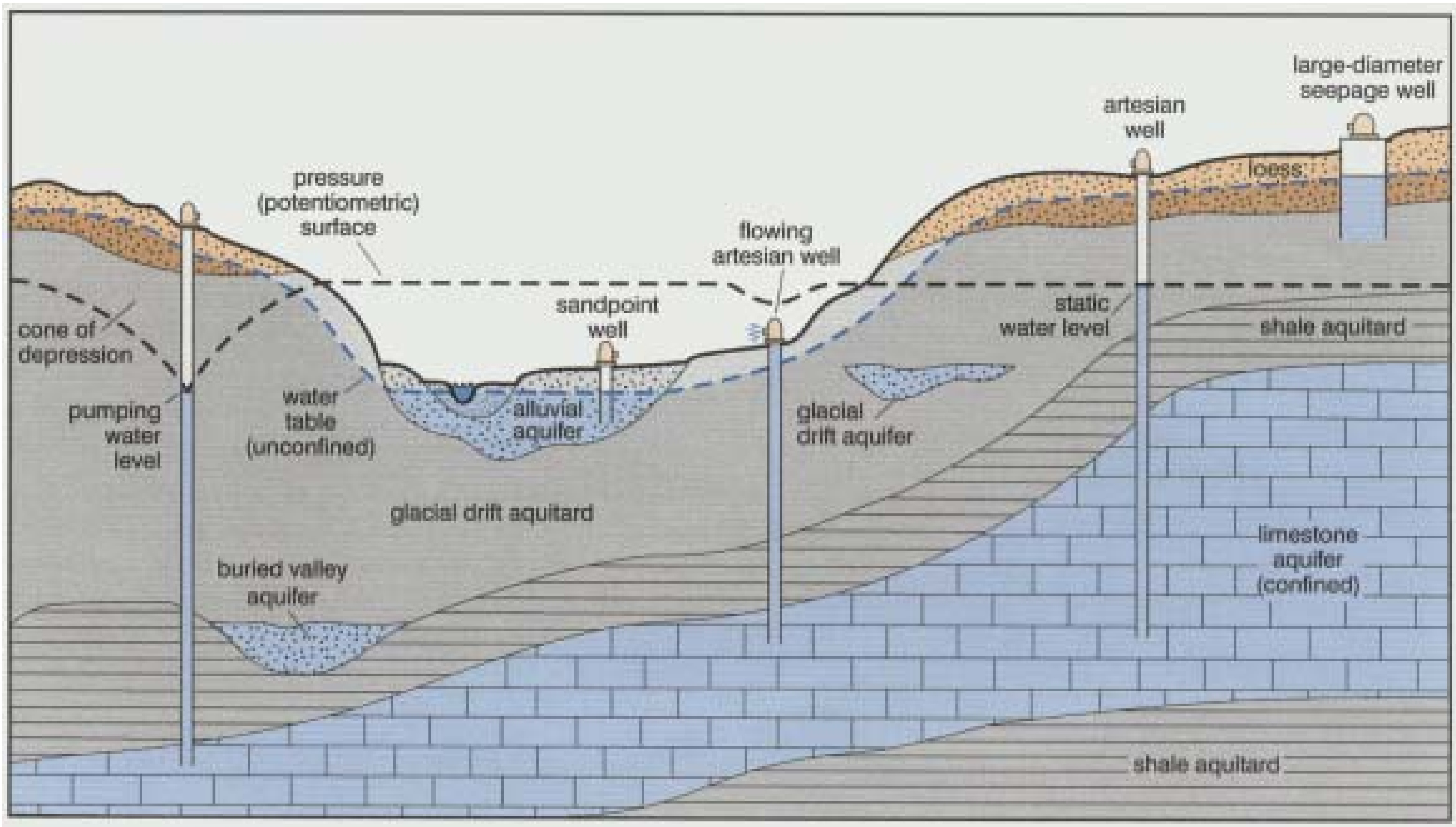


Yields from wells depend largely on the ability of an aquifer to store and transmit water. When water is pumped, water levels in the aquifer decline. The maximum decline occurs at the pumping well itself, and the decline, or *drawdown*, radiates from there, decreasing with increasing distance from the pumped well. In three dimensions, the drawdown is generally cone-shaped and therefore referred to as the well's *drawdown cone*, or *cone of depression* (diagram, right). In an unconfined aquifer, the drawdown cone reflects lowering of the water table. In a confined aquifer, it reflects lowering of the potentiometric (artesian pressure) surface around the well.

When a well no longer produces water or functions as a standby supply in good repair, then it should be properly plugged. Deteriorating wells become direct conduits for contaminants from the land surface to reach an aquifer and for cross-contamination to occur between different aquifers. Since 1987, about 44,000 abandoned wells in rural Iowa have been plugged, assisted by a Grants-to-Counties program funded by the Iowa Department of Natural Resources. The key aspects of proper well closure are to isolate the aquifers penetrated by a well from each other and from the land surface using impermeable filling material such as bentonite.

Since a well owner can't examine the inside of a well to troubleshoot problems, it is important to maintain basic information about its construction, performance, and water quality. Starting with construction records provided by the well drilling contractor, keep all records about a well's performance, routine pump maintenance, and needed repairs or remediation measures. Careful documentation of a well's history can be invaluable to diagnosing future well problems, suggesting appropriate treatment, and predicting the useful life of the well. Basic information about a well should include

Wells and Aquifers in Iowa



its precise location on a map (¼, ¼, ¼, ¼, Section, Township, and Range), well depth, *static water level*, pumping water level, estimated yield, and basic water quality.

A drilled well in Iowa can yield much more than water. Since the late 1800s, the Iowa Geological Survey has routinely archived well samples from cooperating drillers around the state. This library

Wells were drilled at Briggs Woods Park in Hamilton County to test aquifer characteristics in the surficial and Mississippian aquifers. These nested wells enable water levels and quality of the groundwater supplies to be monitored over the long term.

photos by Clay Smith

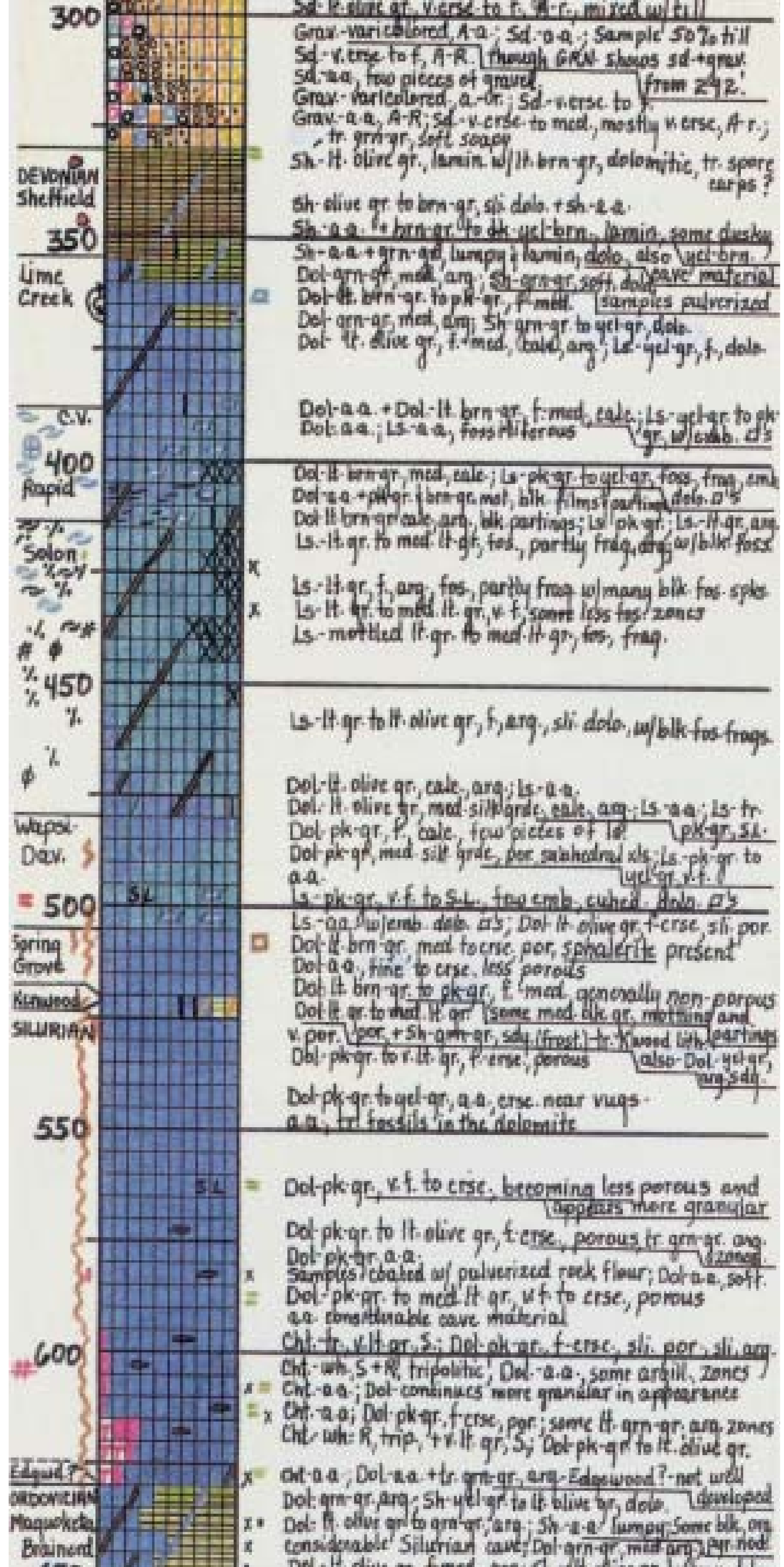
of 36,000 sets of drill chips and some 900 cores (solid cylinders of rock), totaling over 400,000 feet, account for over 90 percent of the information used to interpret the state's subsurface environments and their groundwater resources. Logs prepared from these samples are invaluable as baseline records of well conditions at the time of drilling (photo, right). They are solid pieces of geologic and hydrologic data to be used many times over as information to forecast conditions at prospective drilling sites or any site having engineering or contamination problems. When combined with sample sets from other wells, they become part of a database that is essential for both immediate and long-range use in solving the underground puzzles of Iowa's geologic strata and their associated groundwater resources.

Wells also reveal much about the health of an aquifer. By sampling well water periodically, changes can be noted in its quality and in the presence or absence of annoying or harmful contaminants. Also, keeping records of water levels can identify long-term trends in whether groundwater is being used faster than it is being naturally replenished. Such monitoring activities are valuable in identifying potential problems, tracking the geographic extent and depth of contaminant plumes, and supplying basic information about individual aquifers and how they differ from one another (photos, left).

One of the most interesting effects on water levels in Iowa wells occurred on March 27, 1964, following the Great Alaskan Earthquake, some 3,000 miles away. This earthquake, one of the largest ever recorded on the North American continent, disturbed water levels in all of Iowa's major aquifers. The effect in some wells was noted as sharp fluctuations in water levels on recorder charts. In other wells and in some springs, the water became turbid for a short time from disturbed silt and clay in the aquifer. Still other wells showed a permanent rise or fall in the water level of the aquifer, likely because the earthquake caused either compression or expansion of the porosity within the aquifer.

Then on the afternoon of November 3, 2002, another strong earthquake in central Alaska had noticeable repercussions in Iowa wells. The 7.9 Richter Scale quake along the Denali Fault struck at 4:12 p.m. Iowa time, and by 6:00 p.m. reports of discolored water in northeast Iowa started coming into local and state offices. Over the next two days, owners of limestone wells throughout northeastern Iowa reported water that ranged from lime-green to almost black (photo, p.51). Shock waves from the quake caused groundwater in Iowa's aquifers to slosh. This agitation stirred up fine sediment lying along rock fractures and in the bottoms of wells, and loosened the buildup of iron and manganese on submerged well pipes, casing, and pumps, contributing to the temporary discoloration of the water.

Water quality is a major factor in the development of a water



Logs of wells are prepared from microscopic study of samples collected during drilling. Details of soil and rock materials are keys to understanding the occurrence of groundwater resources in Iowa and to predicting conditions in untested areas.

Significance of Commonly Occurring Constituents in Drinking Water

Constituent	Maximum contaminant level (MCL) for public water supplies	Recommended maximum level	Naturally occurring	Comments
Microorganisms Total coliform bacteria	No bacteria in 95% of samples collected		✓	Indicates pathway for potentially harmful microorganisms; inadequate well condition
Inorganic chemicals Arsenic (As)	0.01 mg/L		✓	Adverse health effects; carcinogenic
Chloride (Cl)		250 mg/L	✓	Salty taste when sodium present; corrosion of pipes
Fluoride (F)	4.0 mg/L	2.0 mg/L	✓	Affects dental health
Hardness: calcium (Ca) and magnesium (Mg) ($CaCO_3$)			✓	Limits lathering ability of soap; causes scale buildup
Iron (Fe)		0.3 mg/L	✓	Objectionable taste; stains laundry and porcelain
Manganese (Mn)		0.05 mg/L	✓	Objectionable taste; stains laundry and porcelain
Nitrate: as N as NO_3	10 mg/L 45 mg/L		✓	Land-applied fertilizer; leaching from septic tanks and sewage; adverse health effects; causes "blue baby syndrome" in infants
Sodium (Na) and potassium (K)			✓	Salty taste when combined with chloride

Sulfate (SO_4)		250 mg/L	✓	Objectionable taste; laxative effects; forms scale when combined with calcium
Total dissolved solids (TDS)		500 mg/L	✓	Refers to all material in solution; limits lathering of soap; objectionable taste
Suspended sediment			✓	Gives water a muddy or turbid appearance; pump wear
Dissolved gases				
Hydrogen sulfide (H_2S)			✓	Odor; corrosion of pipes, casing, and pumps
Methane (CH_4)			✓	Explosive
Organic chemicals				
Pesticides	Atrazine 0.003 mg/L Alachlor 0.002 mg/L			Land-applied herbicides; adverse health effects
Benzene	0.005 mg/L			Leaking gasoline storage tanks; adverse health effects
Trichloroethylene (TCE)	0.005 mg/L			Industrial solvent and degreaser; adverse health effects
Radionuclides				
Gross alpha particles	15 pCi/L		✓	Formed by decay of radioactive elements; adverse health effects
Beta particles	4 millirems per year		✓	Formed by decay of radioactive elements; adverse health effects
Radium 226 & 228 (Ra)	5 pCi/L (combined)		✓	Formed by decay of radioactive elements; adverse health effects
Radon 222 (Rn)	4000 pCi/L (in review)		✓	Colorless gas formed by decay of radium; adverse health effects

mg/L = milligrams per liter; equivalent to parts per million (ppm)   pCi/L = picocuries per liter

Lowell Washburn

Abandoned wells are direct pathways for contaminants from the land surface to reach underground aquifers. Proper closure of these wells is essential to maintaining groundwater quality.

supply and problems can arise from a multitude of sources. As already noted, groundwater moving through soil and rock dissolves minerals, and these naturally occurring constituents can present health concerns and cause economic problems. In addition to mineral content, bacterial and chemical contamination can also affect water quality. Contaminants affecting health include bacteria, nitrate, pesticides, radionuclides, organic chemicals, arsenic, and lead. Contaminants that do not affect health, at least in small quantities, include sulfate, total dissolved solids, calcium and magnesium, hydrogen sulfide, iron, manganese, and iron bacteria.

The table on page 48-49 summarizes commonly occurring constituents that can cause problems in Iowa drinking water supplies, as well as those that are regulated and nonregulated ("recommended") for public water supplies.

Total *coliform bacteria*, which includes both fecal and non-fecal bacteria, is the most commonly reported health-related water quality problem in Iowa. Water containing coliform bacteria should not be consumed unless properly disinfected by boiling or chemical treatment.

Nitrate occurs naturally in soil, but concentrations exceeding 10 mg/L as NO_3-N often indicate pollution from sources of nitrogen such as fertilized cropland or human or animal waste-disposal sites.

Agricultural pesticides have been detected in Iowa groundwater since 1964. The U.S. Environmental Protection Agency (EPA) has established maximum contaminant levels (MCLs) for many commonly used pesticides. Two of those used in Iowa, atrazine and alachlor, have MCLs of 0.003 mg/L and 0.002 mg/L respectively.

Total dissolved solids are all the materials in water that are in solution. Water with less than 500 mg/L is considered excellent; 500 to 1,000 mg/L is good; 1,000 to 1,500 mg/L is fair; and greater than 1,500 mg/L is considered poor.

Calcium and magnesium are the primary cause of "hardness" and scale-forming properties in plumbing, and they also reduce the lathering ability of soap. Hardness is reported in terms of an equivalent amount of calcium carbonate ($CaCO_3$). Water is considered "soft" when the hardness is below 100 mg/L. Commercial water softening companies often use "grains per gallon" to report hardness. One "grain" equals 17.1 mg/L (or parts per million). "Very hard water" is reported as anything over 10.5 grains per gallon.

Adapted from photo by Michael Wade

Water discolored by suspended sediment appeared in northeast Iowa wells just hours after a major earthquake in central Alaska. Water in left jar from a 600 ft. well; water in right jar from a 200 ft. well.

Hydrogen sulfide (H_2S) is a dissolved gas that imparts a "rotten egg" odor to water and accelerates the corrosion of steel pipes, casing, and pumps. It is commonly produced by sulfate-reducing bacteria that live in aquifers or water distribution systems. Elimination of hydrogen sulfide odors in wells can be accomplished through aeration or chemical oxidation.

Following exposure to oxygen or chemical oxidizing agents, ferrous iron (soluble) is converted to ferric iron (insoluble), which imparts a yellow or reddish color to water. Iron concentrations exceeding 0.3 mg/L often will stain laundry or plumbing fixtures and can affect the taste of water. The accumulation of insoluble iron often causes deterioration of softening capacity and plugging of water softeners. Manganese concentrations exceeding 0.05 mg/L also cause brown stains on laundry and plumbing fixtures.

A common problem in Iowa is the clogging of well screens or pump components with iron bacteria. This nuisance aquatic bacteria, in the presence of dissolved oxygen, will precipitate an insoluble iron-oxide slime that can plug water distribution systems and impart an unpleasant odor to drinking water. Shock-chlorination can be effective in loosening such bacterial growths, though this procedure may have to be repeated on a regular basis. To distinguish whether the rusty color in water is caused by iron bacteria or simply the oxidation of dissolved iron, microscopic examination of the water is necessary.

Radioactivity is another natural contaminant in groundwater, derived from contact with rocks where the water is stored. While generally not excessive, it is highest in deep bedrock aquifers, especially in central and southeast Iowa, where it often exceeds drinking water standards.

After constructing a well, the water should be tested. In most areas the county health or sanitation department will work with well owners to test their water.

Good sources of information about well construction, maintenance, remediation, and abandonment include local well-drilling contractors, the Iowa Department of Natural Resources (IDNR) Water Supply Section, and county sanitarians. Publications about these topics are available from the U.S. Environmental Protection Agency and the U.S. Geological Survey. A local library can be another good source of water well information. The Iowa Geological Survey will provide individual well forecasts to landowners to help them estimate drilling depths, yields, and quality of water-bearing units beneath their property.