COMMONWEALTH OF MASSACHUSETTS

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PRIVATE WELL GUIDELINES

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Drinking Water Program

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INTRODUCTION

A private water supply provides water for human consumption and consists of a system that has less than 15 service connections and either (1) serves less than 25 individuals or (2) serves an average of 25 or more individuals daily for less than 60 days of the year. In the Commonwealth of Massachusetts over 500,000 people rely on private wells to provide potable water because public water is not available to them.

The improper design, construction, repair, maintenance, or decommissioning of a private water supply system represents a potential hazard to public health and safety. In order to protect the health and general welfare of the citizens who depend on private wells and to protect the groundwater resources of the Commonwealth so that the consuming public can be assured of potable water, it is necessary for regulators to know what constitutes a private water supply system and understand the measures that should be taken to protect the water supplied by the system.

The Private Well Guidelines and accompanying Model Board of Health Regulations for Private Wells were written primarily to assist Boards of Health but also to assist drillers by attempting to introduce some consistency regarding construction standards from town to town. The Private Well Guidelines also provides information useful to private well owners, developers, and interested local officials.

The Model Board of Health Regulations for Private Wells provides general guidance because subsurface geology varies considerably across the Commonwealth. Well construction and water quality concerns on Cape Cod, for example, differ substantially from those in western Massachusetts. The Private Well Guidelines, on the other hand, is a more comprehensive reference and provides information regarding well construction in addition to discussion of issues concerning local groundwater protection and water quality. Because the Private Well Guidelines is intended as a reference, it was written with a built-in redundancy.

Although these guidelines contain information that is applicable to private water supply systems that derive water from surface water sources, the primary focus is on systems that utilize a well to obtain groundwater.

Household irrigation wells have become an issue recently because of the dramatic increase in water rates in parts of Massachusetts. The well construction requirements recommended in the Private Well Guidelines and the Model Board of Health Regulations for Private Wells should be applied to irrigation wells. For wells used exclusively for irrigation, unique water quality testing requirements are described in the Water Quality section of these guidelines.

In addition, some wells may serve the dual purpose of providing domestic water and acting as a heat transfer medium for ground source heat pump (geothermal) systems. These wells are regulated under the Massachusetts Department of Environmental Protection's Underground Injection Control program. The reader is referred to the Department's "Guidelines for Ground Source Heat Pump Wells" for additional information.

Neither the Private Well Guidelines nor the Model Board of Health Regulations for Private Wells are a substitute for existing regulations and statutes.

SUMMARY OF LAWS AND REGULATIONS APPLICABLE TO PRIVATE WATER SUPPLY SYSTEMS

There are a number of Massachusetts laws that protect the quality of the water obtained from private wells This section summarizes laws and state regulations that are applicable to private water supply systems. State regulations developed pursuant to the Massachusetts General Laws (MGL) are contained in the Code of Massachusetts Regulations (CMR) and can be purchased individually from State House bookstores in Boston, Fall River and Springfield. https://www.sec.state.ma.us/spr/sprcat/catidx.htm. The CMR is also available online at https://www.mass.gov/code-of-massachusetts-regulations-cmr.

STATE JURISDICTION

Department of Environmental Protection

In Chapter 111 of the Massachusetts General Laws, MassDEP is granted general responsibility and authority for protecting drinking water supplies within the Commonwealth. Specifically, Section 159 confers upon MassDEP "the general oversight and care of all inland…and underground waters used by any city, town, water supply or fire district or public institution or any person in the Commonwealth as sources of ice or water supply…". In Section 160, MassDEP is authorized to "make rules and regulations and issue such orders as in its opinion may be necessary to prevent the pollution and to secure the sanitary protection of all such waters used as sources of water supply and to ensure the delivery of a fit and pure water supply to all consumers." Section 5G states that MassDEP "may require by order a city, town, person or district maintaining a water supply to provide and operate such treatment facilities as are, in its opinion, necessary to insure the delivery of a safe water supply to all consumers."

Chapter 21G, Section 20 of the Massachusetts General Laws (MGL) requires the Department of Environmental Protection (MassDEP) to adopt such regulations as it deems necessary to carry out the purposes of this section. Section 20 requires any person engaged in the business of digging or drilling wells within the Commonwealth to certify annually with MassDEP. It also states that "within thirty days after completion of any well by digging or drilling, the person engaged in the business of digging or drilling wells shall submit a report to the department setting forth such information as may be required under said rules and regulations."

The regulations developed by the Department pursuant to MGL Chapter 21G, Sections 14 and 20, are contained in 310 CMR 46.00, "Certification of Well Drillers and Filing of Well Completion Reports." These regulations, among other things, (1) provide the criteria necessary for the certification of well diggers and drillers in the Commonwealth of Massachusetts, (2) establish the information that must be furnished as a prerequisite for certification (3) establish the information that must be submitted to the department upon the completion of any well, and (4) set forth penalties, including revocation of certification if a driller is found to be in noncompliance with the well driller regulations.

In order to protect underground sources of drinking water as required in the Federal Safe Drinking Water Act, and pursuant to MGL Chapter 111, Section 160 and MGL Chapter 21, Section 27, and other authority, MassDEP promulgated 310 CMR 27.00, "Underground Injection Control Regulations." These regulations prohibit the underground injection or disposal of hazardous wastes, and fluids having the potential to contaminate groundwater. In addition to the requirements provided in 310 CMR 27.00, MGL Chapter 21C, Section 5 states that no person shall dispose of hazardous waste "in a manner which could endanger human health, safety or welfare, or the environment." In accordance with MGL Chapter 21C, Section 5 and 310 CMR 27.00, it is illegal to use a private water supply well, test hole, or dry or inadequate boring as a drain or disposal receptacle for any fluid or material including, but not limited to, sludge, solid waste or trash, and waste oil or other hazardous waste.

Chapter 21A, Section 13 of the Massachusetts General Laws requires the Commissioner of MassDEP to adopt, and from time to time amend, regulations to be known as the State Environmental Code. More specifically, this code "shall deal with matters affecting the environment and the well-being of the public of the commonwealth." Section 13 also states that “local boards of health shall enforce said code in the same manner in which local health rules and regulations are enforced..."

Pursuant to MGL Chapter 21A, Section 13, MassDEP has promulgated 310 CMR 15.000, "The State Environmental Code, Title 5: Standard Requirements for the Siting, Construction, Inspection, Upgrade and Expansion of On-Site Sewage Treatment and Disposal Systems and for the Transport and Disposal of Septage." These regulations provide minimum standards, among other things, for the location, design, construction, and operation of subsurface sanitary sewage disposal systems that discharge less than 10,000 gallons per day. The improper location, construction, or maintenance of a subsurface disposal system is of concern because it may adversely affect the quality of the water obtained from a nearby private water system.

It should be noted that the standards presented in the current version of Title 5 were developed primarily to protect public health from bacteria and nitrogen. Pursuant to the Massachusetts General Laws Chapter 111, Section 31, local Boards of Health have the authority to adopt reasonable health regulations including regulations that are more stringent than Title 5. On the other hand, a variance may be granted by the local Board of Health if (1) site specific conditions indicate that adequate protection can be provided without complying with the standards required by Title 5, and (2) Title 5 requirements would be a manifest injustice.

Chapter 131, Section 40 of the Massachusetts General Laws provides MassDEP with the authority to promulgate regulations to protect wetland areas and confers upon the local Conservation Commission the responsibility for administering the law. Among the seven statutory interests listed are "public or private water supply" and "groundwater supply." Pursuant to MGL Chapter 131, Section 40, MassDEP has promulgated 310 CMR 10.00, "Wetlands Protection." In accordance with MGL Chapter 131, Section 40 and 310 CMR 10.00, any person proposing construction or alteration of the land within 100 feet of a wetland or within the 100-year floodplain of any river or stream must apply to the local Conservation Commission for a Determination of Applicability. The Commission evaluates the impact prior to issuing a permit or denial and must ensure that “the capacity of an area to prevent pollution of groundwater shall not be adversely affected." The Commission's decision may be appealed to MassDEP.

The "Drinking Water Regulations," 310 CMR 22.00, promulgated by MassDEP, pertain specifically to public water systems. However, they include water quality standards which can be used as guidelines for interpreting the results of analyses performed on water samples obtained from private water systems.

MassDEP promulgated regulation 310 CMR 42.00, “Certification and Operation of Environmental Analysis Laboratories” to establish certification requirements for laboratories to conduct analytical measurements of chemical, radiochemical, and microbiological parameters in environmental samples, including drinking water. Public water suppliers are required to use MassDEP-certified laboratories for water analysis. MassDEP strongly recommends that local Boards of Health and homeowners require the use of Mass DEP certified labs for private well testing.

Department of Agricultural Resources- Pesticide Board

Pursuant to the Massachusetts General Laws Chapter 132B, the Pesticide Board promulgated 333 CMR 11.00, "Rights of Way Management." These regulations include procedures and requirements for marking and recording the location of private wells which are within 100 feet of a right-of-way, prior to herbicide application in the right of way. For private drinking water supplies that are marked and recorded in accordance with these regulations, no herbicide shall be applied within 50 feet of the private well, and no herbicide shall be applied in an area that is both in a right of way and between 50 feet and 100 feet of the water supply unless a minimum of 24 months shall elapse between applications, and herbicides shall be applied selectively by low pressure foliar techniques or cut stump application. Uniform standard signs have been produced and are currently available at the Department of Agricultural Resources (MDAR).

Department of Public Health

Chapter 111, Section 127A of the Massachusetts General Laws states that the Department of Public Health (DPH) "shall adopt, and may from time to time amend, public health regulations to be known as the State Sanitary Code." This code "shall deal with matters affecting the health and well-being of the public including, standards of fitness for human habitation." Pursuant to Chapter 111, Section 127A, DPH has promulgated 105 CMR 410, Minimum Standards of Fitness for Human Habitation (State Sanitary Code, Chapter 11) which establishes the requirements for residential dwellings. 105 CMR 410.180 requires property owners to provide a safe supply of drinking water to occupants from a public water supply or a private source approved by the local Board of Health.

State Plumbing Board

The Uniform State Plumbing Code, 248 CMR 10.00 is founded on certain principles of public health, environmental sanitation and safety through properly designed, acceptably installed, and adequately maintained plumbing systems in order to comply with all Articles of the State Sanitary Code and Titles of the Environmental Code. Specifically, Principles No.1 and 2 refer to domestic water supplies.

1. Principle No. 1 -- All Occupied Premises Must Have Potable Water. All premises intended for human habitation, occupancy, or use must be provided with a supply of potable water. Such a water supply shall not be connected with unsafe or questionable water sources, nor shall it be subject to the hazards of backflow, backpressure, or back-siphonage.

2. Principle No. 2 -- Adequate Water Required. Plumbing fixtures, devices, and appurtenances must be supplied with water in sufficient volume and at pressures adequate to enable them to function properly and without undue noise under normal conditions of use.

MUNICIPAL JURISDICTION

Pursuant to the Massachusetts General Laws Chapter 40, section 54, which governs the powers and duties of cities and towns, "no building permit shall be issued for the construction of a building which would necessitate the use of water therein, unless a supply of water is available" from either a public water system or a private well.

Chapter 40, Section 21 of the Massachusetts General Laws grants municipalities the authority to adopt ordinances and bylaws which may, for example, require land owners to properly maintain their private water supply system and properly decommission abandoned water supply systems located on their property.

In accordance with the Massachusetts General Laws Chapter 111, Sections 122 and

122A, if the available supply of drinking water in any place of habitation is so unsafe or inadequate as to constitute a nuisance, the local Board of Health may issue a written order requiring the owner to discontinue use of the water supply, or, at his option, to provide a safe and adequate supply of drinking water.

Chapter 83, Section 3 of the Massachusetts General Laws grants local Boards of Health the authority to require any landowner whose land abuts a public sewer system to hook into the public system at his or her own expense. Thus, the Board of Health can protect underground water supplies when a septic system threatens groundwater quality. Furthermore, the Board of Health's decision on such matters cannot be overridden by the Sewer Commissioners.

Chapter 111, Section 31 of the Massachusetts General Laws grants local Boards of Health broad authority to "make reasonable health regulations." Boards of Health are encouraged to adopt locally appropriate private well regulations which take into consideration local geology, land uses, and zoning regulations. It is the duty of local Boards of Health to monitor local conditions and create necessary regulations which address those conditions in order to protect public health. The following are examples of reasonable private well regulations that local Boards of Health may adopt under MGL Chapter 111, Section 31:

(1) setback distances

(2) well construction, alteration, and maintenance standards

(3) well decommissioning standards

(4) periodic water quality testing

Adoption of health regulations by a Board of Health pursuant to MGL Chapter 111, Section 31, requires a majority vote of the Board and publication in a local newspaper. Pursuant to the Massachusetts General Laws, Chapter 21A, Section 8, regulations adopted under Chapter 111, Section 31, must be filed with MassDEP.

Disclaimer

Please be advised that these Guidelines may not reflect the current versions of MA laws and regulations. Official versions of MA laws and regulations are available from State House Bookstores. MA regulations also are available through the Secretary of State's Publications and Regulations Subscription Service. When downloading laws, regulations or policies from the MassDEP website, the copy you receive may be different from the official version for a number of reasons, including, but not limited to:

- The document may not print or transfer accurately given the software/hardware used.
- The file on the website may be out dated.

If it is necessary to know that a version of state laws or regulations is correct and up to date, then please contact the State Bookstore or the Secretary of State's office and, for DEP policies, the appropriate DEP program.

DOMESTIC WATER SUPPLY SOURCES

Water supplies in Massachusetts are supplied by either groundwater or surface water. Groundwater supplies most often utilize water wells to draw water from unconsolidated (sand and gravel) deposits or from fractured bedrock. Springs, also supplied by groundwater, serve a small percentage of the population and may utilize a cistern for storing water. Surface water bodies such as lakes, ponds, streams, rivers and brooks supply a relatively small population when compared with households utilizing wells.

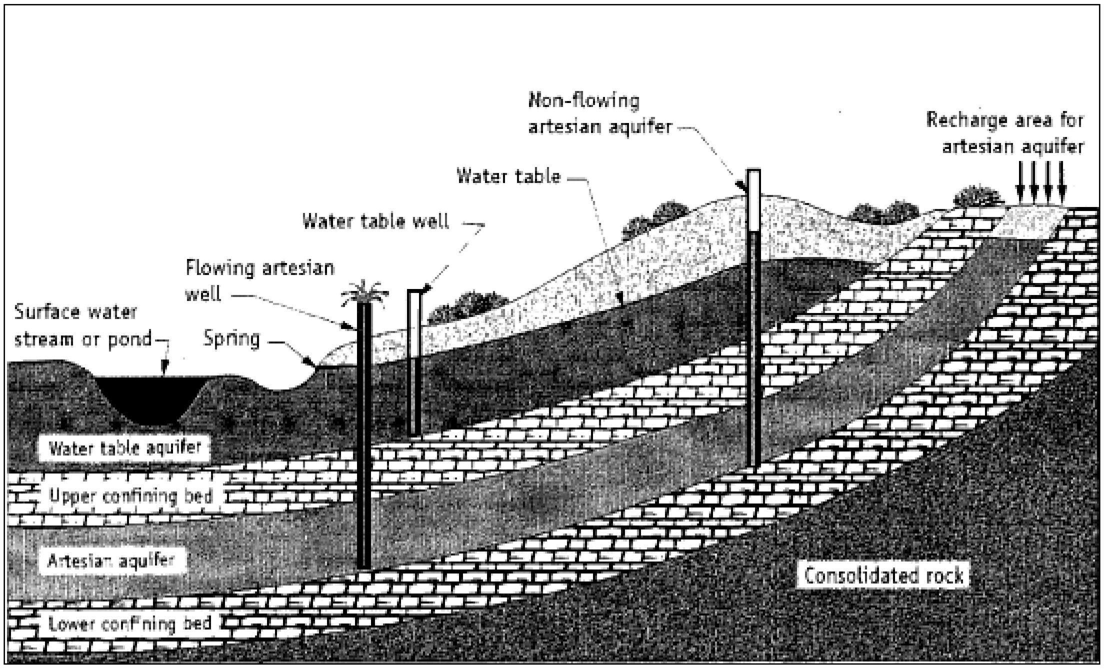

Figure 1: Ground and Surface Water Sources
(Midwest Plan Service-14, 2009)

Water Wells

Subsurface geologic conditions throughout Massachusetts generally require one of two well construction techniques. A well drawing from a sand and gravel aquifer (overburden well) should be cased down to the most productive strata where an appropriately sized screen is installed. A well drawing water from bedrock fractures should be cased securely into the rock and the borehole in the rock is usually left open and unscreened and is used for storage.

There are several modifications of these two basic well types. Sandpoint wells, for example, consist of a screen coupled to a riser pipe which is pounded into a water bearing unit with tools that may be as simple as a sledge hammer. This type of well and installation technique is satisfactorily used in areas where the water table is close to the land surface and the ground being penetrated is sandy and devoid of cobbles, boulders and large gravel.

Drilled or bored wells are the most desirable type of well, as they provide the greatest protection from contamination when properly constructed. The section entitled, "General Well Design and Construction" presents construction details for the aforementioned overburden wells and information pertaining to bedrock wells.

Other household water supply sources less commonly used are dug wells, springs and surface waters. These types of systems are not recommended for drinking water use as they are more susceptible to contamination than drilled wells. Homeowners using drinking water derived from these sources should exercise caution and conduct more frequent water quality sampling and testing.

Dug wells

Dug wells, another modification of the basic overburden water well, are sometimes dug by hand but more often are constructed using a backhoe. These wells consist of large holes in the ground that extend below the water table and are lined with a large well screen, tile, or brick. Dug wells are generally constructed in areas where the water table is close to the land surface and where the geologic deposits are tight and compact, such as glacial till. Dug wells act as collection galleries or cisterns as groundwater seeps slowly into the collection area to the same level as the surrounding water table. Fluctuations, in the level of the water table may cause them to go dry and, unless they are adequately sealed to prevent infiltration of surface water, they are also vulnerable to contamination problems associated with the large annular space that typifies dug well construction.

Springs

Springs emanating from rock or glacial till areas provide drinking water for a small percentage of the population that depends on private sources. Springs are frequently connected and piped to concrete galleries that allow spillover to be piped elsewhere. Because springs may flow some distance as surface water and their collection systems are frequently open, they can easily become contaminated. Spring boxes or spring houses may add some sanitary protection to a spring and, if constructed properly (Figure 2), can provide a sanitized discharge point and isolate the spring from land surface introduced contamination.

(Salvato, 1958)

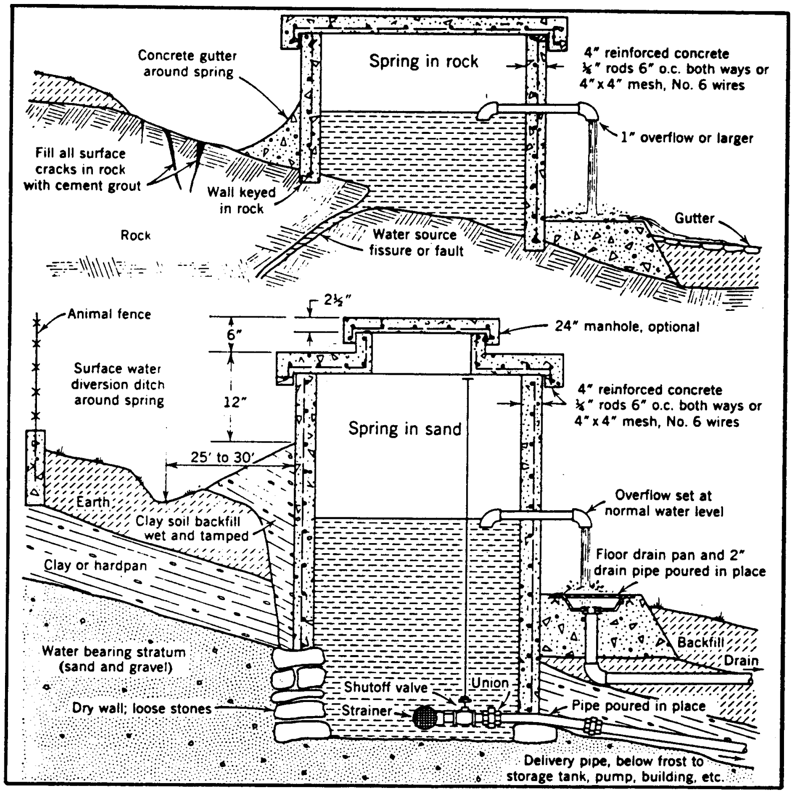

Figure 2: Properly Constructed Springs

Surface Water Supplies

Surface waters are rarely used for private drinking water supplies in Massachusetts. Because of their exposure to the air and a lack of filtering media, surface waters often experience water quality problems not associated with groundwater sources and frequently require some form of treatment in order to meet aesthetic and public health concerns. Algal blooms, bacterial contamination, turbidity, sedimentation and temperature fluctuations are some of the water quality problems associated with surface water supplies.

PERMITS AND REPORTS

PERMITS

Required Registration of Well Diggers and Drillers

Chapter 21G, Section 20 of the Massachusetts General Laws requires any person engaged in the business of digging or drilling wells within the Commonwealth to register annually with MassDEP Drinking Water Program and authorizes the Department to establish regulations necessary for the proper administration of the law. The regulations developed by the Drinking Water Program are contained in 310 CMR 46.00, "Registration of Well Drillers and Filing of Well Completion Reports" These regulations (1) provide the criteria necessary for the registration of well diggers and drillers in the Commonwealth of Massachusetts, (2) establish the information that must be furnished as a prerequisite for certification, (3) establish the information that must be submitted to the Drinking Water Program upon the completion of any well, and (4) set forth penalties, including revocation of registration, if a driller is found to be in noncompliance with state or town regulations.

Accordingly, any person in the business of digging or drilling who constructs, repairs, or alters a private well must be certified with the Drinking Water Program at the time the work is performed. In addition, any person who decommissions (seals) an abandoned well must have a valid Well Driller certification. All rigs employed in drilling wells in the Commonwealth must display a valid rig permit.

Required Building Permit

Pursuant to MGL Chapter 40, Section 54, which governs the powers and duties of cities and towns, "no building permit shall be issued for the construction of a building which would necessitate the use of water therein, unless a supply of water is available" from either a public or a private water system.

Recommended Permits

Requiring permits for activities related to private wells can provide information necessary for the protection of public health. In addition, local water supply resources can be properly evaluated and protected only when information pertaining to the use and quality of these resources is available. Chapter 111, Section 31 of the Massachusetts General Laws grants local Boards of Health broad authority to "make reasonable health regulations." Accordingly, various permit requirements may be established for activities related to private wells.

It is recommended that local Boards of Health establish, for example, requirements for the following:

(1) private well construction permit
(2) plumbing permit (for new potable sources only)
(3) private well alteration permit
(4) permit for decommissioning (sealing) abandoned wells, test holes, and dry or inadequate borings

A private well construction permit allows the regulating agency to identify well sites that may require special water quality monitoring or may not be acceptable due to water quality problems that have occurred in the vicinity of the site. It is recommended that the application for a well construction permit be filed by the certified well driller installing the well and filed with the Board of Health on a form furnished by the Board. The application should include:

(1) the property owner's name and address

(2) the well driller's name and proof of valid state certification
(3) a plan with a specified scale, signed by a registered surveyor or engineer, showing the location of the proposed well in relation to existing or proposed above or below ground structures..
(4) a description and location of visible prior and current land uses within two-hundred (200) feet of the proposed well location, which could adversely impact the well, including but not limited to the following:
    (a) existing and proposed structures
    (b) subsurface sewage disposal systems
    (c) subsurface fuel storage tanks
    (d) public ways
    (e) utility rights-of-way
    (f) any other potential sources of pollution
    (g) other wells
(5) a permit fee

A plumbing permit can ensure that only qualified persons connect a private well to the distribution system of the residence. A private well use permit allows the Board of Health to identify wells which may be threatened by contamination; can assist with the establishment of a local water quality monitoring program, and aids in identifying abandoned wells which should be plugged.

The local Board of Health shall require all wells, including non-potable wells, be installed by a Massachusetts Certified Well Driller. Other requirements concerning non-potable wells (such as irrigation wells) may be imposed by the local Board of Health private well regulation

Geothermal Well Permits

Some wells may serve the dual purpose of providing domestic water and acting as a heat transfer medium for ground source heat pump (geothermal) systems. In addition to a Board of Health Well Permit and meeting the associated water quality requirements as a drinking water source, a permit will be required from the MassDEP Underground Injection Control (UIC) program unless the property is only used for one single-family residential unit. The MassDEP geothermal well permitting guidelines contain requirements concerning well siting, well design and water quality. These specific requirements can be found in the *Guidelines for Ground Source Heat Pump Wells* at https://www.mass.gov/files/documents/2016/08/ot/gshpguid.pdf.

REPORTS

Well Completion Report

Requirements of 310 CMR 46.00 state, in part, that within 30 days after completion of any well (productive or nonproductive), or after plugging of an abandoned well, a certified well driller shall submit to the Drinking Water Program, a Well Completion Report (Figures 3 and 4) with a copy to the local Board of Health, containing:

(1) well address and the name and address of the owner of the well
(2) the latitude and longitude in decimal degrees
(3) work performed (e.g., new installation, repair, abandonment, etc.)
(4) well type (e.g., domestic, irrigation, geothermal, etc.)
(5) drilling method
(6) drilling log describing the material penetrated, including:
 (a) well depth
 (b) depth to refusal or bedrock
 (c) bedrock type
(7) date drilling completed
(8) casing type, depths, thickness and diameter
(9) protective well seal
(10) well screen type, slot size, diameter and depths at which screen is set
(11) description of filter pack and grouting materials used
(12) method of plugging an abandoned well
(13) well test results including:
 (a) method
 (b) date and length of time (in hours and minutes) well was tested
 (c) drawdown and recovery
 (d) well yield
(14) static water level
(15) pump description, depth and installer
(16) water bearing zones

Well Completion Report forms shall be submitted electronically through the MassDEP electronic filing system. Well completion reports must be submitted for all activities covered under 310 CMR 46 including well drilling, decommissioning, Ground Source Heat Pump wells (“geothermal”), repairs, deepening, yield enhancement, pump installation and replacement. Any driller who files a false report is subject to revocation of certification. Violators will be subject to enforcement currently up to $25,000 per day depending on the infraction and specifics of the violation. It should be noted that performing activities under the regulations cited without being certified in Massachusetts is a violation and the violator(s) subject to enforcement action.

Massachusetts Department of Environmental Protection
Bureau of Resource Protection
GENERAL WELL REPORT

Note: GPS coordinates must be in WGS84 datum, in degrees.decimal degree format.

1. WELL LOCATION GPS (Required) North ___ ___.___ ___ ___ ___ ° West ___ ___.___ ___ ___ ___ °

Address at Well Location ______ ☐ Property Owner ______
Subdivision/Property Description ______ ☐ Engineering Firm ______
City/Town ______ Mailing Address ______
Assessors Map ______ Assessors Lot # ______ City/Town ______ State ______
Board of Health permit obtained ☐ Yes ☐ Not Required Permit Number ______ Date Issued ______

2. WORK PERFORMED ☐ ☐
3. WELL TYPE ☐ ☐ ☐ ☐
4. DRILLING METHOD Overburden ☐ ☐ Bedrock ☐ ☐

5. WELL LOG — OVERBURDEN LITHOLOGY

From (ft)	To (ft)	Code	Color	Comment	Drop in Drill Stem	Extra Fast or Slow Drill Rate	Loss or Addition of Fluid
					☐ Y ☐ N	☐ F ☐ S	☐ L ☐ A
					☐ Y ☐ N	☐ F ☐ S	☐ L ☐ A
					☐ Y ☐ N	☐ F ☐ S	☐ L ☐ A
					☐ Y ☐ N	☐ F ☐ S	☐ L ☐ A
					☐ Y ☐ N	☐ F ☐ S	☐ L ☐ A
					☐ Y ☐ N	☐ F ☐ S	☐ L ☐ A
					☐ Y ☐ N	☐ F ☐ S	☐ L ☐ A
					☐ Y ☐ N	☐ F ☐ S	☐ L ☐ A

5. WELL LOG — BEDROCK LITHOLOGY

From (ft)	To (ft)	Code	Comment	Drop In Drill Stem	Extra Large Chips	Extra Fast or Slow Drill Rate	Loss or Addition of Fluid	Visible Rust Staining
				☐ Y ☐ N	☐ Y ☐ N	☐ F ☐ S	☐ L ☐ A	☐ Y ☐ N
				☐ Y ☐ N	☐ Y ☐ N	☐ F ☐ S	☐ L ☐ A	☐ Y ☐ N
				☐ Y ☐ N	☐ Y ☐ N	☐ F ☐ S	☐ L ☐ A	☐ Y ☐ N
				☐ Y ☐ N	☐ Y ☐ N	☐ F ☐ S	☐ L ☐ A	☐ Y ☐ N
				☐ Y ☐ N	☐ Y ☐ N	☐ F ☐ S	☐ L ☐ A	☐ Y ☐ N
				☐ Y ☐ N	☐ Y ☐ N	☐ F ☐ S	☐ L ☐ A	☐ Y ☐ N
				☐ Y ☐ N	☐ Y ☐ N	☐ F ☐ S	☐ L ☐ A	☐ Y ☐ N
				☐ Y ☐ N	☐ Y ☐ N	☐ F ☐ S	☐ L ☐ A	☐ Y ☐ N

6. ADDITIONAL WELL INFORMATION
Developed ☐ Y ☐ N — Fracture Enhancement ☐ Y ☐ N
Disinfected ☐ Y ☐ N — Surface Seal Type ☐ ☐
Total Well Depth ______ — Depth to Bedrock ______

7. CASING

From	To	Type	Thickness	Diameter
		☐☐☐		
		☐☐☐		

8. SCREEN

From	To	Type	Slot Size	Diameter
		☐☐☐	.___ ___ ___	
		☐☐☐	.___ ___ ___	

9. WATER-BEARING ZONES

From	To	Yield (gpm)

10. PERMANENT PUMP (IF AVAILABLE)
Pump Description ☐☐☐☐ — Horsepower ______
Pump Intake Depth ______ ft — Nominal Pump Capacity ______ gpm

11. ANNULAR SEAL / FILTER PACK

From	To	Material 1	Weight	Material 2	Weight	Water (gal)	Batches	Method of Placement
		☐ ☐		☐ ☐				☐ ☐
		☐ ☐		☐ ☐				☐ ☐
		☐ ☐		☐ ☐				☐ ☐

12. GEOTHERMAL INFORMATION *(Opt.; Open Loop only)*

Thermal Conductivity (BTU/hr·ft·°F)	Thermal Diffusivity (ft^2/day)	Formation Water Temperature (°F)

DEP UIC # ______ Sample taken from this well ☐ Y ☐ N

13. WELL TEST DATA

Date	Method	Yield (GPM)	Time Pumped (hrs)	Time Pumped (min)	Pumping Level (ft BGS)	Time to Recover (hrs)	Time to Recover (min)	Recovery (ft BGS)
	☐ ☐							
	☐ ☐							

14. WATER LEVEL

Date Measured	Static Depth BGS (ft)	Flowing Rate (gpm)

15. COMMENTS

16. WELL DRILLERS STATEMENT This well was drilled or altered under my direct supervision, according to the applicable rules and regulations, and this report is complete and accurate to the best of my knowledge.

Driller ______ Supervising Driller Signature ______ Certification # ______
Company ______ Date Job Complete ______ Rig Permit # ______

NOTE: Well Completion Reports must be filed by the registered well driller within 30 days of well completion.
Rev. 9/2/2010

Figure 3: Well Completion Report Required by the Drinking Water Program. Completed in triplicate, the driller retains the first page and is required to submit the second and third pages to the local Board of Health and MassDEP Drinking Water Program.

Massachusetts Department of Environmental Protection
Bureau of Resource Protection

WELL DRILLER

Please specify work performed: Deepen

Please specify well type: Domestic

Number Of Wells:

Well Location

In public right-of-way: ○ Yes ○ No

Subdivision/Property/Description:

Property Owner:

Engineering Firm: JOHN DUMONT

Address at well location:

Street Number: 357
Street Name: FOREST HILL ROAD
Building Lot#:
Assessor's Map #:
Assessor's Lot#:
ZIP Code:

City/Town: DUNSTABLE

GPS

North: 42.66868
West: 71.46291

Mailing Address:

☑ click here if same as well location address

Street Number: 357
Street Name: FOREST HILL ROAD
City/Town: DUNSTABLE
State: MASSACHUSETTS
ZIP Code:

Board of health permit obtained: ● Yes ○ Not Required

Permit Number: 5904
Date Issued: 7/9/2012

Figure 4: Electronic Well Completion Report (WCR) Form.

Submitted electronically to the Drinking Water Program, copy to be forwarded to local Board of Health.

Massachusetts Department of Environmental Protection
Bureau of Resource Protection – Well Driller Program
Well Completion Reports(General)

Well Driller - General Well Form

DRILLING METHOD

Bedrock

Air Hammer

WELL LOG OVERBURDEN LITHOLOGY

From (ft)	To(ft)	Code	Color	Comment	Drop in drill stem	Extra fast or slow drill rate	Loss or addition of fluid
		Choose Code	Choose Color		Yes	Fast Slow	Loss Addition

WELL LOG BEDROCK LITHOLOGY

From (ft)	To(ft)	Code	Comment	Drop in drill stem	Extra fast or slow drill rate	Loss or addition of fluid	Visible Rust Staining	Extra Large Chips
445	545	Granite		Yes	Fast Slow	Loss Addition	Yes	Yes
545	640	Granite		Yes	Fast Slow	Loss Addition	Yes	Yes

ADDITIONAL WELL INFORMATION

Developed: Yes No

Disinfected: Yes No

Total Well Depth: 640

Depth to Bedrock: 445

Surface Seal Type: None

Fracture Enhancement: Yes No

CASING Is Casing above ground?

Type	Diameter
Steel	6

WATER-BEARING ZONES DRY WELL

From	To	Yield (gpm)

PERMANENT PUMP (IF AVAILABLE)

Pump Description: 2 Wire Constant Speed Submersible

Horsepower: 1

Pump Intake Depth (ft): 600

Nominal Pump Capacity (gpm): 5

Figure 4: Electronic WCR- cont'd

Massachusetts Department of Environmental Protection
Bureau of Resource Protection – Well Driller Program
Well Completion Reports(General)

WELL TEST DATA

Date	Method	Yield (gpm)	Time Pumped (HH:MM)	Pumping Level (ft BGS)	Time To Recover (HH:MM)	Recovery (ft BGS)
7/19/2012	Air Blow With Drill Stem	4	00:30	640	24:00	540

WATER LEVEL

Date Measured	Static Depth BGS (ft)	Flowing Rate (gpm)

COMMENTS

WELL DRILLERS STATEMENT

This well was drilled or altered under my direct supervision, according to the applicable rules and regulations, and this report is complete a knowledge.

Driller	TJBERNIER	Registration #	546	Monitoring [M]		Supervising Driller	TJBERNIER
Firm	SKILLINGS & SONS, IN	Rig Permit #	020			Date Job Completed	7/19/2012

NOTE: Well Completion Reports must be filed by the registered well driller within 30 days of well completion.

Figure 4: Electronic WCR- cont'd

Well Test Information

The drilling contractor should submit the following well information concerning well yield to the well owner after completion of the pumping test:

(1) name and address of the well owner
(2) GPS well location in decimal degrees
(3) date the pumping test was performed
(4) well test method
  AB- Air Blow with Drill Stem
  AL- Air Lift
  BL- Bailing
  CR- Constant Rate Pump
  VR- Variable Rate Pump
  SL- Slug
(5) static water level in feet below ground surface (ft. BGS)
(6) flowing (discharge) rate in GPM
(7) pumping level (ft. BGS) (i.e., maximum drawdown during test), if applicable
(8) duration of the test, including both:
  a) the pumping time, and
  b) the recovery time during which measurements were taken
(9) recovery water level (ft. BGS)

<u>Water Quality Information</u>

It is recommended that the local Board of Health require the well owner to submit to the Board a copy of the laboratory test results anytime a private water supply is tested. The submitted copy should indicate:

(1) Name, address and phone number or other contact information for the individual who performed the sampling (i.e., BOH member, BOH agent, lab personnel, well owner, well owner's agent);

(2) where in the system the sample was obtained (at the wellhead, prior to treatment, or at the tap) and, if sampled at the tap, whether or not the system was flushed prior to sampling;

(3) date and time of sample collection;

(4) date and time sample received by the laboratory; and

(5) a copy of the laboratory's test results, which includes the MassDEP laboratory certificate number and the EPA method(s) used in the analysis.

Results that indicate no contamination are as important as those that indicate water quality problems because these results provide background data in case of future contamination. A complete record of all testing results is also useful when designing local water quality testing programs.

WELL LOCATION

Any person intending to have a private well constructed should identify all potential sources of contamination which exist within 200 feet of the site. Where possible, a well should be located upgradient of all potential sources of contamination and should be as far removed from potential sources of contamination as the general layout of the premises and surroundings permit.

In selecting a well location, all OSHA and Dig Safe requirements must be taken into consideration. Dig Safe should be contacted at least three days before drilling begins. Additionally, every well should be located so that it will be reasonably accessible with proper equipment for repair, maintenance, testing, and inspection.

The well should be completed in a water bearing formation that will produce the required quantity of water under normal operating conditions without adversely impacting adjacent wells. Water quantity considerations are discussed in the section entitled "Water Quantity" (page 47).

RELATION TO PROPERTY LINES AND BUILDINGS

Private water supply wells should be located at least 10 feet from all property lines. The center line of a well should, if extended vertically, clear any projection from an adjacent structure by at least 5 feet.

RELATION TO ROADS AND RIGHTS-OF-WAY

All private water supply wells should be located a minimum of 25 feet from the normal driving surface of any roadway or a minimum of 15 feet from the road right-of-way, whichever is greater. Additionally, it should be noted that the "Rights-of-Way Management" regulations (333 CMR 11.00) include procedures and requirements for marking and recording the location of private drinking water supplies which are within 100 feet of any right-of-way. Private drinking water supplies that are marked and recorded in accordance with the aforementioned regulations are protected by restrictions on the use of herbicides for maintaining rights-of-way. Uniform standard signs for marking water supplies have been produced and are currently available from the Department of Agricultural Resources (DAR).

RELATION TO SURFACE WATER AND WETLANDS

Private water supply wells should be located at least 25 feet laterally from the normal high water mark of any lake, pond, river, stream, ditch, or slough. Additionally, it should be noted that land use within 100 feet of a wetland or within the 100-year floodplain of any river or stream is regulated under Chapter 131, Section 40, of the Massachusetts General Laws and 310 CMR 10.00, "Wetlands Protection." Prior to constructing a private water supply in these areas, approval must be obtained from the local Conservation Commission. Where possible, private water systems should be located in areas above the 100 year floodplain. When a well must be located in an area subject to flooding, special protection should be provided, as is discussed in the section entitled "Wellhead Completion and Alteration" (page 59).

REQUIREMENTS OF THE STATE ENVIRONMENTAL CODE TITLE 5

Pursuant to Chapter 21A, Section 13, of the Massachusetts General Laws, MassDEP promulgated 310 CMR 15.00, "Minimum Requirements for the Subsurface Disposal of Sanitary Sewage, State Environmental Code, Title 5." These regulations provide minimum standards for the location, design, construction, and operation of subsurface sanitary sewage disposal systems that discharge less than 10,000 gallons per day.

It should be noted that the standards presented in the current version of Title 5 were developed primarily to protect public health against pathogenic viruses and bacteria. Local hydrogeologic conditions may require more stringent regulations. Boards of Health have the authority to strengthen Title 5 by implementing appropriate and reasonable local regulations.

Title 5 requires that a potable well or suction line is located a minimum of:

(1) 10 feet from a building sewer constructed of durable corrosion resistant material with watertight joints, or 50 feet from a building sewer constructed of any other type of pipe
(2) 50 feet from a septic tank
(3) 100 feet from a leaching field
(4) 100 feet from a privy

Title 5 also requires that irrigation wells be located a minimum of 25 feet from a leaching field, and 10 feet from a septic tank.

For (3) and (4) above, Title 5 notes that "100 feet is a minimum acceptable distance and no variance shall be granted for a lesser distance except with prior written approval of MassDEP."

In regard to pressurized water supply lines, Title 5 states that "it is suggested that the disposal facilities be installed at least 10 feet from and 18 inches below water supply lines. Wherever sewer lines must cross water supply lines, both pipes shall be constructed of class 150 pressure pipe and should be pressure tested to assure watertightness."

Part II of Title 5 includes procedures for obtaining a variance. Generally, the local Board of Health may grant a variance but there are also specific requirements for which Title 5 expressly states that only MassDEP (Wastewater Management Program) may grant variances. In order to grant a variance, however, it is important to have site specific hydrogeologic information submitted which documents that adequate protection can be provided without complying with the standards required by Title 5. All variances granted by the local Board of Health must be sent to MassDEP for review. MassDEP has the authority to overrule the Board of Health's decision.

SETBACK DISTANCES

These distances may be used as guidance for locating a potable well and they may be adopted in the local regulation because of the potential hazard to a well. Lesser setback distances may be applied for non-potable wells in accordance with Title 5 regulations.

Consideration should also be given to the direction of ground-water flow and the location of any groundwater discharge to a surface water body. Where possible, wells should be located upgradient of potential sources of contamination. Wells should not be located between a potential source of contamination and an area where groundwater discharges to the land surface. Other considerations for locating a well include the permeability, transmissivity, and composition of the subsurface geologic materials. It should be kept in mind that contaminants can be transported great distances through fractured bedrock and groundwater flow in the overburden may not be in the same direction as in the bedrock.

The following table contains the minimum lateral setback distances in feet :

Land Use	**Setback in feet**
Property Line	**10**
Public/Private Roadway	**25**
Right Of Way	**15**
Sewer line/septic tank*	**50**
Leaching field or drywell*	**100**
Stable, barnyard, manure storage	**100**
Aboveground fuel storage or pesticide tank	**100**
Underground fuel storage or pesticide tank	**250**
Surface water, wetlands**	**25**

*Setbacks required by Title 5

**Referral of well location to local Conservation Commission for approval required if proposed within 100 feet of surface water regulated under the Wetlands Protection Act.

Table 1 : Lateral Setback Distances

GENERAL WELL DESIGN AND CONSTRUCTION

Massachusetts has a wide range of geologic conditions encompassing both consolidated and unconsolidated formations. Consolidated formations consist of all the varied bedrock material that is found throughout the State. Sometimes this bedrock can be found at the surface, but usually it is covered by overburden formations that may be thin or thick. These overburden deposits are known as unconsolidated formations and generally consist of sand, silt, clay, and/or gravel. Groundwater exists in the fissures, cracks, and cavities within bedrock formations and in the pore space of unconsolidated formations. Depending on the formation characteristics and well design, well yield can range from hundreds of gallons per minute to less than a quart per minute.

Because of the widely varying geology throughout the State, a local well driller is usually best equipped through experience and local knowledge, to successfully complete a private well. All private water supply wells should be designed so that:

(1) the materials used for the permanent construction are durable in the specific hydrogeologic environment that occurs at the well site; and
(2) no unsealed openings will be left around the well that could conduct surface water or contaminated groundwater vertically to the intake portion of the well or transfer water from one formation to another.

In addition, permanent construction materials should not impart toxic substances, taste, odors, or bacterial contamination to the water in the well. It should also be noted that lead packers should no longer be used in the construction of any water supply wells.

The driller should operate all equipment according to generally accepted standards in the industry and should take appropriate precautions to prevent damage, injury or other loss to persons and property at the drilling site.

A well under construction should be protected so that surface wash is diverted away from the construction area and contaminants do not enter the well through the opening or by seepage through the ground surface. In addition, workers employed at the construction site should exercise caution in the disposal of wastes and in handling construction materials so as to avoid contamination of the well and the aquifer. The contractor should also take reasonable precautions to prevent either tampering with the well or the entrance of foreign material into the well during overnight shutdowns and other times when the contractor is away from the site.

During drilling, it is required that formation samples be taken at specific intervals. For wells drilled into unconsolidated formations, samples must be taken every 20 feet or change in formation. In consolidated formations, samples must be taken every 100 feet or change in formation. This information must be reported by the driller in the lithology section of the MassDEP Well Completion Report, a copy of which must be filed with MassDEP and the local BOH. Well yield should be measured and recorded periodically.

All water used for drilling, development, or rehabilitation should be obtained from a source which will not result in contamination of the well or the water bearing zones penetrated by the well. Water should be conveyed in clean sanitary containers or water lines and should be chlorinated to an initial concentration between 50 mg/l and 100 mg/l and a free-chlorine residual of 10 mg/l should be maintained. Water from water bodies such as wetlands, swamps, and ponds should not be used without proper disinfection. Water that has been disinfected should not be discharged after use directly to any surface water body.

All wells, including those that have been yield enhanced should be developed in order to remove fine materials introduced into the pore spaces or fractures during construction. One or more of the following methods should be used for development: over pumping, backwashing, surging, jetting, and air-lift pumping.

The completed well should be sufficiently plumb so that there will be no interference with installation, alignment, operation or future removal of the permanent well pump. Any work involving the connection of the private well to the distribution system of the residence must conform to the local plumbing code. All electrical connections between the well and the pump controls and all piping between the well and the storage and/or pressure tank in the house should be made by a MassDEP certified pump installer or well driller. It is recommended that the well driller/pump installer be certified by the National Groundwater Association for each phase of the work they are performing.

CONSOLIDATED WELLS

Consolidated wells are wells drilled in bedrock. They may be either artesian or non-artesian wells.

An artesian well is drilled through an impermeable strata into an artesian aquifer. The water in the well will seek its own static water level based on the elevation of the recharge area.

The following construction method is recommended for bedrock wells:

1. Extend an oversized drillhole a minimum of 10 feet into competent bedrock.
2. Install an unperforated, watertight protective casing with a drive shoe, a minimum of 10 feet into competent unfractured bedrock.
3. Seal the annular space between the casing and the drillhole with neat cement grout, sand cement grout, or bentonite grout applied from the bottom of the drillhole upward to a depth which will adequately prevent subsurface leakage or surface contamination.
4. After the grout has set, extend the drillhole into the water bearing zone.

Complete the well as recommended in the section entitled "Wellhead Completion and Alteration" (page 59)

If leakage occurs around the well casing or adjacent to the well, the well should be recompleted using additional casing, seals, and/or packers as necessary to completely eliminate leakage.

If a flowing artesian well is encountered, the wellhead should be capped or piped off to a discharge area. The discharge pipe should be air gapped so there is no direct connection between the discharge pipe, the receiving pipe, the receiving discharge area, or any potential source of contamination.

UNCONSOLIDATED WELLS

Unconsolidated well construction differs from bedrock well construction in that a well screen is generally employed as the water intake device. In unconsolidated formations, the well is most commonly constructed by drilling or boring methods. These include auger, mud rotary, cable tool and dual rotary drilling methods. Other specialized drilling methods are sometimes employed for particular geology, well design, or intended well use.

The mud rotary method advances an open borehole to the water bearing formation using the hydraulic properties of the drilling fluid (mud) to hold the hole open until the screen and casing can be installed. The other drilling methods advance either a temporary casing or the permanent casing to the desired depth of the well. The well screen and casing is then set in the desired position and the temporary casing is completely withdrawn or the permanent casing is pulled back to expose the slightly smaller diameter well screen.

The auger method of rotary drilling is typically used for smaller diameter wells up to about 200 feet deep. It is also the principal method of installing driven wells. When constructing a drilled well, the auger machine advances a hollow drill pipe with continuous flight augers on the exterior. The hollow drill pipe serves as a temporary casing to hold back the earth and the auger flights convey the drilled material from the bottom of the hole to the surface where the cuttings can be shoveled away. This method does not require any drilling fluid, produces much less debris at the surface, and does not contaminate the water bearing formation with drilling mud. Once the desired depth is reached, the well screen and casing is lowered inside the hollow auger to the bottom of the hole. The auger pipe is then removed, leaving the screen in direct contact with the sand or gravel formation and the casing to hold back the earth from the top of the screen to the ground surface. The diameter of the hollow auger drill pipe is selected based on the desired diameter of the completed well. Typically, the screen is not artificially gravel packed with this method, but in certain circumstances, with care, it can be. Because no drilling mud is used, one of the principal advantages of this method is that well development is often quick.

The cable tool drilling method is not commonly used today as more modern drilling machines and techniques have, for the most part, taken its place. However, cable tool drilling is still the method of choice when difficult drilling conditions are anticipated or a large diameter well is required. This century’s old drilling method advances a steel casing until the water bearing formation is reached. The well screen is then set inside the casing and the steel casing is either pulled back to expose the screen or completely removed to expose the screen and permanent casing. Cable tool drilling has the ability to advance the well through large rocks and boulders, but the operation is slow and time consuming.

Dual rotary is the modern day version of cable tool drilling. It utilizes a large drilling rig to simultaneously advance the casing and the borehole. It handles boulders and other difficult drilling conditions, but is often an expensive method, and typically employed on large diameter wells.

The above methods are commonly used for well diameters from 4 inches to in excess of 36 inches. They are capable of constructing the very shallowest of wells to wells exceeding 1,500 feet in depth. Obviously, the larger the well diameter and the greater the well depth, the larger the drilling rig required. The majority of private wells in Massachusetts are either 2, 4, or 6 inches in diameter and typically require moderate size drilling rigs. The efficiency of each drilling method depends to a great extent on the type of geologic formation being drilled. Other factors that affect the efficiency of a particular drilling method include the experience of the driller, the presence of geologic anomalies, and the hydraulic head of the aquifer or aquifers penetrated. The specific design of a well depends on the subsurface geology at the well site and the drilling method used.

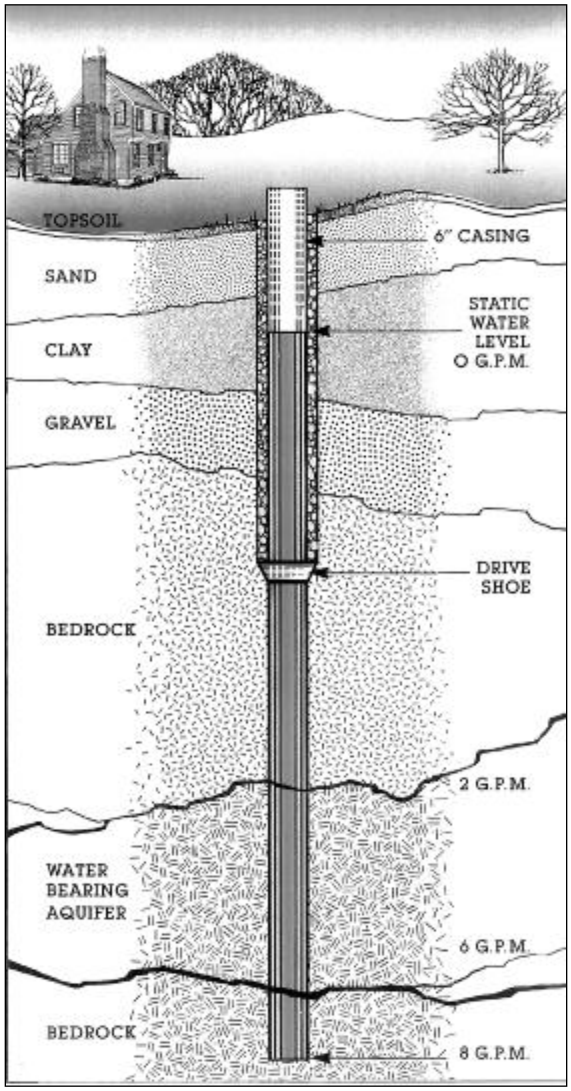

Figure 5 : Typical Construction for Bedrock Well Installations
(Connecticut Valley Artesian Well Company)

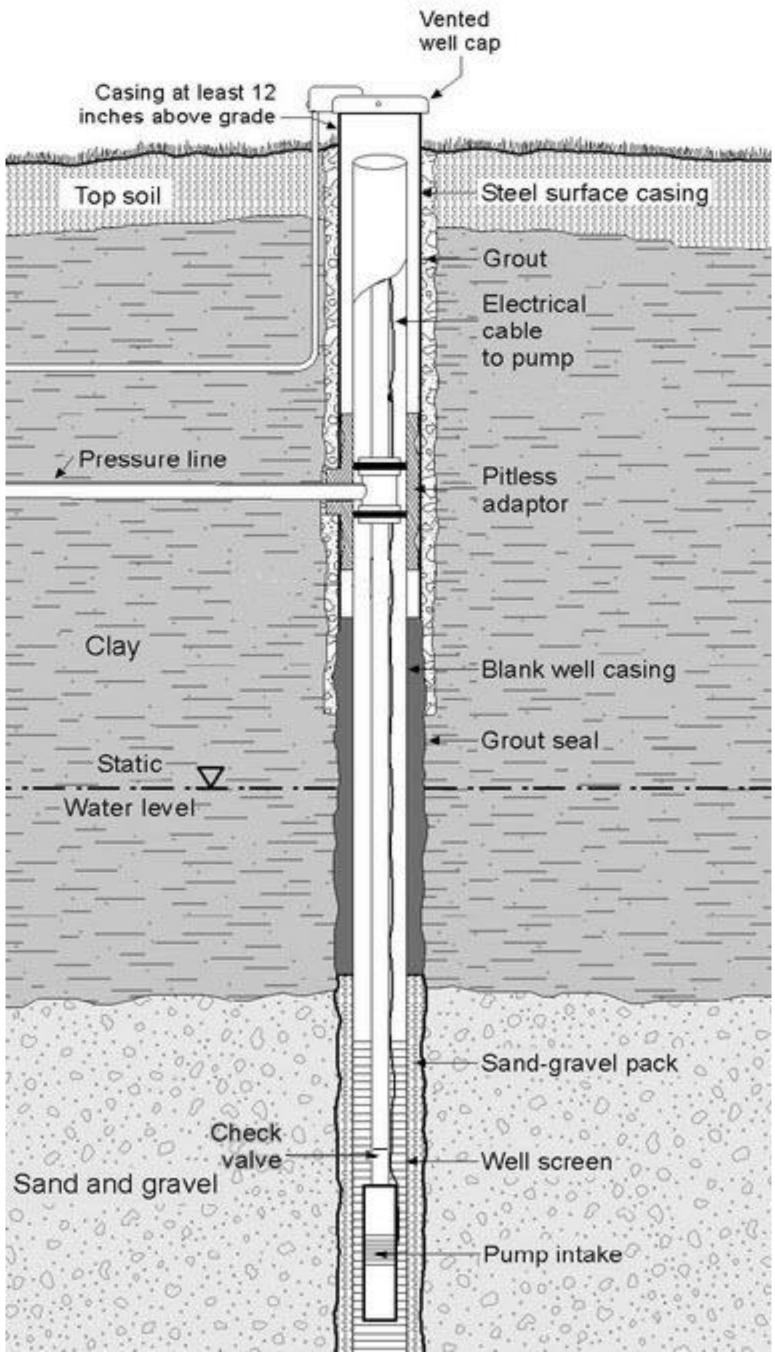

Figure 6 : Typical Drilled Sand and Gravel Well

(Colorado Geological Survey)

Driven Wells

Driven wells, also known as sandpoint wells, are installed only in unconsolidated formations which do not contain numerous cobbles and boulders. The maximum depth that can be attained with a sandpoint well is approximately 30 feet, if the well point is hand driven. If the well is jetted or if the well point is driven by a mechanical driver, however, a depth of 100 feet or more may be attained.

Driven wells are commonly 1 1/4 to 4 inches in diameter. It is recommended that neither the well screen nor the well casing be less than 1 1/4 inch in diameter. In selecting casing, consideration should be given to the depth of the static water table, being sure to account for seasonal fluctuations. When the static water level is within about 15 feet of the land surface, the well can be pumped by suction lift and the casing diameter can be as little as 1 1/4 inch in diameter. However, if the static water level is deeper than about 15 feet, the well must be pumped by a jet pump or a cylinder pump. In 4 inch diameter wells a submersible pump is commonly employed.

All well casing should be unperforated and water tight. Thermoplastic well casing may be used for a driven well if the appropriate well drilling method is utilized. Damage to the casing and screen must be avoided during the driving process.

The depth of a sandpoint well should be sufficient to prevent breaking suction when pumping the well at a rate 50% greater than the capacity of the permanent pump. When possible, the casing should extend to a minimum depth of 20 feet or 10 feet below the pumping level, whichever is greater. The "pumping level" is the maximum drawdown occurring in the well during pumping, as determined by the water well contractor, accounting for usual seasonal fluctuations of the static water level and drawdown level.

Hand Driven Installation

The following procedure is recommended for installing hand driven sandpoint wells:

(1) Use a hand auger or a post hole digger and bore a hole which is:

- (a) slightly larger in diameter than the well point,
- (b) vertical, and
- (c) a minimum of 3 feet deep but as deep as possible.

(2) Using pipe-thread compound approved by the National Sanitation Foundation for water wells and couplings with recessed ends and tapered threads, either:

- (a) connect the well point to a 5-foot length of well casing or to a string of well casing; or
- (b) connect the well point to a coupling and place the well point into a 5-foot length of oversized casing, attaching additional lengths of casing if desired.

Oversized casing protects the well screen and is used most often when driving deep wells.

(3) Place the wellpoint-casing assembly into the bored hole and backfill the hole.

(4) Attach an iron drive cap to the top of the casing.

(5) Drive the casing into the ground either by hand, using a weighted pipe similar to a fence post driver, or by using a mechanical driver. Add additional lengths of casing as needed until the desired depth has been attained.

(6) When oversized casing is used, expose the well screen at the predetermined depth either by driving it with an inner casing inserted through the oversized casing or by pulling back the oversized casing (Figure 7).

Machine Driven Installation

The installation procedure for machine driven wells usually employs an auger drill rig:

(1) A slightly oversized borehole is drilled until a suitable water bearing formation is reached.

(2) A solid, continuous flight auger is used to advance the bore and convey drilled material to the surface. Often the hole is over drilled to loosen up the formation and make the driving process easier.

(3) Since the borehole usually stays open above the water table, screen and casing are lowered until the water table is reached. The well screen is typically heavy-duty metal construction with a tapered point on the bottom and connected to the casing with a threaded joint.

(4) The driving is performed either at the top of the casing as described above, or down the well directly on the bottom of the screen.

(5) A heavy weight, long and smaller in diameter than the inside of the well screen is lowered on a heavy rope to the bottom of the screen.

(6) A rotating cathead on the rig is used to raise the weight a short distance and then allow it to free fall striking the bottom of the screen. This semi-manual process will advance the screen and casing at a slow rate until either the desired depth or refusal is reached.

This down the hole driving method is more effective than driving on the top of the casing and is safer for personnel.

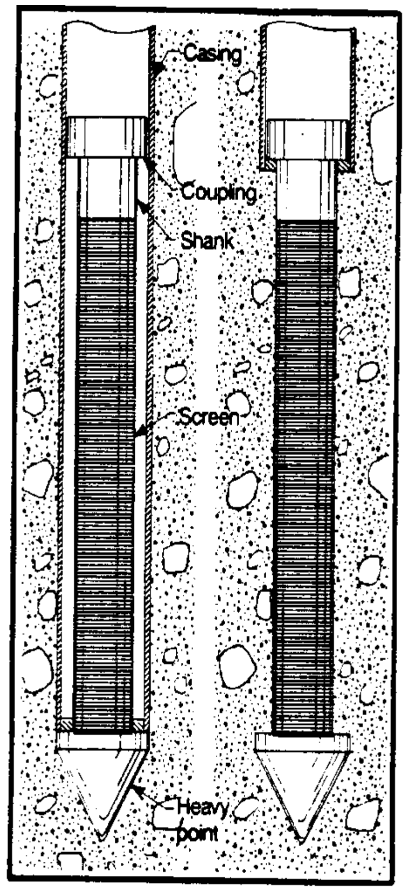

Figure 7 : Sandpoint Installed with Protective Oversized Casing
During driving, the casing pushed a special heavy duty drive point downward while the casing protects the screened portion of the wellpoint (left figure). The screen is exposed at the predetermined depth either by driving it with an inner casing inserted through the oversized casing or pulling back the oversized casing (right figure).
(Driscoll, 1986).

Dug Wells

A dug well is a shallow well that is generally 20 to 35 feet deep and three to five feet in diameter. Dug wells can be excavated by hand but, due to federal occupational-safety laws, are more often excavated using a backhoe. Dug wells are generally less reliable than drilled wells and should be constructed only where hydrogeologic conditions preclude the construction of a satisfactory drilled well. Further, dug wells are more susceptible to contamination and their use for potable purposes should be avoided unless it is impossible to install a drilled deep well. Although the relatively large diameter of a dug well provides a large water storage capacity, these wells often go dry when the water table drops during periods of drought. Additionally, since it is more difficult to dig below the water table, it is recommended that construction of a dug well take place during the months of August through October when the elevation of the water table tends to be at its annual low.

Due to the relatively large diameter of a dug well, concrete casing, also called curbing, may be used instead of steel casing. When concrete is used, it consists of either precast concrete pipe or it is poured-in-place. The wall thickness of precast concrete pipe should be a minimum of 2 inches thick and poured-in-place concrete should have a wall thickness equal to at least 6 inches. Recommended specifications for concrete casing are discussed in the section entitled "Well Casing" (page 36).

The casing of a dug well should be watertight to the depth of the production aquifer or to a depth of 20 feet below the preexisting ground surface, whichever is greater. The upper terminus of the well casing should extend 12 inches above the pre-existing ground surface or 2 feet above the highest recorded flood, whichever is greater. All above-grade and below-grade connections should be watertight.

When precast concrete pipe is used to case a dug well, the excavation should be at least 4 inches larger than the outside diameter of the casing. The annular space between the face of the excavation and the casing should be sealed with neat cement grout, sand cement grout, or bentonite grout to a depth below the local frost line.

The intake portion of a dug well below the watertight casing should consist of perforated casing or a loosely laid wall of stone, concrete block, or brick. It must be of adequate strength to withstand any external pressure to which it may be subjected and must be seated firmly enough to prevent settling.

Dug wells are constructed using either a standard type design or a buried slab design. Specifics pertaining to these two types of design are discussed below.

Construction of Standard Dug Wells

The design and recommended construction specifications for standard dug wells are illustrated in Figure 8. When standard construction is used, the well should be provided with a cover made of reinforced concrete that is at least four inches thick. The cover should rest on and overlap the outer edge of the well casing by at least two inches. The cover should be constructed without joints. Adequately sized pipe sleeve required to accommodate the type of pump and pump piping proposed for the well should be cast in place when the cover is fabricated. The top of the cover should be sloped so that water drains away from the sleeve.

A manhole, if installed, should be provided with a curb which extends at least two inches above the top of the cover and is cast in place when the cover is fabricated. The manhole should be equipped with an overlapping cover, the sides of which extend downward around the curb at least one and one-half inches. The joint between the curbing and the cover of the manhole should be made watertight with a plastic sealing compound and the manhole cover should be locked or bolted in place.

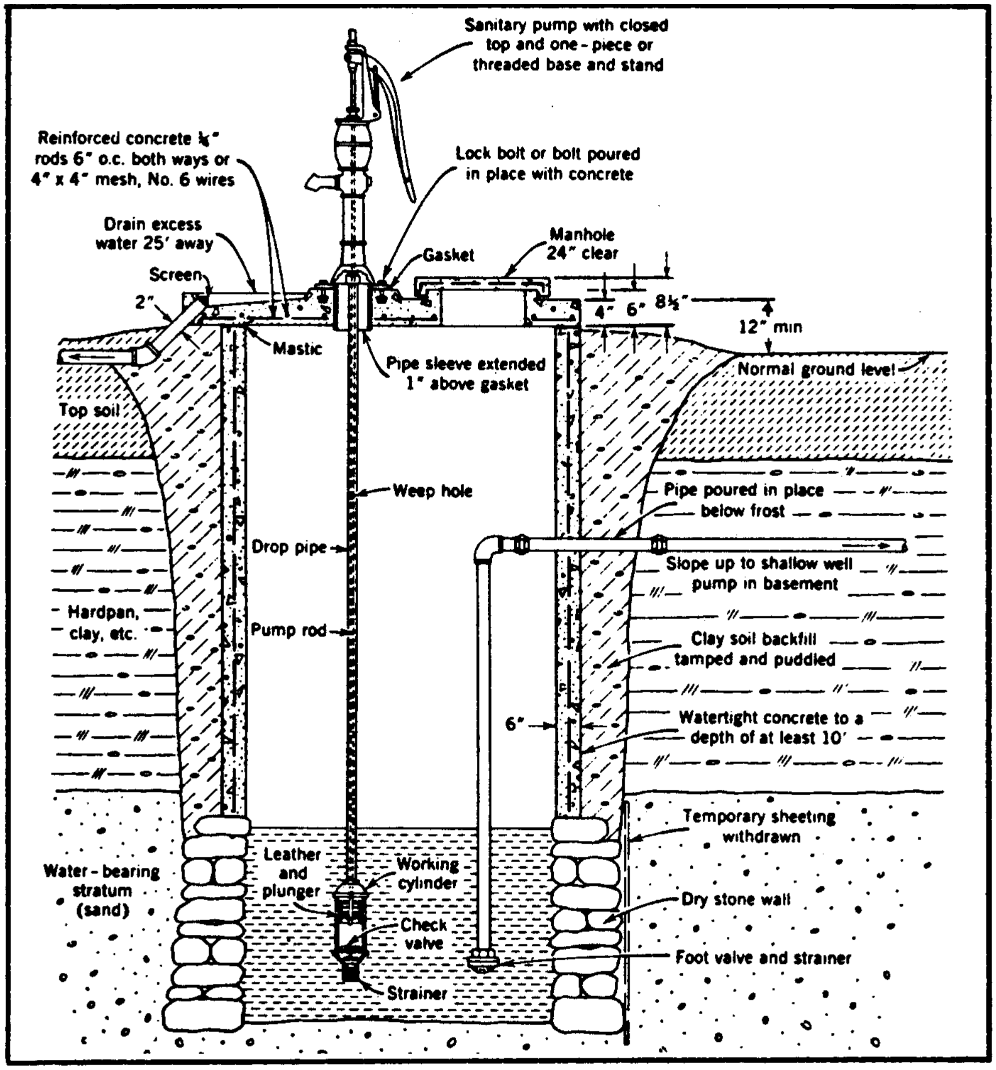

Figure 8 : Construction Details for a Standard Dug Well *(Salvato, 1958)*

DRILLING FLUIDS

Drilling fluids are used with rotary drilling to:

(1) lift the cuttings from the bottom of the hole and carry them to a settling pit
(2) stabilize the borehole wall to prevent caving
(3) lubricate the bit, bearings, mud pump, and drill pipe
(4) control fluid loss by sealing the borehole wall
(5) facilitate the removal of cuttings into a settling pit

Drilling fluids used in the construction of water wells are either water or air based. The major types of water based drilling fluids consist of:

(1) clean, fresh water,
(2) water with clay additives,
(3) water with polymeric additives, or
(4) water with clay and polymeric additives.

The primary types of air based drilling fluids consist of:

(1) dry air,
(2) mist: droplets of water entrained in the airstream,
(3) foam: air bubbles surrounded by a film of water containing a foam-stabilizing surfactant (soap), or
(4) stiff foam: foam containing film-strengthening materials such as polymers and bentonite.

As indicated above, the primary drilling fluid additives are clays, polymers, and surfactants. Other additives which may be used include flocculants, dispersants (thinning agents), weighting materials, corrosion inhibitors, filtrate reducers, nontoxic lubricants, preservatives, lost-circulation materials, and bactericides.

The specific composition of the drilling fluid used depends primarily on the type of subsurface materials expected and the drilling equipment available. Availability of water at the drilling site and the experience of the drilling crew are also factors that affect drilling fluid selection. In general, water based drilling fluids with clay or polymeric additives are typically used for drilling unconsolidated formations while air based fluids are used for drilling well-consolidated or semi-consolidated rocks and sediment.

Regardless of the specific composition, all drilling fluids must be nontoxic. Drilling fluid additives should be stored in clean containers and should be free of material that may adversely affect the well, the aquifer, or the quality of the water to be pumped from the well. In addition, surfactants should be biodegradable. Although biodegradable organic polymers, such as guar gum, are commonly used as drilling fluid additives, it should be noted that their use has resulted in persistent microbiological contamination of groundwater supplies. Consequently, the use of biodegradable organic polymers should, when possible, be avoided.

It is recommended that all water used to mix a drilling fluid, as well as any makeup water added, be chlorinated. Depending on the particular additives used for the drilling fluid, the mix water should be chlorinated to a concentration between 50 mg/l and 100 mg/l. The latter concentration is recommended, for example, when organic biodegradable polymers are used in the drilling fluid. In addition, a free-chlorine residual of approximately 10 mg/l should be maintained in the fluid during drilling. This concentration may be easily determined with chlorine paper and should be checked periodically. Chlorination is important because it retards the growth of bacteria introduced into the well during drilling procedures.

It should also be noted that mix water should never be taken from wetlands, swamps, small lakes, or other similar surface waters because these water supplies often contain both pathogenic bacteria and iron bacteria. Iron bacteria are of concern because their growth in a well can substantially reduce the well yield and can degrade the quality of the water obtained from the well.

TEMPORARY COVER AND DISINFECTION

At all times during construction when the well is not being worked on, the top shall be securely covered by a temporary cap. The temporary cap shall protect the well from entry of airborne or surface contamination or water. It shall be sufficiently secure to protect the well from vandalism. It shall be in place overnight during construction, during any lapse in construction, and between the completion of the well and installation of the permanent pumping system. During or after the well construction and after the permanent pump installation the well shall be disinfected. Bleach, calcium hypochlorite or an alternative chlorine product should be used. Sufficient product should be used to produce a concentration between 50-200 ppm in the well water. The manufacturer's instructions should be followed in using any disinfection product. Sufficient contact time shall be allowed. When there is a pump in the well, if possible, the disinfection solution should be recirculated back down into the well casing to disinfect the non-wetted surfaces. Before placing the pumping system in service, the disinfection solution should be pumped off until all traces are removed. Care should be taken not to discharge chlorinated water directly into any surface water body.

The well driller shall take all reasonable precautions to prevent inadvertent cross contamination of a drinking water well via his tools and equipment. If the same rig or tools are moved from a monitoring well site to a potable well site, the driller shall be especially cognizant of the potential for contamination

WELL CASING

Well casing, also called riser pipe, serves both as a housing for the pumping equipment and as a vertical conduit for the water pumped from the aquifer. Although the well casing generally extends from the intake portion of the well upward to the land surface, the lower portion of a drillhole may be left uncased when the well is completed in competent bedrock.

Private water supply wells should be constructed using steel, thermoplastic, or concrete well casing. The casing should be of adequate strength and durability to withstand anticipated formation and hydrostatic pressures; the forces imposed on it during installation; and the corrosive effects of the local hydrogeologic environment. The casing material used depends on the drilling method, the depth and diameter of the well, the character of the subsurface materials, and local groundwater quality. Thermoplastic casing, for example, is resistant to corrosive groundwater and acid treatment but it is not as strong as steel casing. Steel casing, on the other hand, should always be used when the casing is driven or when the casing is installed in an open drillhole in which formation materials may suddenly collapse against the casing.

All casing used in the construction of private water supply wells should be free of pits, breaks, gouges, deep scratches, and other defects. If previously used casing is installed, it should not only be free of defects, as mentioned above, but should also have been used only in a water well test hole, or a dry or inadequate boring. Additionally, the casing should have been salvaged within 30 days of the original installation. The diameter of the well casing must provide enough clearance for proper installation and operation of the well pump.

Installation of water well casing should be done in a manner that does not alter the shape, size, or strength of the casing and does not damage any of the joints connecting sections of the casing. Upon completion of the installation procedure, the entire length of the casing above the intake should be water tight.

STEEL WATER WELL CASING

Materials Standards

Due to the great variety of tubular steel products available, there are a number of different standards for materials considered acceptable for use as water well casing. All steel casing used in the construction of private water supply wells should comply with one of the materials standards approved by the American Water Works Association (Table 2). The wall thickness should be a minimum of .250 inch and sufficient to withstand hydraulic loading if the casing is pumped dry and should have a collapse strength greater than one pound per square inch for every 2.31 feet of depth beneath the top of the aquifer

Marking of Steel Water Well Casing

Each length of casing shall be legibly marked in accordance with the ASTM, API, or AWWA marking specifications noted in the most recent revision of the applicable standard showing, where respectively required:

(1) the name or trademark of the manufacturer or processor
(2) ASTM, API, or AWWA marking or monogram
(3) standard
(4) size in inches
(5) weight in pounds per foot, or wall thickness
(6) whether seamless or welded and, if welded, type of weld
(7) grade

Methods of Joining Steel Casing

Segments of steel casing should be coupled by using threaded or welded joints.

Recessed or reamed and drifted couplings should be used on threaded casing and no threads should be left exposed once the joint is completed. Welded casing joints should conform to the most recent revision of AWWA C206, "Standard for Field Welding of Steel Water Pipe." The weld should be at least as thick as the wall thickness of the well casing and should be fully penetrating. A fully penetrating weld means that, after the casing ends have been beveled at approximately 35 degrees, the entire beveled and flat area is filled with weld bead by making several passes around the casing. Welding must be done carefully in order to prevent burn-through on the first pass. If burn-through occurs, the slag deposited on the inside of the casing may impede the movement of tools within the casing or interfere with screen installation. When completed, a welded casing joint should have a tensile strength equal to or greater than that of the casing.

AGENCY AND STANDARD #	TITLE OF STANDARD
API[2] 5L	Specification for Line Pipe
API 5LS	Specification for Spiral-Weld Line Pipe
ASTM[3] A53	Specification for Pipe, Steel, Black and Hot-Dipped Zinc-Coated Welded and Seamless
ASTM A120	Specification for Pipe, Steel, Black and Hot-Dipped Zinc-Coated (Galvanized) Welded and Seamless, for Ordinary Uses
ASTM A139	Specification for Electric-Fusion (Arc) Welded Steel Pipe (NPS 4 and Over)
ASTM A211	Specification for Spiral-Welded Steel or Iron Pipe
ASTM A409	Specification for Welded Large Diameter Austenitic Steel Pipe for Corrosive or High-Temperature Service
ASTM A589	Specification for Seamless and Welded Carbon Steel Water Well Pipe
ASTM A714	Specification for High-Strength Low-Alloy Welded and Seamless Steel Pipe
AWWA[4] C200	Standard for Steel Water Pipe, 6 Inches and Larger

[1] The most recent revision of each standard shall apply
[2] American Petroleum Institute, 2101 L Street, N.W., Washington, D.C. 20037
[3] American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103
[4] American Water Works Association, 6666 West Quincy Avenue, Denver, CO 80235

TABLE 2 : MATERIALS STANDARDS FOR STEEL WATER WELL CASINGS[1]

THERMOPLASTIC WATER WELL CASING

Materials and Materials Standards

Three of the more common varieties of thermoplastic casing are: PVC (polyvinyl chloride), ABS (acrylonitrile butadiene styrene), and SR (styrene-rubber). The variety used most often in the construction of potable water supply wells is PVC. Casing made of ABS is generally used for no or low pressure applications such as for drain pipe or low-head irrigation pipe.

Thermoplastic casing used in the construction of private water supply wells should be capable of withstanding pressures equal to or greater than 200 pounds per square inch and should conform to the most recent revision of ASTM Standard F480, "Specification for Thermoplastic Water Well Casing Pipe and Couplings Made in Standard Dimension Ratios (SDR)." In addition, the casing and couplings should meet the requirements of the most recent revision of National Sanitation Foundation Standard Number 14, entitled "Plastics Piping System Components and Related Materials." Materials complying with Standard Number 14 can be recognized by the marking "NSF-WC."

Marking of Thermoplastic Water Well Casing and Couplings

Each length of casing shall be legibly marked in accordance with the ASTM marking specifications noted in the most recent revision of Standard F480 showing, where required:

(1) the nominal well casing pipe size
(2) the wording "well casing"
(3) type of material
(4) pressure rating (should be greater than or equal to 200 psi)
(5) standard dimension ratio
(6) impact classification
(7) ASTM standard designation "F480-95"
(8) "NSF-WC"
(9) designation of ASTM standard used for pressure testing
(10) "NSF-PW"
(11) name or trademark of the manufacturer
(12) the manufacturer's code for resin manufacture, lot number, and date of manufacture

Each thermoplastic coupling shall be legibly marked in accordance with the ASTM marking specifications noted in the most recent revision of Standard F480 showing, where required:

(1) the nominal coupling size
(2) type of material
(3) ASTM standard designation "F480-95"
(4) name or trademark of the manufacturer
(5) the NSF designation of approval for use in water well construction

Storage and Inspection of Thermoplastic Materials

Thermoplastic casing should be stored in such a manner as to prevent deformation, sagging, or bending. Storage of thermoplastic casing and couplings in direct sunlight should be avoided. Prior to use, the casing and couplings should be inspected for deformation, cuts, gouges, deep scratches, damaged ends, and other imperfections. Casing or couplings having any such defects should not be used for well construction.

Methods of Joining Thermoplastic Casing

Plastic casing should be joined by either mechanical or solvent cement.

All joining methods shall be watertight and develop the full pressure rating of the coupling or pipe. Joints may be either integral bell and spigot or plain end and coupling. The casing manufacturer's instructions should be followed in preparing and assembling the joint. The bell end, coupling and plain end of casing should be cleaned prior to assembly and inspected for any defects and if necessary "dry fit" to confirm proper joint tolerance.

Acceptable mechanical joining methods are spline joints and threaded joints. Spline joints employ a thermoplastic, flexible spline to provide 360 degree restraint and a separate O-ring gasket to provide a watertight seal. Threaded joints generally employ a coarse thread and extended bell length. Pipe dope or thread compound is not used. Mechanical joints may be disassembled and reused if necessary.

Solvent joints require the proper application of a solvent cleaner and a PVC cement. Both must be applied per the manufacturer's instructions to a clean surface. The proper type cement shall be selected based on the particular casing joint and temperature requirements. Adequate set time must be allowed for the joint to develop sufficient strength to support the casing and screen weight below the joint. Set time required is increased in cold weather. Once made, the joint cannot be disassemble and must be cut out. The ends of plain end pipe should be beveled first to aide assembly into the coupling or bell. Immediately upon assembly the pipe should be rotated ¼ turn in the bell or coupling. Excess cement should be wiped from the joint. Too much cement will damage the pipe.

Installation of Thermoplastic Casing

Thermoplastic casing should be installed only in an oversized drillhole and should never be driven, pushed, or forced into a formation from the top of the casing. Thermoplastic casing with a steel well screen and drive point may be driven if a down hole drive weight is used. This method allows heavy weights to impact the drive point at the bottom of the well screen, thereby advancing the screen and casing. When pulling back thermoplastic well casing to expose a well screen or adjust the well depth, the minimum force necessary should be applied carefully to prevent casing damage or separation.

Care should be taken when grouting a well constructed with thermoplastic casing because thermoplastics deform and lose strength at relatively low temperatures. Cement grouts should be applied with care and restricted if the heat of hydration will adversely affect the casing. Typical restrictions include limiting the thickness of the annular grout space, using a cement bentonite grout or a straight high solids bentonite grout.

FIBERGLASS WATER WELL CASING

Fiberglass casing is most commonly used for large diameter wells. It has excellent corrosion resistance and is cost effective. A mechanical or threaded joint is typically necessary due to the difficulty of using epoxy or resin cement in the field.

CONCRETE WATER WELL CASING

Concrete water well casing, also called curbing, consists of either precast concrete pipe or concrete which has been poured-in-place. This type of casing should be used only for the construction of dug wells.

Precast concrete pipe that is used for well casing should;

(1) be at least 2 inches thick
(2) meet or exceed ASTM C67 Class III specifications
(3) be free of blemishes that could impair the integrity of the well

Joints between pipe segments should be sealed with a continuous, solid ring rubber gasket having a circular cross section with a diametrical tolerance of plus or minus 1/64 of an inch. Gaskets should have sufficient volume to substantially fill the recessed area when the pipe joint is assembled. A properly sized gasket will form a pressure tight seal when it is compressed between the pipe segments.

Poured-in-place casing should be at least 6 inches thick and be free of voids. Vertical and horizontal reinforcement should be provided, using 3/8 inch steel rods on 12-inch centers. Rods should lap 12 inches but the lap should not occur at construction joints. There should be no construction joint within 10 feet of the original ground surface and, when possible, the walls should be poured in one continuous operation. When construction joints are required, they should be left rough and should be washed and brushed with neat cement grout before the pouring of concrete is continued. The concrete should be composed of clean, hard, durable aggregate with not less than 5 sacks of Portland cement per cubic yard of concrete. The diameter of the aggregate particles should not exceed either 1/5 the minimum thickness of the casing or 1 1/2 inches, whichever is less. The volumetric ratio of coarse aggregate to fine aggregate (passing No. 4 U. S. Standard Sieve) should neither exceed 2 to 1 nor be less than 1 to 2. Generally, a ratio of 1 1/2 to 1 is appropriate.

WELL SCREEN

Well screens are necessary for most drilled wells that are completed in unconsolidated formations. Wells completed in bedrock do not require a screen unless the bedrock formation is highly fractured or decomposed in nature, has a potential for collapse, or bleed fine material during water production.

The three basic forces applied to a water well screen are column load (vertical compression), tensile load (extending forces), and collapse pressure (horizontal forces). These three forces should be considered when choosing a well screen.

The well screen should be installed at a depth corresponding to the depth of the most permeable zone or zones which can yield the required quantity of potable water. These zones should be determined from the driller's log. For relatively thin aquifers, it is advisable to set the screen in the lower portion of the aquifer. For aquifers that are several tens of feet thick, however, it may not be necessary to set the screen near the bottom of the aquifer.

The well screen aperture openings, screen length, and diameter should be selected so as to maximize the aquifer's water yielding characteristics while minimizing the potential for pumping sand or fine particles into the well.

SCREEN MATERIALS AND CONSTRUCTION

The materials to be used as screens should meet strength requirements and be corrosion resistant. "To reduce the possibility of corrosion, the well screen and its end fittings should be fabricated of the same material (Type 304 Stainless Steel, Silicon Bronze, Silicon Red Brass, Monel 400, Armco Iron, Mild Steel, Plastic, etc.)" (U.S. EPA, 1975). Type 304 stainless steel is recommended due to its corrosion resistance and strength. A less expensive plastic screen may be used where strength is not an issue. A chemical analysis of the water will aid in the determination of an appropriate screen material. A screen with defects such as rough edges or gouges can promote corrosion and therefore should not be used.

Well screens should be constructed by one of the following methods:

(1) WIRE-WOUND, CONTINUOUS SLOT SCREENS: continuous-slot well screens should be of all-welded construction. Special shaped wire shall be helically wound around an array of equally spaced longitudinal rods and welded at each point of intersection. The inlet-slot openings between adjacent turns of the outer wire should widen inwardly so as to be nonclogging (AWWA, 1984).

(2) REINFORCED WIRE WRAPPED PUNCHED PIPE: the screen should consist of perforated pipe reinforced with longitudinal bars and wrapped with wire, the wire having a cross-section such as to form between each two adjacent loops of wire an opening so shaped as to increase in size as the slot extends inward. The wire will be firmly attached to the bars which are attached to the pipe (U.S. EPA, 1975).

Other well screen types should be used only if strength requirements so dictate. These well screens should be constructed by one of the methods described below:

(1) PUNCHED (WITH MATERIAL REMOVED) AND SLOTTED PIPE: the screen should consist of a pipe that has been punched (with the material removed) or slotted by saw, mill, casting, or other similar means. The slots should be equal in width as nearly as practical, if slotted, or of uniform spacing and dimension, if

punched (U.S. EPA, 1975).

(2) LOUVRED PIPE: the screen should consist of a pipe that has punched openings in it where material has not been removed. The openings formed should be between the corner of the outside of the pipe and the punched-out area, and the corner of the inside of the punched portion and its side. The openings should be uniform (U.S. EPA, 1975).

SLOT SIZE

Slot size, otherwise known as aperture size, defines the size of the opening in the well screen through which ground water passes. The slot size is expressed as a number which is equivalent to the size of the opening in thousands of an inch. A 10 slot would be 0.010 of an inch; a 125 slot would be 0.125 of an inch or 1/8 inch clear opening. For a naturally packed well common slot size ranges from 10 slot to 20 slot and would be designed to prevent fine to coarse sand from entering the well. For an artificially gravel packed well larger slot sizes are used, often in the 50 to 150 slot range.

The slot size is determined by the uniformity coefficient of the aquifer. The uniformity coefficient is a numerical expression of the variety in particle sizes in mixed natural soils, defined as the ratio of the sieve size on which 40 percent by weight of the material is retained to the sieve size on which 90 percent of the material is retained" (Driscoll, 1986). Total slot area should be sized appropriately in order to maintain an aperture (slot) entrance velocity equal to 6 feet per minute (0.1 ft./sec.) or less

Guidelines for determining screen slot size are available in various reference manuals (Manual of Water Well Construction Practices (U.S. EPA, 1975), Groundwater & Wells, Third Edition, Sterrett, 2007).General guidelines are as follows:

Naturally Packed Wells

These wells have the well screen set in direct contact with the natural sand or gravel formation. It is not necessary, nor desirable, for the screen to retain 100% of the formation material. Generally, the slot size that retains 40% to 50% of the formation is recommended. The 60% passing is removed during well development. Many drillers will use a more conservative approach and based on experience use a smaller slot size to minimize the potential for the well to pump sand. However, assuming the finer particles can be developed out of the well, for a given formation uniformity coefficient, the larger the slot size, the greater the well yield. Other factors that should be taken into account are:

- Homogeneous or non-homogeneous sediments
- Formation thickness and depth below the water table
- The occurrence of multiple, thin, different sediment layers
- Reliability of formation samples and depth accuracy
- Potential corrosiveness of the groundwater.

Artificially Packed Wells

These wells employ an artificial gravel pack on the exterior of the well screen, usually only 2 to 5 inches thick, as a buffer between the natural formation and the screen. To properly size the screen slots, accurate formation samples should be obtained and a sieve analysis performed on each different layer from the anticipated screen zone. The artificial pack material (usually a very coarse sand or gravel) is then sized to be coarser than the natural formation and have a uniformity coefficient of 2.5 or less. Finally, the screen slots are sized to retain 90% of the artificial pack. The well is then developed to remove the fine material from the pack and the formation. Packs thicker than 5 inches will make development difficult and ineffective. During installation, centering devices should be used to maintain the screen in the center of the borehole and provide for a uniform pack thickness. The pack should be extended well above the top of the screen to allow subsequent settlement.

For residential wells, artificial packs are typically used in situations where a natural pack well has insufficient yield. A properly designed pack and screen will often provide an increased well yield. However, it is important to note that one size pack and slot combination does not fit all situations. The pack and slot size must be carefully selected for each situation otherwise low yield or sand pumping will result.

LENGTH

Well screen length is determined by the following factors, in relative order of importance:

- Desired water quantity (see page 53 for further discussion on determining water quantity)
- Expected available drawdown
- Aquifer thickness
- Aquifer stratification
- Unconfined or confined aquifer

For a given formation, screen length is the greatest determinant of yield. Slot size has less of an effect, and screen diameter even less of an effect. Doubling the screen diameter will likely only increase the yield by 10%. Doubling the screen length may very nearly double the yield. For a residential well, a 3 to 4 foot well screen is usually selected and set near the bottom of the water yielding formation.

Any type of joint, whether it is screen to screen or screen to casing, should be accomplished by threaded and coupled joints or electric arc or acetylene welding (U.S. EPA, 1975). These joints should be straight, tight enough to retain aquifer materials, and strong enough to maintain screen strength. A self-sealing neoprene or rubber seal attachment to the screen top may be used when joining the screen to the casing.

SEALING THE BOTTOM OF THE SCREEN

The following acceptable methods of sealing the bottom of the screen are listed in relative order of common installation practices:

(1) "WELDED PLATE METHOD (SCREEN MATERIAL): The bottom of the deepest screen shall have a plate of the same material as the screen welded to it to seal it. The material thickness shall be sufficient to withstand the forces applied during installation and over the service life of the screen."(U.S. EPA, 1975)

(2) "FABRICATED PLUG METHOD: The bottom of the deepest screen shall be sealed with a threaded or welded plug or point. The plug may be of the same material as the screen or other suitable material (PVC) chosen for its strength and corrosion properties. A drive point should be heavy cast iron or steel capable of withstanding the repetitive impact of downhole weights." (U.S. EPA, 1975)

(3) "SELF-CLOSING VALVE METHOD: The bottom of the deepest screen shall be sealed by means of a self-closing valve on the bottom of the screen"(U.S. EPA,

1975)

(4) "BAG CEMENT METHOD: A pipe extension at least four nominal diameters in length shall be attached to the bottom of the deepest screen (the drillhole having been deepened to accommodate the extension). The bottom shall then be sealed by lowering into the extension pipe sufficient dry cement in small cloth bags to fill it to a depth of at least three nominal diameters, packing it firmly into place"(U.S. EPA, 1975)

(5) "WELDED PLATE METHOD (CASING MATERIAL): The bottom of the deepest screen shall be closed by welding to it a plate of the same material as the casing and of the same thickness."(U.S. EPA, 1975).

METHODS OF INSTALLATION

The following are acceptable methods for installing well screens listed in relative order of common installation practices:

(1) SUSPENDED FROM SURFACE METHOD: "the screen, with closed bottom, shall be attached by an approved manner to the casing and lowered into the well with the casing. In no instance shall it be driven or forced. It shall remain suspended from the surface until the formation has collapsed against it or until a filter material or formation stabilizer has been added" (U.S. EPA, 1975).

(2) PULL BACK METHOD: "the screen shall be lowered through the casing by means of a cable attached by a hook to the bail in the bottom of the screen, or by attaching a pipe to a threaded fitting in the bottom of the screen, and lowering the pipe with the screen. A heavy steel bar or line of pipe may be set on the screen bottom to hold it down while the casing is being raised. The casing shall be raised until the screen is exposed to the aquifer with the packer or seal lapped 12 inches into the casing" (U.S. EPA, 1975). In order for the screen to be exposed without it slipping out the bottom of the casing, a riser pipe attached to the top of the screen may be needed.

(3) WASHING METHOD; "the screen shall be fitted with a self-closing valve on the bottom. Next, the screen shall be attached to the well casing. A smaller pipe shall then be placed in the screen and by a method selected by the contractor also fitted to the self-closing valve. The screen with its casing shall then be 'washed' into place by pumping drilling fluid through the inner pipe" (U.S. EPA, 1975).

(4) DRIVEN THROUGH CASING METHOD: "the casing shall be set at a level immediately above the top of the formation or portion of the formation to be screened. A well point screen shall be lowered through the casing to the top of the formation by a cable and hook or an attached string of pipe. The screen shall then be seated in the formation by driving it to the desired depth and sealing it to the casing" (U.S. EPA, 1975). It should be noted that there is a potential for damaging the screen when this method is used.

(5) DRIVEN WITH CASING METHOD: the screen is fitted with a drive point and is attached to the bottom of the casing. A heavy weight, smaller in diameter than the screen is then lowered to the bottom of the screen on rope or wire line. A mechanical device is then used to lift and allow the weight to free fall. The screen and casing are then driven into the formation to the desired depth. Additional casing is added at the surface as the driving progresses. Great care must be taken with this method to prevent damage to the screen or separation of the screen from the bottom of the casing.

(6) BAILED THROUGH CASING METHOD: "the casing shall be placed at a level

immediately above the top of the formation or portion of the formation to be screened. The screen and attachments shall then be lowered through the casing to the top of the formation by cable and hook or an attached string of pipe. The screen shall then be put into place by bailing the aquifer material out from under it and allowing it to settle. After the screen is in place, it shall be sealed to the casing and the bottom plugged" (U.S. EPA, 1975). The string of pipe will help sink the screen if the weight of the screen alone is not enough. Also, continuous bailing permits the screen to settle more easily. It should be noted that any interruption during installation may cause sand to pack around the screen, preventing it from moving any further.

(7) BAILED OR AIR JETTED THROUGH CASING METHOD: “the casing shall be placed at a level immediately above the top of the formation or portion of the formation to be screened. A bail-down shoe shall be attached to the screen and a line of bail-down pipe attached to the shoe by a right and left-hand coupling, or similar release device. The screen shall then be lowered by the bail-down pipe to the top of the aquifer and then bailed into place or seated by blowing air through the bail-down pipe. When the screen has reached the desired depth, the bail-down shoe shall be plugged at the bottom by an approved method, and the screen shall be sealed to the casing" (U.S. EPA, 1975).

(8) WASHED THROUGH CASING METHOD: "the casing shall be placed at a level immediately above the top of the formation to be screened. The screen shall be fitted with a self-closing valve at the bottom and a small inner pipe attached to the valve. The screen shall be lowered through the casing by any means deemed appropriate. The screen shall be washed into place by pumping drilling fluid through the inner pipe. It shall then be sealed to the casing" (U.S. EPA, 1975).

WELL DEVELOPMENT

Proper and effective well development is one of the most important steps in the well construction process. Without effective well development you may simply have a hole in the ground or an unusable water supply producing sand or fine particles. Well development is equally important for both unconsolidated and consolidated formations. It should not be minimized as a result of cost or time pressures on an individual project.

All drilling methods alter the hydraulic characteristics of the formation materials adjacent to the borehole, impairing the transmission of water from the aquifer into the well. The reduced hydraulic conductivity may be caused by the physical rearrangement of the formation materials adjacent to the boring, or by the invasion of drilling fluids or fine sediment into the surrounding formation. Well development removes clay, silt, and fine sand from the formation adjacent to the well intake and restores the natural properties of the aquifer. Ultimately, proper well development maximizes the specific capacity of a well and minimizes the pumping of sediment.

Common well development methods are:

- Surge block agitation
- Jetting with water
- Jetting with air
- Air lift pumping
- Over pumping
- Backwashing

The above list is in general order of effectiveness, from most effective to least. Often more than one method is employed to produce adequate development. Sometimes specialty chemicals are used as an aid in the development process. The majority of chemicals employed are either acids, phosphates, or chlorine. In developing new wells, phosphates are effective in removing fine silts and clays from the formation. Drilling mud manufacturers offer specialty products that break down the drilling mud and aid the development process.

For the redevelopment of existing wells, acids are more commonly used as they are effective in removing incrustation and other forms of buildup from the well screen. Chemicals for development should only be used as a last resort, and should be NSF certified (Standard 60) for potable well use. All chemicals should be carefully chosen for each specific application, neutralized if necessary, and disposed of in a proper manner.

Development should proceed until all drilling fluids are removed, and sediment-free water (water containing no more than 5 mg/L of sediment) can be obtained when the well is pumped at the designed production rate. Regardless of the method used, well development should be initiated gently and gradually increased in vigor as development proceeds.

The bore hole needs to be flushed upon completion of the drilling when air drilling in bedrock with down hole hammer bits, roller bits, or PDC bits. This is to remove all the fines from the formation. This is accomplished by injecting water into the drill rod while blowing the well. This procedure should continue until no fines are coming to the surface.

Although the benefits of development are generally more substantial for wells completed in unconsolidated formations, all wells should be developed by the contractor prior to conducting a pumping test.

Well design and the character of the subsurface materials determine which method or methods of well development are most appropriate. Highly stratified, coarse grained aquifers, for example, are most effectively developed by methods that concentrate energy on small parts of the formation. Uniform deposits, on the other hand, are most effectively developed by methods that utilize strong surging forces over the entire well bore. Powerful surging of a well completed in a formation containing a significant amount of silt or clay, however, may actually reduce the hydraulic conductivity of the formation.

During development, a pump is subjected to sand pumping which causes excessive wear on the pump and may cause it to become sand locked either during the pumping operation or after the pump has been shut off. In order to prevent damage to the permanent pump, a test pump should be used for well development.

Time limits should not be placed on development because incomplete development may lead to premature incrustation of the well screen or cementation of the adjacent formation. The rate and effectiveness of the procedure depends on the physical characteristics of the aquifer, the depth of the well and the properties of the drilling fluid.

WELL YIELD ENHANCEMENT

Well yield enhancement means the science of entering a dry or low yield water well with special mechanical or inflatable well packers, used in conjunction with high pressure volume pumps, to inject water for cleaning out existing seams. Packer settings shall be no less than 40 feet from the bottom of the casing and at least 60 feet below ground surface. The only fluid used in this process should be potable so as not to provide a health risk to the users of the well. Proper disinfection of the well shall be done at the completion of this activity. The use of dry ice or dynamite shall not be used as a means of well yield enhancement or well development in bedrock well construction.

WATER QUANTITY

A properly constructed private water supply well must have a sufficient capacity to provide for anticipated needs. In order to determine if the well can provide an adequate supply of water and to obtain information necessary for the design of the permanent production pump, the well driller or pump contractor should perform a pumping test. This test also provides information that may assist a contractor if the well malfunctions.

PUMPING TEST REPORT

All pumping test data should be recorded and included in a report that the contractor should submit to the well owner. If the well driller performs the pumping test, a copy of the pumping test report should be appended to the Well Completion Report that is submitted to the local Board of Health and MassDEP.

The pumping test report should include, but not be limited to, the following information:

(1) name and address of the well owner
(2) well location(latitude/longitude in decimal degrees)
(3) date the pumping test was performed
(4) depth at which the pump was set for the test
(5) location of the discharge line
(6) the static water level immediately before pumping commenced
(7) the discharge rate and, if applicable, the time the discharge rate changed
(8) pumping water levels and respective times after pumping commenced
(9) the maximum drawdown during the test
(10) the duration of the test, including both:
  a) the pumping time, and
  b) the recovery time during which measurements were taken
(11) recovery water levels and respective times after cessation of pumping
(12) reference point used for all measurements

The local BOH may require the reporting of water quantity information in addition to that listed above as part of their private well permitting process.

GENERAL RECOMMENDATIONS FOR PERFORMING PUMPING TESTS

The following general recommendations apply to all pumping tests:

(1) upon completion of drilling and developing the well, and prior to beginning the pumping test, the aquifer should be allowed to recover from stresses induced by drilling and development procedures

(2) may be terminated after a minimum of 2 hours if the water level has stabilized for the last 30 minutes of the test

(3) a temporary pump should be used for the test

(4) the discharge line should be located where it will not cause recirculation of pumped water

(5) the discharge water should be checked periodically for sediment: excessive sediment in the discharge, which could damage the pump, indicates that the well needs additional development

(6) water level measurements should be measured in feet and hundredths of a foot

(7) water levels can be monitored in other wells that could potentially be influenced by the well being tested

TESTING PROCEDURE

Pumping Test

The pumping test should be conducted until the well has stabilized. Following the pumping test, the water level in the well must be shown to recover to within 85 % of the pre-pumped static water level within a 24 hour period. If the water level in the well fails to recover to within 85% of the pre-pumped static water level within a 24 hour period, the well should be redeveloped, enhanced, and/or deepened. After completing the chosen redevelopment procedure(s), another pumping test should be conducted.

Due to seasonal variations in groundwater recharge, pumping tests performed during times of seasonally high ground water may not accurately predict performance during times of reduced water availability. A well that passes a pumping test in the spring, during high water-table conditions, may not be able to provide an adequate supply in summer or during drought periods when the water table is lower. Tests performed between June and October are more reliable for determining if a well will satisfy household water demands than tests performed at other times of the year.

Estimating Household Water Need

In general, we use 50 to 100 gallons per person per day in our homes. However for the purposes of planning a domestic water system, the total water use is less important than the peak daily water use or the peak demand. In reality, most of the water used in the home occurs over a short period of time, typically in the morning and in the evening, before and after work and school. As a result, it is recommended that the water system be able to supply the projected water use in a 1 hour peak demand period.

For most small single-family homes, a minimum well yield of 5 gallons per minute (gpm) is suggested. Higher flow rates may be necessary for larger homes with more residents, having numerous fixtures and appliances, which may be using water at the same time. The values in the table below give the suggested peak flow rates for a various number of bedrooms and bathrooms in a home.

Number of bedrooms	**Number of bathrooms**				
	1	**1.5**	**2**	**3**	**4**
2	**Flow rate, gpm**				
	5	**6**	**8**		
3	**7**	**8**	**9**	**10**	**12**
4	**8**	**9**	**10**	**12**	**13**
5		**11**	**12**	**13**	**15**
6			**13**	**15**	**17**

Table 3 : Peak flow rates (GPM) for homes based on number of bedrooms and bathrooms

Ideally, the yield of a well will exceed the recommended flow rates in Table 3. If not, the system may need to rely on water storage to meet peak demand periods. The flow rate given above only takes into consideration domestic household water usage such as showering, cooking, laundering and toilet flushing required during peak demand periods. Other residential uses such as lawn irrigation and high volume showerheads will require additional capacity from the water supply system. An outside lawn sprinkler system is estimated to require 12 gpm alone, in addition to the peak demand for household use.

WATER SUPPLY SYSTEMS FOR LOW-YIELD WELLS

If a well has a sustained yield of less than 5 gpm or if the well yield is insufficient to meet peak water demand, other measures should be taken to ensure an adequate supply of water throughout the day. The options generally fall into two categories: reducing peak water use or increasing storage within the water system. (Ohio DNR, 2011)

Reducing Peak Water Use

Peak water demands on the well can be reduced by changing the timing of water using activities or by reducing the amount of water used. Examples of changing the timing of water use include spreading out laundry loads throughout the week instead of doing all loads in one day and having some family members shower at night rather than all showering in the morning. Reducing the amount of water might include changes in water-use behaviors such as taking shorter showers or not washing cars. More permanent solutions are to install water saving devices such as a water efficient clothes washer, and low flow faucets and toilets. Research has shown that the installation of water saving devices and appliances can reduce household water use by up to 30%.

Increasing Water Storage

Inadequacies in the well yield can also be compensated for by increasing the amount of water stored within the water system. Added storage can be achieved in the drilled borehole, in a pressure tank, or in a large storage tank (intermediate storage).

Borehole storage

One method to increase the well capacity is to increase the storage of water within the borehole. The borehole may be able to store several hundred gallons of water to meet peak water demand. Ideally, extra borehole storage is added to a low-yielding well when it is first drilled to meet the expected home demand. The amount of water stored in the well can be increased by widening or deepening the borehole.

For example, a typical 6-inch diameter well with 100 feet of borehole would store approximately 147 gallons of water (Table 4). If the 6 inch well was redrilled to 10 inches in diameter, the storage would increase dramatically to 408 gallons of water. Increasing diameter alone should not change the water quality since the new well draws from the same aquifer as the old well. However, increasing diameter alone is risky because its success depends on a relatively constant depth of water in the well. In reality, the depth of water may vary dramatically during wet and dry periods, causing the change in storage to also vary considerably.

In wells where the water level changes significantly during dry periods, deepening the well may be a better alternative to increase borehole storage. Drilling an existing 6 inch diameter well 100 feet deeper would increase the water storage by about 147 gallons. There can be, however, significant changes in water quality as the well is deepened. The deeper well may access groundwater with water quality problems that may require treatment. (Penn State, 2005)

DIAMETER OF WELL IN INCHES	GALLONS OF WATER PER FOOT OF WATER DEPTH	GALLONS OF WATER PER 100 FEET OF WATER DEPTH	DIAMETER OF WELL IN FEET	GALLONS OF WATER PER FOOT OF WATER DEPTH
1 ½	0.092	9.2	2	23.5
2	0.163	16.3	3	52.9
3	0.367	36.7	4	94.0
4	0.653	65.3	5	146.9
5	1.020	102.0	6	211.5
6	1.469	146.9	7	287.9
8	2.611	261.1	8	376.0
10	4.080	408.0	9	475.9
12	5.876	587.6	10	587.6

TABLE 4
GALLONS OF WATER PER FOOT OF DEPTH
FOR VARIOUS CASING OR HOLE DIAMETERS

Flow Volume (gpm)	Flow Volume (gpd)
0.3	432
0.4	576
0.5	720
0.6	864
0.7	1008
0.8	1152
0.9	1296
1.0	1440
1.5	2160
2.0	2880
2.5	3600
3.0	4320
3.5	5040
4.0	5760
4.5	6480
5.0	7200

TABLE 5
FLOW VOLUMES IN GALLONS PER MINUTE AND
CORRESPONDING FLOW VOLUMES IN GALLONS PER DAY

Pressure Tank Storage

The pressure tank in a private water system has three purposes. Its primary purpose is to maintain pressure on the water in the distribution system when the pump is not running. Secondly, it builds up a reserve supply so that the pump starts and stops less often, prolonging the life of the pump. In addition it supplies a limited reserve supply of water for use during times of high demand.

As water from the well is pumped into the tank, the air in the space above the water is compressed. When the pressure on the surface of the water reaches about 60 pounds per square inch (psi), a pressure activated switch stops the pump. When a faucet is opened, the air pressure forces the water out of the tank into the distribution system until the pressure drops to about 40 psi. Then the pressure regulator trips the switch and starts the pump, which forces an equal amount of water into the pressurized tank.

Total tank volume (gallons)			Usable water storage for pressure switch range (gallons)		
Galvanized steel tank	Pre-charged steel tank with wafer	Diaphragm or bladder tank	20 to 40 psi	30 to 50 psi	40 to 60 psi
15	4.5	4.5	1.7	1.4	1.2
30	14	14	5.1	4.3	3.7
42	20	20	6.5	5.5	5
82	32	32	12	10	8.5
120	45	45	18	15	12
160	62	62	21	19	17
225	90	90	30	26	23

Table 6 : Usable pressurized storage amount in gallons for various types of pressure tanks with common constant speed pressure switch settings

(Midwest Plan Service, MWPS-14, 2009)

About 20 % of the capacity of the pressure tank contains usable water. Larger pressure tanks will provide slightly larger amounts of stored water, but the increased storage may not be enough to solve problems with a low-yielding well.

Intermediate Tank Storage

An intermediate storage system is simply a storage reservoir that is added to receive water from the well to meet peak demand for the home. A typical system is shown in Figure 9.

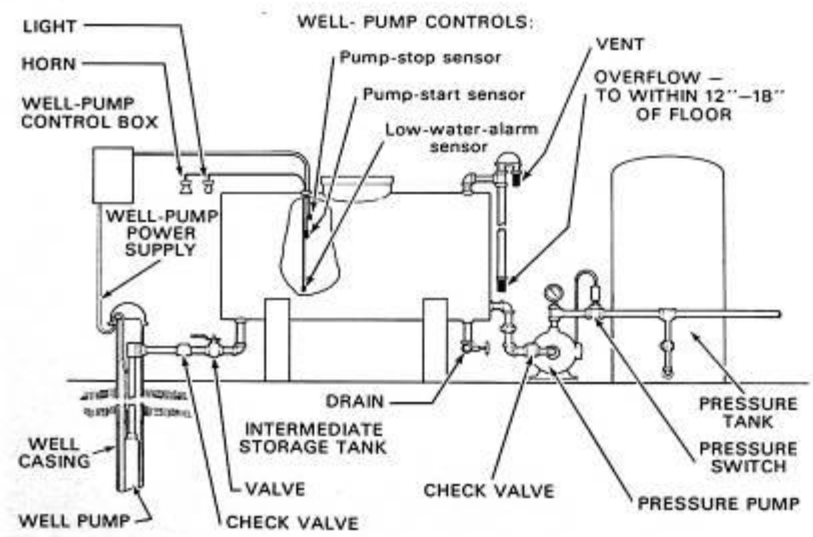

Figure 9 : Typical Water Treatment System
(M Kizer, OSU presentation on Household Water Systems)

Intermediate storage systems are based on the concept that many low-yielding wells can provide a constant but limited flow 24 hours a day without appreciable drawdown. In this case, a typical well pump may cause the water level to drop to the critical point during periods of high use, and the pump will not be able to obtain the water needed to replenish the pressure tank at the rate at which it is withdrawn. This problem can be solved by installing an intermediate storage reservoir between the well and the pressurized water system. This reservoir then serves as the primary source of supply for the pressure pump.

An intermediate storage tank requires two pumps and a large non-pressurized holding tank or reservoir. The pump in the well pumps water into the reservoir; the pressure pump transfers the water from the reservoir to the pressure tank and into the distribution system. The depth of water stored in the non-pressurized storage reservoir is regulated either by a float switch or water level sensor that controls the on-off operation of the well pump.

There are many types of non-pressurized storage tanks that can be installed to provide intermediate water storage. Possibilities include steel, plastic, and concrete tanks in a variety of sizes. In some instances it may be desirable to install two intermediate tanks in parallel rather than one single unit. This arrangement provides some flexibility in that one tank can be removed from service for cleaning and maintenance while the other keeps the water system in operation.

For home systems, the tank must be protected from freezing by either burying them below the frost line or placing them in a heated garage or basement. Ideally, the storage tank(s) will hold enough water to meet a full day's water use or more. The tanks can then be slowly refilled overnight from the low-yielding well.

A booster pump is added after the intermediate storage tank(s) unless the system can be gravity fed to the home. The booster pump provides water to the pressure tank for distribution in the home. The capacity of the booster pump can be determined by estimating the total water demand from the well. Since most water will be needed during the peak 2 hour demand period, the total daily demand should be divided by 2 hours and then by 60 minutes per hour to get the pump capacity in gallons per minute. For example a single family home requiring 840 gallons of water per day (gpd) would need a booster pump capacity of: 840 gpd/2hrs/60 minutes=7.0 gpm.

The well pump capacity for an intermediate storage tank should have a rated capacity slightly less than the yield of the well. The pump should be expected to operate more or less continuously, if necessary, to keep the storage tank full. Normally. a low water cut off switch controlled by water level sensors in the well should be connected to a relay at the pump switch box. A low water signal relayed to the main switch should override other pump controls and stop the pump if the water level drops to a critically low point where air or sediment would be pulled into the system.

DETERMINING ADEQUACY OF A WATER SUPPLY SYSTEM

The State Sanitary Code (105 CMR 410.180) requires that a potable water source be provided that supplies drinking water in sufficient quantity to meet the occupant's needs. Prior to approving occupancy, it must be determined if the well will provide sufficient water to meet average household needs using the information contained in the previous sections.

Methodology:

a. Estimate Peak Demand in gallons required to meet peak demand period of one hour (or 60 minutes) using Table 3 above based on number of beds and baths in house

(gpm required x 60 minutes = gallons needed for peak demand)

b. Calculate volume of water the well can produce in peak demand period of 60 minutes, based on pumping test results

(well yield in gpm X 60 minutes =gallons produced)

c. Estimate borehole water storage using information obtained from the Well Completion Report. To determine the available water in feet subtract the depth to static water level from the depth to the pump intake. Multiply the available water in feet times the gallons of water per foot for the well diameter (see Table 4) to calculate the number of available gallons held in storage in the borehole.

(Total depth to pump intake – static water level) X gallons per foot of water = available water from borehole storage)

d. Subtract gallons of water held in borehole storage (step c) and total amount the well is capable of producing in 60 minutes (step b) from the estimated peak demand (step a) to determine if well is capable of meeting peak demand. If the difference between the two is zero or less, then the well will meet peak demand. If the difference is greater, then additional storage in the form of a storage tanks will be required.

[*(a) Estimated peak demand (gallons) – (b)[well yield (gallons) + (c)borehole storage (gallons)] = estimated storage requirements*]

Example 1: The well completion report indicates that a 6 inch diameter domestic well was installed that has a pump intake set at a depth of 300 feet, with a measured static water level depth of 15 feet and an estimated well yield of 2 gpm.

a. For a 2 bedroom, 2 bathroom home, a peak demand rate of 8 gpm for one hour, or 480 gallons, is estimated from Table 3, are needed to meet the household peak demand (8 gpm X 60 min = 480 gallons)

b. The well report indicates that the well is only capable of producing 2 gpm or 120 gallons during the 1 hour period (2 gpm X 60 minutes = 120 gallons)

c. Borehole storage is calculated to be 419 gallons (300 foot depth to pump intake – 15 foot static level) X 1.469 gallons /feet of 6 inch diameter casing = 419 gallons)

d. 480 gallons needed to meet peak demand – 120 gallons (well yield over 1 hour) – 419 gallons (borehole storage) = **-59 gallons (surplus)**.

In this example, the well installation will not require any additional storage to meet the peak demand,, because the well yield plus the borehole storage provides a volume in excess of the peak demand requirements.

<u>*Example 2*</u>: assuming same well completion information as example 1 (above)

a. For a 3 bedroom, 3 bathroom home, a peak demand rate of 10 gpm for one hour, or 600 gallons, is estimated from Table 3 are needed to meet the household peak demand (10 gpm X 60 minutes=600 gallons)

b. The well report indicates that the well is only capable of producing 2 gpm or 120 gallons during the 1 hour period (2 gpm X 60 minutes = 120 gallons)

c. Borehole storage is calculated to be 419 gallons (300 foot depth to pump intake – 15 foot static level) X 1.469 gallons/feet of 6 inch diameter casing = 418.67 gallons)

d. 600 gallons needed to meet peak demand – 120 gallons (well yield over 1 hour) – 419 gallons (borehole storage) **= +61 gallons (deficit)**.

In this example the well installation does not meet the daily peak demand and an additional 61 gallons will be required daily.

In instances where the above methodology indicates that peak demand can be met by a combination of well yield and borehole storage, the well yield alone should also be able to refill the borehole storage volume over a 12-hour time period. Minimum well yields of between 0.5 gpm to 1.5 gpm would be needed to accomplish this for the 1-hour peak demand volumes calculated using the recommended peak flow rates provided in Table 3. These minimum well yields would be necessary in order to sufficiently replenish the borehole storage between peak demands events.

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CASING SEALS

PURPOSE OF CASING SEALS

The exterior of the well casing should be provided with an impervious material (grout) that is used to seal the annular space between the casing and the borehole wall. Wells are grouted in order to protect the well from contaminated surface water; prevent the transfer of water between two water-bearing zones that differ in water quality or hydrostatic pressure; protect the well casing from corrosion, and prevent the well casing from being damaged. Casing grouting may not be necessary for wells completed in highly pervious sand and gravel formations, such as found on the Cape and the Islands.

MATERIALS

The most appropriate material or combination of materials for a casing seal depends on the construction of the well and the geologic and hydrologic nature of the formation or formations penetrated by the well. These subsurface conditions should be taken into consideration when selecting the type of grout seal. The composition of acceptable grouts are the following:

(1) **Neat cement grout** is a mixture consisting of one bag (94 pounds) of Portland cement (ASTM Standard C150, Type I or API Standard 10, Class A) to not more than 6 gallons of clean water. Bentonite (API Standard 13A), up to 2 % by weight of cement, shall be added to reduce shrinkage. Other additives, as described in ASTM Standard C494, may be used to increase fluidity and/or control setting time. Although one bag of cement to 6 gallons of water produces a very fluid mixture, it sets up like concrete when it hardens. Once the neat cement grout has been placed, it should cure for 24 hours before drilling resumes.

Neat cement may be used in all geologic formations and is ideal for sealing small openings, for penetrating annular space outside of casings, and for filling voids in the surrounding formation. When applied under pressure, it is favored for sealing wells under artesian pressure or borings that penetrate more than one aquifer. Unlike many other grouts, neat cement will not separate into a two-phase substance.

(2) **Bentonite grout** consists of NSF/ANSI Standard 60 certified product made up of sodium montmorillonite clay. It shall contain a minimum 20% solids by volume with a permeability rating of less than 1×10^{-8} cm/sec in fresh water. The solids content of the bentonite should be a minimum of 20%. The driller should refer to the manufacturer's recommendations for mixing rates and applications. Once the bentonite grout has been placed, it should cure for 2 hours before drilling resumes.

Bentonite expands in size after placement in the annular space around the well casing. It will not shrink or crack as long as it remains hydrated. If the bentonite based grout dries out it will rehydrate when water is re-introduced from the formation

If the groundwater chemistry indicates a total hardness greater than 500 ppm, or a chloride content greater than 1,500 PPM, bentonite grout should not be used. A neat cement grout may be a better choice for this application.

(3) **Sand cement grout** is a mixture consisting of Portland cement (ASTM Standard C150, Type I or API Standard 10, Class A), sand, and water in the proportion of one part cement to 3 or 4 parts sand, by volume, and not more than 6 gallons of water per bag (94 pounds) of cement. Up to 5%, by weight, of

bentonite (API Standard 13A) shall be added to reduce shrinkage. Once the sand cement grout has been placed, it should cure for 24 hours before drilling resumes.

When mixing the grout, the bentonite should be mixed with the water component of the grout first. The remaining components should then be added to the bentonite-water mixture. Although this procedure for mixing the grout is more difficult, it produces a product that is less pliable than one in which the bentonite is added after the other components have been mixed.

INSTALLATION METHODS

It is recommended that positive placement methods be used to install well seals rather than gravity placement or installation using a dump bailer. Furthermore, placement should be from the bottom of the section being grouted upward and should be completed in one continuous operation.

The more common installation methods are:

(1) **Positive Placement Exterior Method** (Figure 10): Grout material shall be placed by a positive displacement method such as pumping or forced injection by air pressure (after water or other drilling fluid has been circulated in the annular space sufficient to clear obstructions). The bottom of the inner casing shall be fitted with a suitable drillable plug to prevent grout from entering the casing. Grout shall be injected in the annular space between the inner casing and either the outer casing or the borehole. The annular space must be a minimum of 1 1/2 inches (3.81 cm) for sand cement, bentonite or neat cement grout, and not less than three times the size of the largest coarse aggregate used. The grout pipe shall extend from the surface to the bottom of the zone to be grouted. The grout pipe shall have a minimum inside diameter of one inch for sand cement or neat cement grout. Grout shall be placed, from bottom to top, in one continuous operation. The grout pipe may be slowly raised as the grout is placed but the discharge end of the grout pipe must be submerged in the emplaced grout at all times until grouting is completed. The grout pipe shall be maintained full to the surface at all times until the completion of the grouting of the entire specified zone. In the event of interruption in the grouting operations, the bottom of the pipe should be raised above the grout level and should not be resubmerged until all air and water have been displaced from the grout pipe and the pipe flushed clean with clear water. .

(2) **Continuous Injection Method** (Figure 11): Grout shall be placed by the float shoe continuous injection method (after water or other drilling fluid has been circulated in the annular space sufficient to clear obstructions). The bottom of the casing shall be fitted with a suitable drillable float shoe equipped with a back pressure valve. Tubing or pipe shall be run to the float shoe to which it shall be connected by a bayonet fitting, left hand thread coupling, or similar release mechanism. Water or other drilling fluid shall be circulated through the tubing and up through the annular space outside the casing. When the annular space is clean and open, grout shall be pumped down the pipe or tubing and forced by continual pumping out into the annular space surrounding the casing. Pumping shall continue until the entire zone to be grouted is filled. The grout pipe shall then be detached from the float shoe and raised to the surface for flushing. After the grout has set, the float shoe, the back pressure valve, and any concrete plug remaining in the bottom of the casing shall be drilled out. A neat cement, bentonite or sand cement grout shall be used for this procedure with a minimum annular space of 1.5 inches completely surrounding the casing.

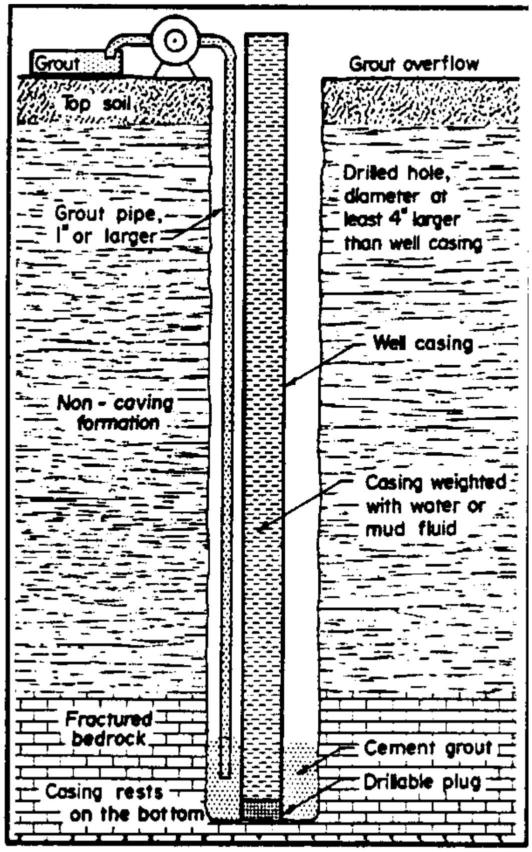

Figure 10: Grout Installation by Positive Placement Exterior Method. Grout is pumped through a pipe lowered into the annular space outside the casing. *(Johnson 1966)*

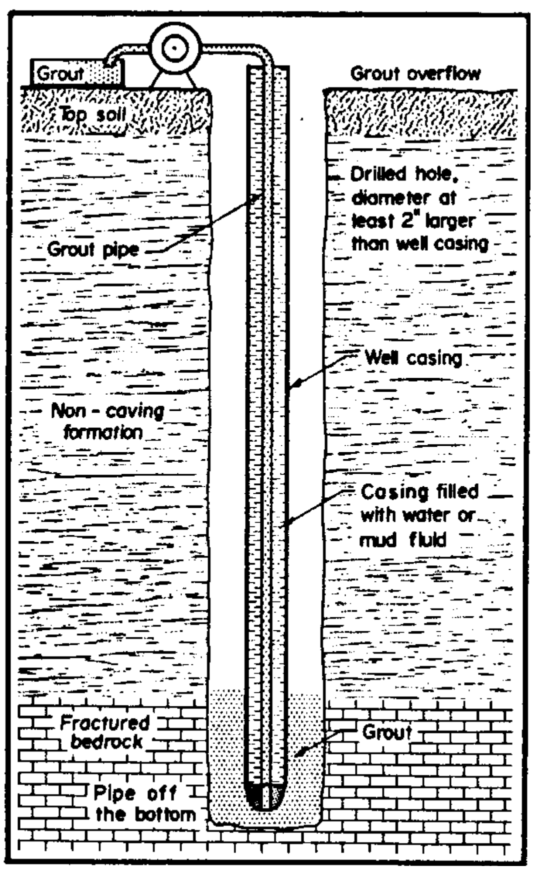

Figure 11: Grout Installation by Continuous Injection Method: Grout pipe placed inside the casing is connected to a drillable float shoe at the bottom of the casing. *(Johnson, 1966)*

Less common installation methods include:

(3) **Positive Placement Interior Method with Upper Plug, Lower Plug or Two Plugs**: In the upper plug method, a measured quantity of grout, sufficient to seal the casing in place, is pumped into the capped casing. Because the grout is in direct contact with the drilling fluid, there is a narrow zone of weak grout between the drilling fluid and the stable grout. In order to prevent the weak zone at the grout-drilling fluid interface from being located at the critical position at the bottom of the casing, the casing should be uncapped; a drillable plug, constructed of plastic or other suitable material, should be inserted on top of the grout; and the casing should be recapped. A measured volume of water, equal to the volume of the casing, should then be pumped into the casing, forcing the plug out the bottom of the casing.

In the lower plug method, the casing is uncapped; a drillable plug, constructed of plastic or other suitable material, is inserted; and the casing is recapped. A measured quantity of grout, sufficient to seal the casing in place, is then pumped into the capped casing followed by a volume of water sufficient to force most of the grout out the bottom of the casing and up the annular space. A common practice is to leave 10 to 15 feet of grout in the casing.

In the two plug method, which is a variation of the two preceding methods, the casing is uncapped, a drillable plug is inserted, and the casing is recapped as in the lower plug method. A measured volume of grout, sufficient to seal the casing in place, is pumped into the casing. The casing is then uncapped, a second plug is inserted, and the casing is recapped. A measured volume of water slightly less than the volume of the casing is then pumped into the casing until the second, or uppermost of the two plugs, is pushed out the bottom of the casing, and the grout is forced upward into the annular space

In all three of these methods, grout should be placed after water or other drilling fluid has been circulated in the annular space for a sufficient period of time to clear obstructions. Backflow should be prevented by maintaining constant pressure within the casing until the grout has set. Pressure should be maintained for a minimum of 24 hours or until such a time that a sample of grout indicates a satisfactory set.

(4) **Positive Placement Interior Method with Capped Casing** (Figure 10): Grout shall be placed by pumping or air pressure injection through the grout pipe installed inside the casing from the casing head to a point 5 feet (1.5 m) above the bottom of the casing (after water or other drilling fluid has been circulated in the annular space sufficient to clear obstructions). The grout pipe shall extend airtight, through a sealed cap on the casing head of the well casing. The casing head shall be equipped with a relief valve and the drop pipe shall be equipped at the top with a valve permitting injection. The lower end of the drop pipe and the casing shall be open. Clean water shall be injected down the grout pipe until it returns through the casing head relief valve. The relief valve is then closed and injection of water is continued until it flows from the borehole outside of the casing to be grouted in place. This circulation of water is intended to clean the hole and condition it to better take the grout. Without significant interruption, grout shall be substituted for water and, in a continuous manner, injected down the grout pipe until it returns to the surface outside of the casing. A small amount of water, not to exceed 17 gallons per hundred lineal feet (30 m) of 2 inch (5.08 cm) drop pipe may be used to flush the grout pipe. A constant pressure shall be maintained on the inside of the grout pipe and the inside of the casing until the grout has set. Pressure shall be maintained for at least 24 hours, or until such time as a sample of the grout indicates a satisfactory set. Neat cement or sand cement grout shall be used for this procedure with a minimum annular space of 1 1/2 inches (3.8 cm) completely surrounding the casing.

WELLHEAD COMPLETION and ALTERATION

UPPER TERMINUS OF WELL CASING

Well casing terminating above-grade should extend at least 12 inches above the predetermined ground surface at the wellhead except when the well is located in a floodplain. When a well is prone to flooding, if practical, the well casing should extend at least 2 feet above the level of the highest recorded flood. The top of the well casing should be reasonably smooth and level.

Wellheads should only be completed below grade in the following situations:

- Jet pump installations where the well head connections are made below the frost line. These connections shall be made via threaded, glued, or insert fitting joints. Well seals shall not be permitted for these applications when used on potable wells.
- Wells equipped with submersible pumps that are located in driveways or other areas that prevent above grade completion. In this case the well head should be enclosed in a suitable manhole with roadway type frame and cover. The manhole and cover should be capable of supporting the anticipated vehicle wheel loads. The manhole should be of sufficient diameter and depth to allow removal of the well cap and access to the well for maintenance. It should have an open gravel bottom and readily drain any surface water that enters. Particular care should be taken to assure adequate drainage and the prevention of a backup of water up to the well cap.
- When the soil percolation rate at the well location is greater than 2 inches per minute it is acceptable to use an open bottom manhole. For lessor percolation rates, a drainage pipe or sump pump shall be installed to drain any water that enters the pit.
- Irrigation wells and other non-potable wells.

When wells are located near driveways or in areas where they could be impacted by a vehicle, the well head should be protected by one or more steel bollards or heavy wood posts. This is particularly important when thermoplastic casing is used or when the site is subject to snow plow or delivery truck activity. The protection post(s) should extend 2 to 3 feet above grade.

Some older wells equipped with submersible pumps have been completed with their well buried just below grade. When well or pump maintenance is performed, these homeowners should be encouraged to have their well heads extended above grade in accordance with the above requirements.

SANITARY SEAL OR WELL CAP

Any well, except a dug well, that does not terminate in the base of a pump should be equipped with a sanitary seal or watertight well cap designed to prevent surface water and foreign matter from entering the well. A well cap is used in the construction of new potable wells. A well seal (as depicted in Figure 12) is typically used for potable well repairs and irrigation wells.

A proper well cap is mandatory to provide sanitary protection for the well. The well cap should be both watertight and vented. It should be NSF approved and should be designed and installed to prevent entry of surface water, rain water, insects, or any other contaminants into the well. The joint between the removable cap and the flange should be gasketed. The flange should be attached to the well casing via a means that provides a watertight seal. Cap bolts should be tightened down evenly and securely. Vent holes should be screened with 24 mesh corrosive resistant screen material. Plastic caps with molded vent holes (which are too large) are not capable of excluding small insects and should not be used on potable wells.

When a water system has had a bacterial contamination episode, the well cap should be checked first as the possible source. Damaged, poor quality or improperly installed well caps are often the problem.

A well seal consists of a “sandwich” of two steel or heavy plastic plates with a thick rubber middle piece held together by four or more through bolts. Holes through the assembly are provided for the drop pipe, submersible wire, and for a vent. They are primarily used in submersible pump installations. When installed at the top of a cleanly cut well casing, the rubber center section seals against the inside of the well casing and drop pipe when the bolts are tightened. In addition, the top plate of the seal bears on the top of the well casing and supports the entire weight of the well pump. In theory, when properly installed with great care, well seals can provide a proper sanitary well seal. In actual practice, these seals frequently allow water leakage, insects, dust, and fine debris into the well. When installed above grade they do not provide freeze protection. When installed below grade the potential for contamination is increased.

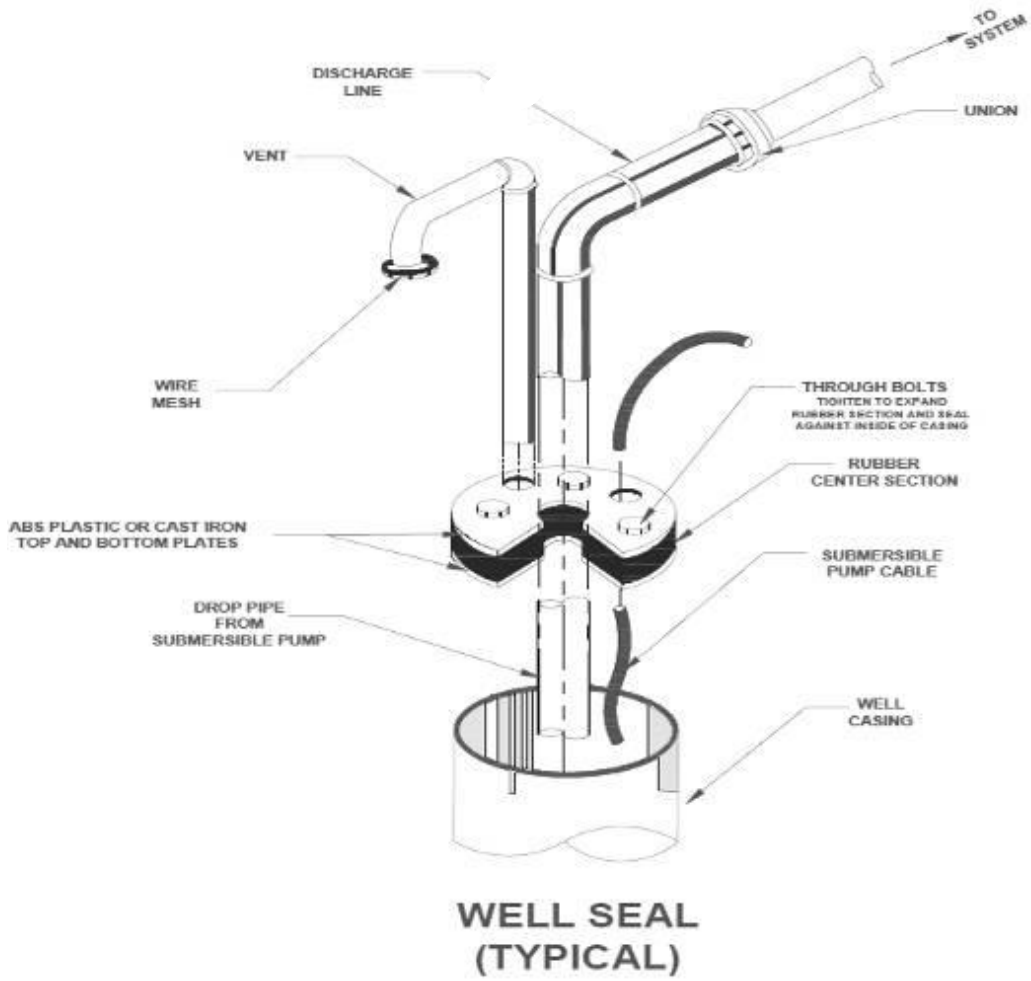

Figure 12 : Well Seal
(Water Systems Council)

WELL VENT

All wells except flowing artesian wells and dug wells should be vented. The opening of the vent pipe should be covered with a 24 mesh corrosion resistant screen and should be large enough to prevent water or dirt from being drawn into the well through electrical conduits. The vent may be an integral part of the well cap or a separate vent pipe. If separate, the vent pipe should terminate in a downward position at or above the top of the casing. In areas subject to flooding, the well may have to be vented through the waterproof electrical conduit.

BELOW-GRADE CONNECTIONS

All water line connections to a well casing made below ground should be protected by a pitless adapter or a pitless unit that complies with the most recent revision of National Sanitation Foundation Standard Number 56, entitled "Pitless Well Adapters." Native materials should be packed tightly around the pitless device after it has been installed and the necessary connections have been completed. The pitless adapter (Figure 13) is one of the most important components in a typical submersible pump installation. It not only provides a sanitary means to connect the water line to the well casing below the frost line, it supports the full weight of the pump. Pitless adapters are typically made of steel, brass, stainless steel or plastic. Care must be taken during installation that the proper size hole is made in the casing, that no dirt or debris enters the well, and that the outer half of the pitless is properly aligned.

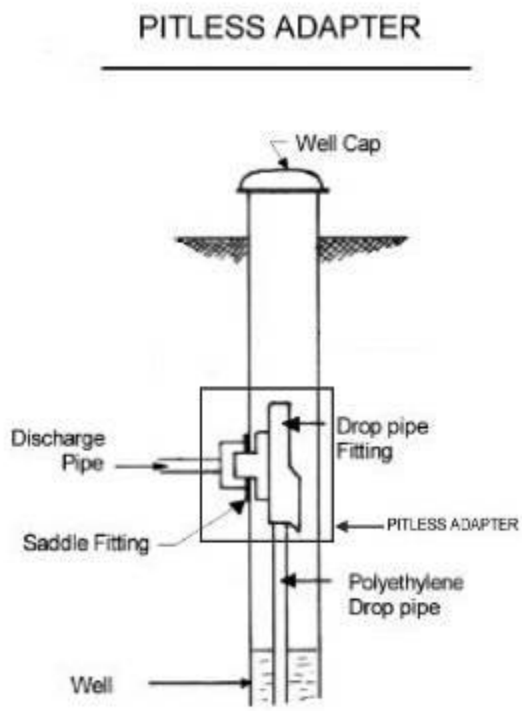

Figure 13 : Pitless Adapter Installation

(adapted from Water Systems Council)

ABOVE-GRADE CONNECTIONS

Above-grade connections into the top or side of a well casing should be at least 12 inches above the established ground surface or higher in areas prone to flooding. Above-grade connections should be sealed so that they are watertight. One or more of the following techniques should be used to ensure that an above-grade connection is watertight; (1) a threaded connection, (2) a welded connection, (3) a rubber expansion sealer, (4) bolted flanges with rubber gaskets, and (5) extension of the casing at least one inch into the base of a pump that is mounted and sealed on a concrete pedestal.

SURFACE GRADING OF WELL SITES

In order to prevent ponding of water around the well casing and to drain surface water runoff away from the wellhead, the ground immediately surrounding the well casing should be sloped away from the well in all directions. When earth materials are used for surface grading, they should be firmly compacted.

WELL ALTERATION

Extension of Existing Casing

An existing casing can be extended above ground by welding a casing extension to the existing casing. Another method is to carefully telescope a section of larger casing over the existing one for a length of 5 feet. The casing should extend 18 inches above the surrounding ground and the inside diameter of the addition should be 3 inches greater than the inside diameter of the existing well casing. The annular space between the casings should be made equal all around and then filled with cement grout. The space around the outside of the casing extension should be filled with tamped concrete. Regardless of the method used to extend the well casing above ground, it is necessary to provide a sanitary well seal. The well should then be disinfected as described in the Disinfection section on page 72.

<u>Upgrading Of Wells Completed Below Grade</u>

Historically, it was common practice to construct a large diameter pit around a small diameter well. The pit provides convenient access to underground water line connections below the frost line. Unfortunately, wells pits are always unsanitary because they literally invite drainage into the well, creating a contamination hazard to the water well system. Well pits should be eliminated by extending the casing above grade and installing a pitless unit. Only experienced and qualified personnel should complete any upgrading work.

Power to the well must be turned off prior to starting any work. All electrical wiring and associated piping must be disconnected, and the pump removed from the well. The well cribbing creating the well pit must then be removed using excavation equipment. Once the casing is exposed, it should be inspected for damage or corrosion. Any damaged or corroded sections must be removed before an extension can be made to the remaining structurally sound casing. Alternatively, if a casing extension cannot be attached by threading or welding, a pitless connector or rigid coupler can be used to join the existing well casing to the casing extension. The new extended well casing should be completed to a level of at least 12 inches above the finished grade. A new pitless unit is then installed onto the new casing. The pumping mechanism and any electrical and associated piping must be re-installed, including a properly attached conduit for any electrical wiring.

Care should be taken in backfilling the excavation hole, as to ensure that the well casing and extension are kept vertical and inline at all times, and the pitless unit is not damaged or dislodged. A properly vented well cap must be installed onto the well casing. Final grading around the well should be completed to direct surface water away from the well. Finally the well, pump and household plumbing system should be disinfected prior to being used again as a drinking water source.

If it is necessary for the well head to be below grade, it can be achieved in the following manner.

1.) The well head should be encased in a well pit, well tile or irrigation box.

2.) The well head should extend a minimum of 6 inches above the floor of the encasement.

3.) The encasement should have a pitched 4 inch pipe that drains to daylight or a sump pump installed so that no water can pond around the well head.

4.) If the soil surrounding the well is a sand/gravel formation as found on Cape Cod, then it is not necessary to drain the well head encasement provided no water can accumulate at the well head.

PUMPS and TANKS

PUMP TYPES

Pump selection is based on the water requirements and the design, depth, and yield of the well. There are basically two types of pumps; centrifugal and positive displacement.

Deep-well pumps utilize pistons, impellers, or jets to lift, or push, the water upward. The depth from which deep-well pumps can obtain water depends on the design of the pump and varies from less than 100 feet to more than 1,000 feet.

A positive displacement pump delivers water at a constant rate regardless of the pressure or distance it must overcome. It may be either a shallow-well or a deep-well design.

The following types of pumps are most commonly used for private water supply systems.

(1) **Submersible Multistage Pump**: several impellers (small centrifugal pumps) act in series to force water up the drop pipe. The pump is directly connected to and driven by a submersible electric motor, usually the same diameter as the pump. These installations usually require a minimum of 4 inch well diameter. An electric cable provides electricity to the pump motor. These pumps provide greater efficiency, higher capacities and head pressures than jet pumps. (Figure 14)

(2) **Shallow Well Jet Pump**: a single stage centrifugal pump is motor-driven to suck water into the inlet and force it out the higher pressure discharge side. The pump incorporates an integral jet assembly that recirculates a portion of the pumped water back to the suction side of the pump to lift more water from the well. The theoretical suction lift (at sea level) of this pump is 34 feet. The practical limit is 22 – 25 feet, to allow for system losses. These pumps are generally employed on 2 inch diameter and smaller wells and capacities are typically 5 – 12 gpm. (Figure 15)

(3) **Deep Well Jet Pump**: is similar to a shallow well jet pump, except the jet assembly is remotely located down the well, below the lowest anticipated pumping level. In the single-pipe jet, the well casing is the return, or pressure, line. If the well diameter is large enough, a two-pipe system can be used where two pipes are hung in the well. The centrifugal pump may be either single or multi-stage and is equipped with a pressure control valve on the discharge to regulate the amount of pumped water diverted back down to the jet assembly. These pumps can be installed on any well 2 inch diameter or larger, but their capacity is limited to about 15 gpm and pumping levels of about 200 feet. (Figure 16)

Less common well pumps that are generally only employed in special applications, include the following:

(4) **Turbine Pump**: the deep well multistage turbine operates the same as a submersible centrifugal, but the motor is located at the surface of the well and drives the pump via a lineshaft that extends down from the top of the pump. The lineshaft is centered within the column pipe which conveys the pumped water to the surface. These pumps are employed for high capacity installations such as industrial or municipal and are not generally found in residential installations.

(5) **Piston Pump**: the double-acting piston positive displacement pump sucks water from the well during both strokes and forces the water out the pressure side. The deep-well piston sucks water through the check valve on the upstroke and forces

it past the piston on the downstroke. These pumps may be either hand operated or motor driven.

(6) **Helical Rotor Pump:** in this positive displacement pump, the rotor operates like an auger to force water up through the pump .

Conventional well pumps operate at a constant speed (typically 3500 rpm for residential systems) and consist of three main components: the well pump, pressure switch, and well tank. The pump propels water to the well tank and is automatically controlled by a pressure switch that turns the pump on and off at preset pressures. Today, pressure switches with settings of 30-50 psi or 40-60 psi are most commonly used. When a faucet is turned on, water is first delivered from stored water in the well tank. When the system pressure falls to some preset psi, the pressure switch turns the well pump on. The well pump continues to run to meet the system demand or restore stored water in the tank and will turn off when the pressure switch senses the shutoff pressure. These three components are extremely reliable and often provide many years of trouble free service. However, they must be properly sized for the individual application. The following guidelines apply to sizing a pump system.

- The pump must be sized to prevent over pumping the well.
- The well tank should be sized to provide a minimum of 1 minute run time for the pump.
- The pressure switch setting should provide reasonable pressure at the highest fixture in the house.
- Pipe and fitting sizes should be selected to limit the friction loss to about 15 feet per 100 feet of pipe.
- The well tank size should be increased if necessary to meet the submersible motor manufacturer’s limitations on maximum number of starts per day.

For some systems a well tank and pressure switch are not used. In this case the well pump propels water directly to the system and is controlled by some other device. These include some irrigation systems (irrigation control panel activates pump), open loop geothermal systems (heat pump controls pump), process systems (temperature, flow, time control), and manual control. Great care should be exercised in the design of these systems to prevent short cycling of the pump, extremely low flow conditions, or operation at capacities well beyond the pump rated capacity. These conditions are more likely to occur without a well tank as part of the system and will lead to premature pump failure.

Booster pumps are sometimes utilized for private water supply systems. These pumps increase pressure, but cannot increase the flow rate. A booster pump may be utilized when water lines extend a long distance from the water source. Pump selection is based on use and pressure requirements. The in-line centrifugal booster pump works best for small pressure increases and flow rates below 20 gpm and the end-suction centrifugal booster pump is commonly used for both large pressure increases and high flow rates. A submersible booster pump is ideal for in-line boosting because it does not disrupt the continuity of the line or require a pump house.

Variable speed well pumps have been developed and have gained widespread acceptance by homeowners and commercial facilities. Generally known as “Constant Pressure” systems, these pumps vary the speed of the rotating impellers to deliver the required amount of water to the system while continuously maintaining a preset system pressure. These systems consist of a well pump, a pressure sensing device, a control, and generally a much smaller tank than required on a conventional system. Either a variable frequency drive (VFD) or propriety control is utilized to control the speed of the pump. The sensing device is either a pressure transducer or very special pressure switch. The well pump can be either a conventional submersible pump and motor with special oversizing requirements or a proprietary pump that only works with the manufacturer’s controls. Generally, above 2 HP three phase submersible motors are required, and above 5 HP a three phase power supply is required. The tank is often as small as 5 gallons and can be mounted on the well.

As the name implies, these systems provide a constant pressure to the home. The set pressure is easily field adjustable and is usually set for 60 or 70 psi. As more water is used in the home, a small pressure drop occurs. A control immediately responds by increasing the pump speed, delivering more water and recovering the pressure. The response is quick and the pressure variation is usually less than 10 psi. When all water use is curtailed the control shuts off the pump. If the system is leak tight, the pump will not come on again until water use occurs .

As with a conventional pump system, these constant pressure systems must be properly designed. The pump is sized for the maximum water use that is expected to occur at any given time and for the desired pressure. Assuming that there is no limitation on well capacity, the pump should be slightly oversized. The small well tank provides no additional system capacity; it only dampens system pressure fluctuations.

PUMP INSTALLATION

All pumps should be installed either below the frost line with a pitless adapter or in some heated and protected sanitary location. When a pitless adapter is used, it should comply with the most recent revision of National Sanitation Foundation Standard Number 56, entitled "Pitless Well Adapters”. Above-ground pumps should be installed in sheltered, dry, accessible locations and should be protected from freezing. Whenever possible, well pit installations should be avoided. When upgrading a well pit installation it is particularly desirable to move the well tank and controls into the basement of the building.

Shallow-well pumps should be installed as near the well or water source as possible to minimize suction lift. Deep-well reciprocating and turbine pumps must be installed directly over the well. Submersible and helical rotor pumps must be installed in the well. A deep-well jet pump may be offset from the well.

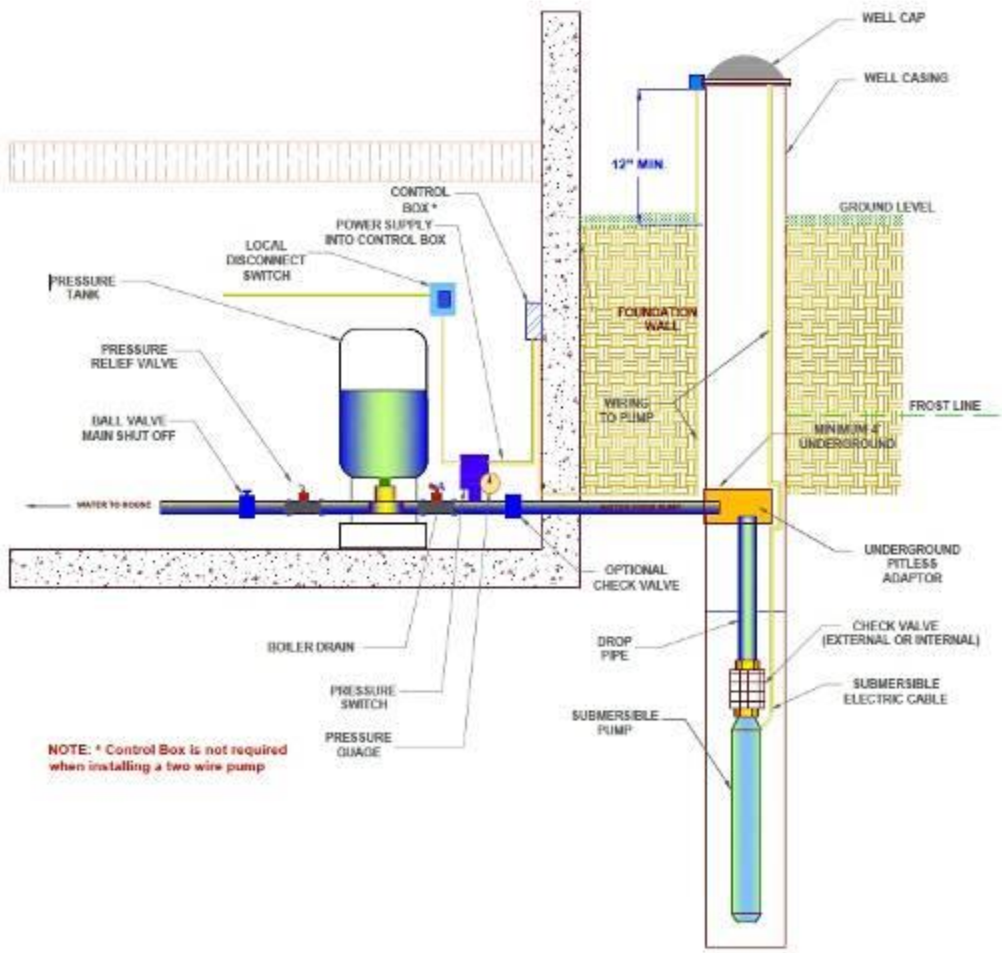

Figure 14 : Typical Submersible Pump Installation

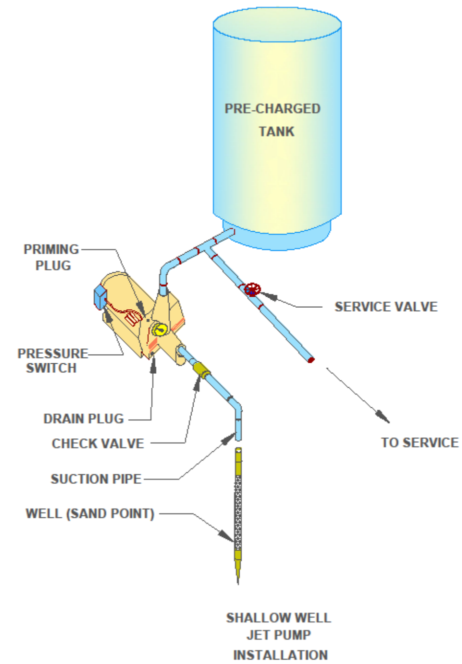

Figure I5 : Typical Shallow Jet Pump Installation

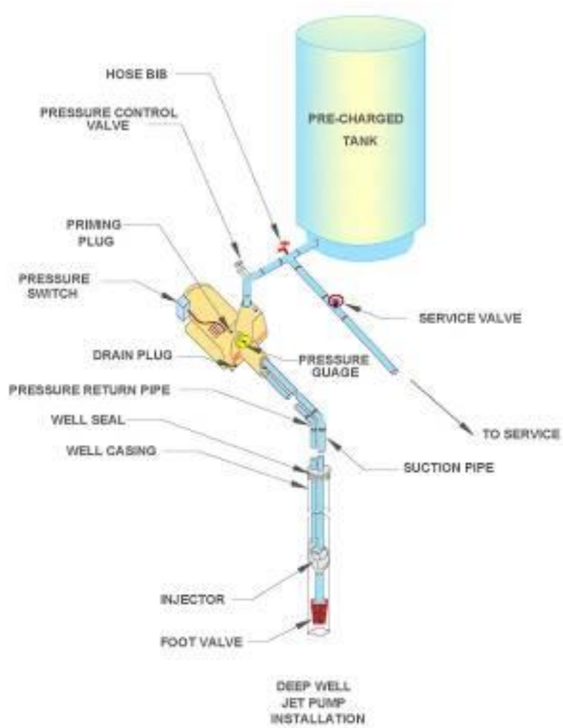

Figure 16 : Typical Deep Well Jet Pump Installation

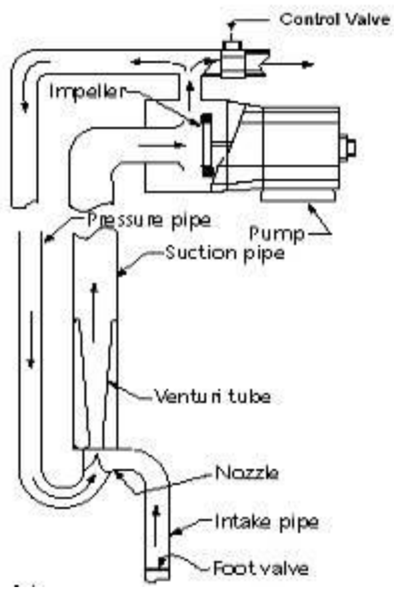

Figure 17 : Jet Pump Cross Section

TANKS

A tank is necessary to provide proper pump operation. Without a tank the pump would come on every time even a small amount of water was used, causing the pump to cycle on and off rapidly. The well tank is designed to protect the pump and extend its life, to provide storage when the pump is not running, and to minimize pressure fluctuations in the water system.

The type of pressure tank is determined by the size of the water pump, the amount of water used, and the water yield from the well. Older types of pressure tanks include galvanized steel pressure tanks and galvanized steel tanks with a floating wafer. More recent installations are usually pressure tanks with a diaphragm, or a rubber bladder, otherwise known as captive air tanks. These tanks provide water storage of about 20% of their total volume, the remainder is the air charge. In order for the tank to function properly the air chamber must be precharged with compressed air. If the air charge is lost, the tank will store less water, and eventually result in the pump short cycling.

Captive air tanks are constructed of steel, stainless steel, or fiberglass, with a butyl rubber diaphragm or polymer air cell.

Manufacturer's charts and procedures should be consulted to properly size the well tank. The basic requirement is to meet the pump or submersible motor manufacturer's requirement for minimum run time or maximum number of starts per day. As system pressure increases, a given size captive air tank will store less water, causing the pump to run more frequently. For a 10 gpm pump, a larger size tank is required for a system operating at 40 – 60 psi than for a system operating at 30 – 50 psi.

A rule of thumb for selecting the proper size for a pressure tank is to base it on the pump's flow rate, by multiplying the flow rate by 4 to determine the size of a diaphragm or bladder tank.

For example, a 9 gpm pump would require a 36 gallon storage tank, This would be the same sizing formula to use for a galvanized steel tank with a wafer installed. A galvanized steel tank is sized 10 times the flow rate: a 9 gpm pump would require a 90 gallon storage tank. These rules of thumb should be checked by the appropriate calculation whenever a non-routine application arises.

When using a variable speed well pump, a smaller well tank may be used. For most residential applications, a tank size of nominal 5 gallons or less is adequate. These tanks may be either wall or pipe mounted. The pressure tank size should be in accordance with the pump manufacturer's recommendations.

Typical recommendations are as follows:

For pump capacities of less than 12 gpm – Use a 2 – 8 gallon nominal size tank.

For pump capacities greater than 12 gpm – Use a 4 – 20 gallon nominal size tank.

The tank precharge should be set at 70% of the system operating pressure. For a system set pressure of 60 psi, the tank precharge should be 42 psi.

Some constant pressure systems employ a pressure control valve (PCV) rather than a variable speed pump. The PCV is installed upstream of the pressure tank, between the conventional submersible pump and the pressure switch. Pressure tank sizes are not reduced for PCV installations.(Michigan DEQ, 2012)

The well tank should be located in the basement. If the home does not have a basement or a suitable crawl space, it should be located in a mechanical room or an "in well" tank may be employed. For crawl spaces with insufficient vertical height, the tank may be installed on its side as long as it is properly supported.

Pressure relief valves, if used, should be carefully sized in relation to the well pump capacity and shut off pressure. Typically installed at the well tank header pipe, they have the potential to flood the basement when they operate. Their size, pressure setting, materials of construction, and reliability should all be carefully considered prior to installation.

DISINFECTION

Care should be taken whenever opening the well casing, for an open well creates a direct conduit for contamination into the aquifer. During the construction, repair, and alteration of a well and during pump installation, maintenance, and repair, bacteria can be introduced into both the well and the aquifer. These bacteria may be pathogenic or may metabolize iron and manganese in the ground-water, and cause incrustation of the well screen or clogging of the pore space in the aquifer. The simplest and most effective way to kill harmful bacteria introduced by these activities is to disinfect the entire water supply system with a chlorine solution.

Immediately following construction, repair, or alteration, the well driller should disinfect the well. If a pump is to be installed by the well driller immediately upon completion of the well, the driller should disinfect the well and the pumping equipment after the pump has been installed.

If the pump is not installed upon completion of the well, the pump contractor should disinfect the well and the pumping equipment after the pump has been installed. The pump contractor should also disinfect the entire water supply system after any maintenance or repair work is done on the pump.

For new well installations, after all the chlorine has been flushed from the water supply system, the local Board of Health should require that a water sample be collected and submitted to a state certified laboratory for a bacteriological analysis that detects the presence of coliform bacteria. If the results of the analysis indicate presence of coliform bacteria, the well should not be put into service and the system should be disinfected again using a higher concentration of chlorine or a longer retention time. After disinfection, the water should be sampled again and analyzed to ensure that the standard for coliform bacteria is not exceeded. For new wells, the local Board of Health may choose to require testing for additional parameters (refer to the following section entitled, "Water Quality and Water Testing").

Effective disinfection may be related to the use of the proper chlorine concentration of the disinfectant, the pH or turbidity of the water, or the retention time of the disinfectant solution. For water with a high pH, a higher initial chlorine concentration is required to obtain the same level of disinfection achieved with less chlorine in low-pH water. This is because the hypochlorous ions, which function as the bactericide, are more effectively neutralized as the pH increases. The effectiveness of the disinfectant also decreases as turbidity increases. Retention time of the disinfectant solution in the system is also critical to the effectiveness of the disinfection procedure; the disinfectant must remain long enough to kill the bacteria.

Existing well systems should be disinfected in a similar manner as new wells. Whenever a well is opened for maintenance, repair, or pump replacement, it should be disinfected upon completion of the work. When a water sample has returned a result of positive for coliform bacteria, the homeowner is encouraged to have a certified well professional assess the situation, disinfect the well system, and take a new sample. Multiple disinfection procedures may be necessary until a negative coliform result is obtained.

When dealing with an existing system, it is necessary to disinfect the entire system; the well, the underground piping, the well tank, and plumbing system in the house. Water filters should be by-passed during the disinfection process. Hot water storage tanks may be by-passed based on the judgement of the well professional.

A special need for disinfection occurs when the well head has been subject to flooding or submerged. Under these conditions, large quantities of non-potable surface water or sea water may enter the well. In order to return the well to potable service, it should first be pumped to waste for a sufficient time to clear it of the contaminated water. It should then be disinfected and tested in accordance with these procedures.

COMMONLY USED CHLORINE COMPOUNDS

Sodium hypochlorite and calcium hypochlorite are the most common chlorine compounds used to disinfect private water supply systems. Sodium hypochlorite solutions are available in several strengths. Most household laundry bleaches consist of sodium hypochlorite dissolved in water. These solutions generally contain 5% to 5.25% available chlorine and can be purchased at most grocery stores. There are bleach products on the market that do not contain sodium hypochlorite. Only regular (unscented) sodium hypochlorite-based bleach without additives or detergents should be used. Stronger sodium hypochlorite solutions, containing 12% to 12.5% available chlorine, are sold for use in water and wastewater treatment plants, and for use in swimming pools.

The calcium hypochlorite compound used most frequently by water well and pump contractors is known as high-test calcium hypochlorite. This compound is available as granules or tablets which commonly contain 65% by weight available chlorine. Synthetic chlorine products are also available from a few manufacturers for professional use. The directions on the packaging should be carefully followed.

STABILITY OF COMMONLY USED CHLORINE COMPOUNDS

The chlorine compounds commonly used in preparing disinfectant solutions are not stable. Therefore, outdated products or compounds which have been improperly stored should never be used to prepare solutions with specified chlorine concentrations.

Sodium hypochlorite is so unstable as a dry compound that it can be purchased only as a solution. Sodium hypochlorite solutions, however, are also unstable. A sodium hypochlorite solution with 10% available chlorine, for example, loses chlorine at a rate such that after six months there is approximately 5% available chlorine remaining in the solution. Sodium hypochlorite solutions more than 60 days old will not contain the same chlorine concentration as the original solution and should not be used in preparing solutions with specified chlorine concentrations.

Dry calcium hypochlorite, on the other hand, is relatively stable. For example, after 12 months of storage in a cool, dry environment, properly packaged calcium hypochlorite will retain approximately 90% of the chlorine originally available in the compound. If, however, the compound becomes moist, it will lose chlorine more rapidly.

Chlorine irritates the eyes, skin, and respiratory tract. Furthermore, dry chlorine compounds become strongly corrosive in the presence of moisture. Chlorine, in solution, is a strong oxidizing agent that reacts vigorously with hydrocarbons, such as oil and grease, and other organic compounds, such as turpentine, ethyl alcohol, glycerol, carbon tetrachloride and charcoal. For safety, follow the handling instructions on the product label.

RECOMMENDED CHLORINE CONCENTRATIONS FOR DISINFECTING WELLS

When a well is disinfected, the initial chlorine concentration should be 100 mg/l throughout the entire water column. Disinfection of the distribution system, when connected, should also be accomplished using an initial chlorine concentration of 100 mg/l.

PROCEDURE FOR DISINFECTING WELLS

Prior to introducing disinfectant into a well, the interior of the well casing, the pump, and any piping, should be thoroughly cleaned and flushed to remove all foreign substances such as oil, grease, joint dope, soil, sediment, and scum. A thorough cleaning is necessary because only bacteria which come in contact with the disinfectant will be killed. Additionally, when chlorine comes in contact with hydrocarbons and other organic compounds which may be used during the construction and completion of a well, the reaction can be violent.

Determining the Required Amount of Chlorine Compound

(1) Determine the number of feet of water in the well.

(2) Referring to the first two columns of Tables 7 and 8, determine the number of gallons of water per feet of water in the well.

(3) Multiply the number of feet of water in the well by the number of gallons of water per foot to determine the total number of gallons of water in the well.

(4) Determine the amount of chlorine compound required to produce a disinfectant solution with the required chlorine concentration. Tables 7 and 8 provide guidance for producing a disinfectant with a chlorine concentration of 100 mg/l using compounds consisting of 5.25% sodium hypochlorite, 12% sodium hypochlorite, and 65% calcium hypochlorite. Note that the required amounts of chlorine compound indicated in Table 7 (for well diameters of one foot or less) were calculated per 100 feet of water depth while the required amounts of chlorine compound indicated in Table 8 (for well diameters of two feet or more) were calculated per foot of water depth.

For specific water volumes or for compounds consisting of concentrations different than those presented in Tables 7 and 8, the following equations apply:

(1) For Sodium Hypochlorite Compounds (liquid):

$$\text{Volume Sodium Hypochlorite Compound Required (cups)} = \frac{\text{Required Concentration}}{\text{Concentration of Compound}} \times \text{Gallons of Water in Well} \times \frac{\text{16 cups}}{\text{1 gallon of water}}$$

(2) For Calcium Hypochlorite Compounds (tablets or granules)

$$\text{Weight Calcium Hypochlorite Compound Required (ounces)} = \frac{\text{Required Concentration}}{\text{Concentration of Compound}} \times \text{Gallons of Water in Well} \times \frac{\text{133 weight in ounces}}{\text{1 gallon of water}}$$

Note that in both equations the Required Concentration and the Concentration of Compound should be in decimal form. For example, a required concentration of 100 mg/l = 0.0001 and a compound with a hypochlorite concentration of 5.25% = 0.0525..

When using the equations, round off the calculated values to the nearest 1/8 cup for liquid sodium hypochlorite compounds and the nearest 0.1 ounce for dry calcium hypochlorite compounds.

Mixing the Disinfectant Solution

Once the required amount of chlorine compound has been determined, the compound should be mixed with or dissolved into clean water, being sure to add additional chlorine compound to compensate for the mixing water. If, for example, 10 gallons of water are used for mixing the compound, an additional 1/2 cup of 5.25% sodium hypochlorite solution, an additional 1/8 cup of 12% sodium hypochlorite solution, or an additional 0.2 ounces of 65% calcium hypochlorite compound should be added.

The purpose of mixing the chlorine compound with water is to ensure that, when the disinfectant solution is placed in the well, the surfaces of all components above the water level in the well will come in contact with the disinfectant. It is best to mix the chlorine compound in a plastic, ceramic, or wood container because metals are corroded by strong chlorine solutions.

DIAMETER OF WELL CASING IN INCHES	GALLONS OF WATER		CHLORINE NEEDED TO PRODUCE A CONCENTRATION OF **100 MG/L**		
			SODIUM HYPOCHLORITE REQUIRED		CALCIUM HYPOCHLORITE REQUIRED
	PER FOOT OF WATER DEPTH	PER 100 FEET OF WATER DEPTH	PER 100 FEET OF WATER DEPTH (CUPS, LIQUID MEASURE)		PER 100 FEET OF WATER DEPTH (OUNCES, DRY WEIGHT)
			USING 5.25% SOLUTION	USING 12% SOLUTION	USING 65% COMPOUND
1 ½	0.092	9.2	¼	1/8	0.2
2	0.163	16.3	½	1/4	0.3
3	0.367	36.7	1 1/8	1/2	0.8
4	0.653	65.3	2	7/8	1.3
5	1.020	102.0	3 1/8	1 3/8	2.1
6	1.469	146.9	4 ½	2	3.0
8	2.611	261.1	8	3 1/2	5.3
10	4.080	408.0	12 3/8	5 1/2	8.4
12	5.876	587.6	17 7/8	7 7/8	12.0

TABLE 7

AMOUNT OF CHLORINE COMPOUND REQUIRED TO PRODUCE A CHLORINE CONCENTRATION OF 100 MG/L (FOR WELL DIAMETERS OF ONE FOOT OR LESS)*

WELL DIAMETER IN FEET	GALLONS OF WATER PER FOOT OF WATER	CHLORINE NEEDED TO PRODUCE A CONCENTRATION OF **100 MG/L**		
		SODIUM HYPOCHLORITE REQUIRED PER FOOT OF WATER DEPTH (CUPS, LIQUID MEASURE)		CALCIUM HYPOCHLORITE REQUIRED PER FOOT OF WATER DEPTH (OUNCES, DRY WEIGHT)
		USING 5.25% SOLUTION	USING 12% SOLUTION	USING 65% COMPOUND
2	23.5	¾	1/4	0.5
3	52.9	1 5/8	3/4	1.1
4	94.0	2 7/8	1 1/4	1.9
5	146.9	4 ½	2	3.0
6	211.5	6 ½	2 7/8	4.3
7	287.9	8 ¾	3 7/8	5.9
8	376.0	111/2	5	7.7
9	475.9	14 1/2	6 3/8	9.8
10	587.6	17 7/8	7 7/8	12.0

*THE FOLLOWING INFORMATION APPLIES TO TABLES 6 AND 7:
REQUIRED AMOUNTS WERE CALCULATED USING EQUATIONS 1 AND 2 (REFER TO TEXT) AND:
(1) LIQUID MEASURES WERE ROUNDED OFF TO THE NEAREST ONE-EIGHTH CUP (1/8 CUP = 2 TABLESPOONS)
(2) DRY WEIGHTS WERE ROUNDED OFF TO THE NEAREST ONE-TENTH OUNCE:
(A) SIX 65% CALCIUM HYPOCHLORITE TABLETS = APPROXIMATELY I OUNCE
(B) THREE HEAPING TABLESPOONS OF 65% CALCIUM HYPOCHLORITE =: APPROXIMATELY 1 OUNCE
FOR COMPOUNDS WITH CHLORINE CONCENTRATIONS DIFFERENT FROM THOSE IN THE TABLES, USE EQUATION 1 OR 2 (REFER TO TEXT) TO DETERMINE THE AMOUNT OF COMPOUND REQUIRED.

TABLE 8
AMOUNT OF CHLORINE COMPOUND REQUIRED TO PRODUCE A CHLORINE CONCENTRATION OF 100 MG/L (FOR WELL DIAMETERS OF TWO FEET OR MORE)*

Placement of the Disinfectant Solution

For drilled or driven wells, pour the disinfectant solution into the top of the well, being sure that the casing walls are wetted completely. In order to thoroughly distribute the disinfectant, the well should be pumped, recirculating the pumped water back into the well for at least 15 minutes. Recirculation should be accomplished by connecting a hose to a faucet on the discharge side of the pressure tank and running it back to the well. If a pump has not been installed and a temporary pump is not available, a bailer or plunger should be used to mix the disinfectant throughout the well.

After the disinfectant has been circulated throughout the well and the pressure tank, all the household faucets should be turned on, letting the water run until the odor of chlorine is detected. Then turn off the faucets and seal the top of the well.

For dug wells, the disinfectant solution should be splashed around the lining or walls of the well, being sure that the solution comes in contact with all parts of the well. The top of the well should then be sealed and the well should be pumped until the odor of chlorine is detected in the discharge.

Caution: Liquid chlorine bleach can be hazardous. It is a strong oxidizing agent. Never pour pure (concentrated bleach) directly down the well; prolonged contact with concentrated bleach can cause corrosion of the well casing and well equipment, and damage rubber and polybutylene gaskets and fittings.

Precautions should be taken to protect the components of the water supply treatment system. All non-cartridge water treatment systems, such as a water conditioner, should be bypassed when disinfecting the system. In any treatment system that uses cartridges, such as a sediment or activated carbon filters; the cartridge should first be removed and disposed of properly before disinfection. After flushing is complete, a new cartridge should be installed.

Retention Time for the Disinfectant Solution

The disinfectant solution should remain undisturbed in the well and, if connected, in the distribution system for a minimum of 12-24 hours. Make sure no one in the home uses the water for drinking or bathing during the treatment period. Arrangements should be made for an alternative source of drinking water during this period.

Flushing the System

Pump the well and flush all traces of chlorine from the distribution system, being sure to turn on all the household faucets, beginning with the tap closest to the well. Be careful not to draw water down below the pump intake level to avoid damage to the pump. If there is a storage tank in the system, make sure to maintain 30 psi of pressure in the distribution lines. If the water supply system ultimately discharges to a septic tank, care should be taken to flush the distribution system to prevent the septic system from becoming overloaded. In these cases, water should be flushed first to the ground away from the well until the chlorine odor cannot be detected at the hose end. Then the interior faucets should be opened to flush only the chlorine solution contained in the distribution system.

Start up and Shut down Disinfection Procedures for Seasonal Water Supply Systems

When preparing to turn on a well after months of inactivity, the condition of the system should be checked, any necessary repairs made, and the system disinfected to make sure the system is free from coliform bacteria.

Start up

1. Inspect water system and make any necessary repairs.

2. Activate the source and treatment. Refresh treatment chemicals if necessary.

3. Operate the water system while running water through the entire system with all faucets open. Make sure all pressure tanks are pressurized

4. Disinfect the well, pressure tank, storage tank and distribution lines. Leave chlorinated water in the lines for 12-24 hours.

5. Flush the system of chlorine until no chlorine odor can be smelt in the water at the taps.

6. Test for coliform bacteria.

Shut down

When preparing to close a seasonal water system, it should be inspected, cleaned and protected in preparation for the next season.

1. Evaluate the system, looking for problems that need attention before the season.

2. Drain all the water out of the storage tank. Inspect tank for cracks and make needed repairs. Clean out accumulated sediment in the tank. Check vents and overflows for openings that could allow rodents, insects or other contaminants and rescreen if needed.

3. If there is a potential for freezing, drain the pressure tank (following manufacturer's instructions). If freezing is not an issue, the tank and piping may be left full of water. If necessary blow out the system with compressed air.

4. Turn off the power supply to the well. Insulate system components to protect from freezing

5. Turn off power to the treatment system

6. Protect the distribution system. Do not leave taps open in the off season. If using antifreeze, use only food grade propylene glycol.

WATER QUALITY AND WATER TESTING

REGIONAL WATER QUALITY DIFFERENCES

The geologic materials from which groundwater is pumped differ regionally within Massachusetts and, therefore, natural water quality differences can be expected. The four principal types of geologic materials (aquifers) tapped by private wells are; (1) unconsolidated, glacially derived stratified drift deposits consisting of layered sand and gravel with some silt, (2) crystalline bedrock consisting primarily of granite, schist, and gneiss, (3) sedimentary bedrock consisting of red sandstone, shale, conglomerate with interbedded basaltic lava (traprock), and (4) carbonate rock consisting of limestone, dolomite, and marble with interbedded schist and quartzite.

The homeowner and the local Board of Health should be aware of the naturally occurring water quality characteristics common in the principal types of aquifers.

Stratified drift aquifers occur in scattered river valleys throughout Massachusetts and form a continuous layer over the bedrock on Cape Cod, Nantucket, and most of Martha's Vineyard. Wells completed in stratified drift aquifers are commonly less than 100 feet deep and yield water that is generally slightly acidic (pH less than 7.0), soft (low calcium carbonate concentration), contains low concentrations of dissolved solids, and is corrosive to metal and cement pipe. Stratified drift aquifers in Berkshire County, however, yield water with characteristics similar to those described for carbonate rock aquifers. Some stratified drift aquifers yield water containing high concentrations of iron and manganese which cause taste, color, and staining problems, and may cause decreased well efficiency due to encrustation of the well screen.

Crystalline bedrock aquifers are present throughout a large portion of Massachusetts. However, these aquifers are not utilized on Cape Cod, Martha's Vineyard and Nantucket because in these areas the bedrock occurs at great depth, contains saline water, or is overlain by more accessible stratified drift deposits. Wells completed in crystalline bedrock aquifers are commonly 100-400 feet deep and generally yield moderately hard water with low concentrations of dissolved solids.

Variations in the composition of crystalline bedrock aquifers, however, cause local variations in water quality. Elevated radionuclide concentrations are associated with bi-mica granite formations. High arsenic concentrations have been found in well water completed in crystalline bedrock aquifers in Hampden, Worcester, and Middlesex counties. High levels of naturally occurring radon, arsenic and selenium have been found in wells in the Berwick Formation which underlies Tyngsborough, Haverhill, Methuen, and parts of Dracut, Dunstable, East Pepperell, Groton, Lowell, North Chelmsford, and Westford.

Sedimentary bedrock aquifers exist in the Connecticut River valley. Wells completed in these aquifers are commonly 100-250 feet deep and yield water which often contains relatively high concentrations of sulfate, sodium and fluoride. The upper 200 feet of the aquifer generally produces moderately hard water with moderate levels of dissolved solids while water from deeper parts of the aquifer is often hard and commonly contains high concentrations of dissolved solids. High concentrations of sulfate and/or dissolved solids typically cause the water to taste bitter. Water quality may be affected locally by ore deposits that contain copper, lead, and zinc sulfides, fluorite, and uranium-bearing minerals.

Carbonate rock aquifers are present in Berkshire County. Wells completed in these aquifers are commonly 100-300 feet deep. The aquifer yields hard water with relatively high concentrations of calcium carbonate. Extreme hardness prevents soaps and detergents from forming suds and can cause scaling (encrustation) of plumbing.

NATURALLY OCCURRING CONTAMINANTS

Radionuclides

Elevated concentrations of radionuclides are typically associated with bi-mica granite formations. The concentration of radioactive minerals in well water can vary substantially based on rainfall and other factors. For this reason, at least two samples (taken a month or two apart, if possible) should be taken before conclusions are reached regarding the average concentration of any radionuclide. The recommended approach is to request that the laboratory first test for gross alpha (Figure 18). If the gross alpha result is less than 5 picocuries per liter (pCi/L) then no testing for radium 226, radium 228, or uranium is needed because the results will be below the drinking water standards. If the gross alpha result is equal to or greater than 5 pCi/L then testing for radium 226 and radium 228 should be requested of the laboratory. If the gross alpha result is equal to or greater than 15 pCi/L then testing for uranium should also be required.

Treatment systems for radionuclides should be designed to specifically mitigate the radioactive mineral(s) that exceed the drinking water standards indicated by the water analysis. Using a mixed resin bed to treat all possible radionuclides, rather than using the resin type specific to the radionuclide of concern can be problematic. Due to the ability of the mixed resins to treat a variety of contaminants by design, the resins may become saturated early on by other less hazardous contaminants and allow for the breakthrough of the radionuclide of concern. The early saturation and breakthrough will also result in the more frequent need to replace or regenerate the resin material. The waste from the regeneration process, which may be radioactive, must be disposed of in accordance with local and federal regulations. In the long run, what may seem like a cost savings initially by not getting all of the analyses done, or overdesigning the treatment system may end in expensive disposal costs or a potential health risk.

A factsheet with more information on radionuclides in drinking water can be found on our website at: https://www.mass.gov/info-details/faqs-radionuclides.

Uranium

Uranium is a naturally occurring radioactive element found in small amounts in virtually all rock, soil, and water. Significant concentrations of uranium occur in some substances such as phosphate rock deposits, and minerals such as uraninite in uranium rich ores. Uranium's three natural isotopes found in the environment (U-234, U-235, and U-239), undergo radioactive decay by emission of an alpha particle accompanied by weak gamma radiation. The dominant isotope (U-238) forms a long series of decay products that includes the key radionuclides radium 226, and radon 222. The release of radiation during the decay process raises health concerns. Exposure to uranium can occur by inhaling dust in air, or ingesting water and food. Intakes of high concentrations of uranium can lead to increased cancer risk and liver damage.

Radium

Radium is a naturally occurring radioactive metal. It is formed by the decay of uranium and thorium in the environment. Like uranium, it occurs at low levels in virtually all rock, soil and water. The various isotopes of radium originate from the radioactive decay of uranium or thorium. Radium-226 is found in the uranium-238 decay series, and radium-228 and -224 are found in the thorium-232 decay series. Inhaled or ingested radium increases the risk of developing such diseases as lymphoma, bone cancer and diseases that affect the formation of blood, such as leukemia and aplastic anemia. Radium decays to form isotopes of the radioactive gas radon.

Radon

Radon is a naturally occurring highly radioactive odorless, colorless gas. The primary routes of potential human exposure are inhalation and ingestion. Although high concentrations of radon in groundwater may contribute to radon exposure through ingestion, the inhalation of radon released from water is usually more important. If radon levels are found to be elevated in the well water, the indoor air should also be tested for radon. Long term exposure to radon has been linked to lung cancer. Although radon is typically associated with wells drilled in crystalline bedrock aquifers, there have been cases where wells installed in unconsolidated (overburden) deposits had elevated radon levels. It is recommended that Boards of Health require testing for radon throughout Massachusetts.

If the radon level measured in the well water exceeds 4,000 pCi/l, the homeowner should consider measuring the level of radon in the air within the lower living spaces of their home.

Arsenic

Arsenic is a toxic chemical element that is unevenly distributed in soil, rocks and minerals. It is odorless and colorless and can occur naturally in the environment or as a by-product of some agricultural and industrial activities. Arsenic has been well documented as a human carcinogen of the bladder, lungs and skin. High arsenic concentrations have been found in water from a few wells completed in crystalline bedrock aquifers in Hampden, Worcester and Middlesex counties.

Variations in the composition of crystalline bedrock aquifers can cause local variations in water quality. In 2011, USGS undertook an investigation into the occurrence of uranium and arsenic in private bedrock wells(**Arsenic and Uranium in Water from Private Wells Completed in Bedrock of East-Central Massachusetts-Concentrations Correlations with Bedrock Units, and Estimated Probability Maps,** *(USGS, Scientific Investigations Report 2011-5013)).*

High concentrations of arsenic have been found in Hampden, Worcester, and Middlesex counties. High levels of arsenic and uranium has been found in wells located in a north-south trending belt through the central part of the state. Table 9 (below) includes towns that were identified in the 2011 USGS study as having a high or medium probability of exceeding the drinking water standard for arsenic and/or uranium in bedrock wells. The USGS area of study only investigated towns in the central part of Massachusetts. There are other towns that were not part of this study that may also have elevated levels of arsenic and/or uranium, such as Monson.

AMESBURY	HARVARD	PEPPERELL
ANDOVER	HOLDEN	PRINCETON
ASHBY	HOPKINTON	RUTLAND
AUBURN	HUDSON	SOUTHBOROUGH
BLACKSTONE	LEICESTER	SOUTHBRIDGE
BOLTON	LEOMINSTER	SPENCER
BOXBOROUGH	LITTLETON	STERLING
BOXFORD	LUNENBURG	STOW
BOYLSTON	MENDON	STURBRIDGE
CARLISLE	MERRIMAC	SUTTON
CHARLTON	MIDDLETON	TOWNSEND
CONCORD	MILLBURY	TYNGSBOROUGH
DOUGLAS	MILLVILLE	UPTON
DRACUT	NEWBURYPORT	UXBRIDGE
DUDLEY	NORTHBOROUGH	WEBSTER
FITCHBURG	NORTHBRIDGE	WESTBOROUGH
GRAFTON	OAKHAM	WESTFORD
GROTON	OXFORD	WESTMINSTER

Table 9 : Towns with High or Medium Probability of Exceeding Arsenic and/or Uranium MCL

A more detailed discussion of the results of this study, including detailed local maps depicting areas of high uranium and arsenic concentrations, can be found at: https://www.mass.gov/info-details/arsenic-uranium-bedrock-well-study.

Lead

Lead is a naturally occurring element that when ingested or inhaled can be harmful to humans, particularly children under the age of six. The health effects may include interference with red blood cell chemistry, delays in normal physical and mental development in babies and young children, slight deficits in the attention span, hearing, and learning abilities of children, and slight increases in the blood pressure of some adults and can potentially cause strokes, kidney disease and cancer.

Natural levels of lead in unconsolidated soil range between 50 and 400 ppm. Elevated levels of naturally occurring lead have been found in some bedrock wells drilled in the rock formations that underlie all or parts of the towns of Monson, Blackstone, Douglas, Bellingham, Mendon, Hopedale, Uxbridge, Millville, Milford and Holliston. The bedrock in these areas consists mostly of rusty biotite schists, amphiboles and quartzites, with some pyrite content. Naturally occurring lead in bedrock is also seen in granites that contain sulfide materials.

Lead can also be leached from old pipes, lead soldered joints, or brass or bronze plumbing fixtures as the well water sits in the household plumbing. Water that has lower alkalinity or pH is more corrosive and can leach more lead into the water.

Manganese

Manganese is an essential nutrient, required in trace amounts for human health. The presence of black stains, particles and metallic taste often makes it obvious that manganese is present in the water even without water testing. Initially clear water that subsequently forms black solid particles over time contains reduced manganese. Dissolved or reduced manganese is most common in groundwater with a pH less than 7.0. Solid black particles that appear immediately in water contain the oxidized form of manganese. Manganese toxicity targets the brain and central nervous system. Exposures to manganese in drinking water are much lower than the high inhalation exposures seen in industry that have been associated with severe neurological and neuromuscular effects. However, elevated manganese in drinking water is of particular concern for formula-fed infants. These infants may get a higher manganese dose than the rest of the family since infant formula is already supplemented with manganese. Infants also tend to absorb more manganese and have a reduced capacity to excrete it. Usual treatment for manganese removal includes water softening (ion exchange), polyphosphate addition, oxidizing filters or oxidizing followed by filtration. Less common treatments include aeration, ozonation and catalytic carbon.

Methane

Methane is an odorless, colorless gas occasionally found in Massachusetts groundwater. It is not known to be a health hazard when ingested. However, methane can be flammable and explosive when mixed with air and it can displace oxygen if released into a confined space, resulting in asphyxiation. Methane can also cause problems with the operation of the pump and water system. A pocket of methane gas was found at a depth of 1000 feet in a well in Tyngsborough which ignited and consumed the drilling rig. Methane gas has been reported in other Tyngsborough wells in addition to wells located in (but not limited to) Dunstable, Pepperell, Wales, Brimfield and Holland.

A “sputtering” or “spitting” faucet, or a gurgling noise may indicate the presence of methane or other dissolved gases. Visible gas bubbles in a water sample may also indicate that methane is present. The water may appear clear with bubbles, milky, frothy, or have a bluish tint. Testing for methane involves a specialized sample collection process. Removal of methane from water commonly involves aeration.

Methane from the well and water system should be vented to the atmosphere, outside of the home. MassDEP recommends that all wells have a vented cap or cover. Water tanks and water treatment tanks should also be vented outside, above the ground surface and away from any building. (Minn.MDH, 2013)

SOURCES OF CONTAMINATION

Boards of Health should consider potential threats to groundwater quality when deciding what testing program is most appropriate for their town. Naturally occurring contaminants and past and present land uses are of primary importance. Land uses that have a potential to adversely impact water quality include industrial, commercial and agricultural activities, improperly constructed wastewater disposal facilities, and the use, storage and disposal of pesticides, fertilizers, road deicing, and hazardous materials. Typical residential activities, such as the application of fertilizers and pesticides, fueling of lawn equipment, and disposal of household chemicals can contaminate the groundwater when done improperly. Historically, public and private wells alike have been contaminated by petroleum products, cleaning solvents, sewage, road salt, and pesticides.

The "Land Use/ Pollution Potential Matrix" (Table 10) is a guide for assessing the potential water quality impacts various land uses may have on groundwater systems. Appendix B contains a matrix of land uses and contaminants associated with these uses that have Massachusetts drinking water standards or guidelines. Test requirements for other contaminants should be required in areas known to be, or suspected as being, impacted by other anthropogenic pollutants listed in the MassDEP/Office of Research and Standards (ORS) *Standards and Guidelines for Chemicals in Massachusetts Drinking Waters*. The MassDEP Bureau of Waste Site Cleanup(BWSC) maintains a Searchable Waste Site List/Site Files database by site address at https://www.mass.gov/find-out-about-a-contaminated-property.

RECOMMENDED SAMPLING

Land Use Categories	Potential Contaminants: Chloride	Metals	Nitrogen: Nitrate\Nitrite	Pathogens	Pesticides\ Herbicides	Petroleum Products	Sodium	Solvents	Perchlorate	PFAS
Agriculture/Golf Courses			■		■					■
Chemical Manufacturing		■	■			■		■		■
Commercial Composting Facilities		■	■	■	■					■
Fire Training Facilities		■				■				■
Fireworks/Blasting			■						■	
Gas Stations/ Automotive Repair		■				■		■		■
Hazardous Material Storage and Transfer	■	■	■			■		■		■
Junkyards/Landfills	■	■	■		■	■		■		■
Light Industry		■				■		■		■
Road Maintenance Depot	■				■	■	■			
Septic Systems/ Cesspools / Water Softeners	■	■	■	■			■			■
Stables/ Piggeries/ Manure Pits			■	■						
Above/Underground Fuel StorageTanks/Depots					■	■		■		

Table 10 : Land Use/Pollution Potential Matrix

MassDEP recommends that prospective homebuyers test the water in a home with a private drinking water well before purchase. Most well water quality parameters, other than microbial, are stable. If a change is going to occur, it typically takes place slowly. However concentrations for some water quality parameters can change seasonally, often with fluctuation in the water table Thus the interval between water quality tests for most parameters, once you've purchased the home, can generally be in terms of years if a well is properly constructed and located in a safe area.

Although, private well water quality problems are often identified through detection of an unpleasant or unnatural taste or odor, consumers should keep in mind that harmful concentrations of several contaminants do not impart a noticeable taste or odor to the water. When taking any sample, MassDEP recommends that it be taken after a heavy rainstorm. These events tend to highlight conditions of improper well construction or poor soil filtration. It is prudent to have the well water sampled periodically and tested by a MassDEP laboratory certified for performing drinking water analyses for the analytes of interest (https://www.mass.gov/certified-laboratories).

A water sample should be collected either after running the tap for 15 minutes or following the stabilization of the pH, temperature and specific conductance in the pumped well. The water sample to be tested should be collected at the pump discharge or from a disinfected tap in the pump discharge line. The sample should be taken by a qualified water professional such as a certified well driller, water treatment operator, or a certified lab technician.

A sample tap should be installed as near as possible to where the well water enters the household water system so that a sample can be taken that is representative of the well raw water quality.This can also be accomplished by using the first tap on a line near where the plumbing enters the house, which may be an outside faucet, provided the tap precedes any water treatment devices. It is a good idea to have a faucet placed near the pressure tank for flushing the tank and collecting water samples for testing.

Tables 11 and 12 are provided to assist local Boards of Health in evaluating the quality of private drinking water supplies and to provide guidance regarding testing frequencies for various contaminants listed in Appendix A. Table 13 lists possible causes of common taste, odor, and appearance problems in well water, usually associated with EPA secondary standards, which are not based on health considerations. Tables 11, 12 and 13 do not include all contaminants for which the MassDEP/ORS has established drinking water guidelines and standards. A complete list of the drinking water quality parameters, based on the requirements for public water supply sampling, is provided in Appendix A. For the complete list of Massachusetts Drinking Water Standards and Guidelines visit: https://www.mass.gov/guides/drinking-water-standards-and-guidelines.

MassDEP recommends that private wells used only for irrigation be tested annually for E. coli bacteria and Nitrate/Nitrite, as accidental consumption could result in acute exposure. Irrigation wells should be signed appropriately to indicate that the water is not meant for human consumption.

MassDEP recommends the following testing of private drinking water wells:

(1) For newly constructed wells:

A raw water sample should be obtained from the well and analyzed for all of the parameters listed in Tables 11 and 12 at least once to assess the suitability of the well as a source of drinking water and to establish a base-line of the well water chemistry. These base-line results can be compared to subsequent water quality analyses to determine whether any changes in water quality are occurring that may indicate a contaminant threat

The raw water results are used to determine if and what type of treatment is necessary to ensure a potable source of water. In no event should a water treatment device be installed prior to baseline sampling. If a treatment system is installed, a sample taken from a household tap post treatment should be taken and analyzed for the contaminant of concern to ensure the system is functioning properly prior to occupancy.

If current or historic land uses indicate commercial or industrial activities in the vicinity of the well, then testing for parameters in addition to those listed in Tables 11 and 12 may be warranted (see Appendix B-*Land Use/Associated Contaminants Matrix).*

(2) For Existing Wells:

Each year, preferably in the spring, all private wells, should be tested for total coliform bacteria and nitrate/nitrite (Table 11). If Total Coliform bacteria is detected, the well water should be sampled for *E.-coli* to determine if wastewater has contaminated the well.

Total coliform bacteria and nitrate/nitrite should be tested for annually as they can both represent acute exposure risks that can change over a short period of time. Coliform bacteria include both non-pathogenic bacteria that occur naturally in the environment and fecal coliforms associated with wastewater. *Escherichia coli,* commonly called *E.coli.* is one of the most common species of fecal coliform bacteria. *E.coli* is used as an indicator organism in drinking water to determine if a well has been impacted by either animal or human wastes containing pathogenic or disease-causing organisms.

At least, every 10 years, homeowners should test for parameters listed in Table 12. These results should be compared to the previously collected water chemistry results to see if any adverse changes have occurred in water quality. If the initial base-line testing did not indicate water quality issues with fluoride, copper, radon or radionuclides, the homeowner may choose not to test for these parameters as they typically remain at stable concentrations in the well water.

(3) Transfer of Property

Prior to selling, conveying, or transferring title to real property, the owner should have tested the water of every private drinking water well serving that property. A water sample from each well should be submitted to a Massachusetts certified laboratory for testing for the parameters listed in Tables 11 and 12. This water quality testing should have been performed not more than one (1) year prior to transfer of the property. The results of the water quality testing should be submitted to the Board of Health prior to property transfer.

The owner of a rental property should make results of all water quality tests available to all tenants of the property and the Board of Health. In cases where the well water does not meet the water quality standards, the Board of Health may require the property owner to provide an alternative source of drinking water approved by the BOH for the tenants.

Persons intending to purchase a home served by a private well should request the results of available water quality analyses and/or have the well sampled and tested for the parameters listed in Tables 11 and 12 to establish a water chemistry base-line based on the parameters listed. For all wells, a raw water sample should be taken to ensure that the well water is of good quality. For wells with a treatment system, a sample from a household tap should also be taken to ensure that the system is functioning properly.

If an existing cesspool, privy, or any portion of a soil absorption system is located between 50-100 feet from a private well, the wastewater disposal system is considered to be in failure (under 310 CMR 15.303) unless the well water quality analysis indicates the absence of fecal coliform bacteria, and that ammonia nitrogen and nitrate nitrogen is equal or less than 5 mg/l.

(4) Dual Purpose Geothermal wells

If the private drinking water supply well is also used as an injection well for the effluent from a ground source heat pump (geothermal) system, MassDEP recommends that the home owner collect a post heat pump sample for lead, nickel, and copper analyses in August once every 3 years. If the post heat pump lead, nickel, or copper results from any sampling event exceed 0.007, 0.05, and 0.65 mg/L, respectively, then MassDEP recommends that post heat pump samples be collected annually in August and analyzed again for those parameters that exceed these limits. If subsequent sample results drop below these limits, then MassDEP recommends that sampling be continued in August once every 3 years. These limits are equal to one half (1/2) the recommended maximum concentration limits for drinking water.

In addition, the following conditions may prompt more frequent testing of private drinking water wells:

- Noticeable variations in quality like a water quality change after a heavy rain, extended drought, or an unexplained change in a previously trouble-free well (i.e. strange taste, cloudy appearance, etc.).
- Recent well construction activities or repairs. MassDEP recommends taking a bacterial test after any well repair or pump or plumbing modification, but only after disinfection and substantial flushing of the water system.
- Contaminant concentrations above state or federal standards found in earlier testing in the well or neighboring wells.
- Someone in the household is nursing or pregnant
- There is an unexplained illness in the family
- The well is a shallow overburden well less than 50 feet deep.
- The well is sited in a heavily developed area with land uses that handle hazardous chemicals
- There is a spill of chemicals or fuels into or near the well

Owners of wells in commercial or agricultural areas are encouraged to conduct more frequent sampling. Private wells installed in areas used for agricultural activities (currently or historically) can be contaminated by synthetic organic compounds (SOCs) associated with pesticide use. Comprehensive testing for these compounds can be very expensive. It is recommended that rather than testing for individual parameters, a laboratory screening method (such as EPA Method 505 or 508) be used first to determine if these types of compounds are present.

If any of the limits noted in Tables 11 and 12, are exceeded, a second water quality test should be conducted to confirm the results of the first analysis. If the limit is exceeded in the second analysis, treatment may be necessary and the local Board of Health should be notified.

Well owners should test for total coliform bacteria and nitrate/nitrite annually (Table 11) and other contaminants listed in Table 12 initially and then every 10 years. Tables 11 and 12 include possible interpretations of those test results. A water treatment professional should be consulted for a more detailed interpretation of the test results.

Recommended Test	**Interpreting Your Result**	
	If the lab	**Things to consider:**

	report shows:	
Total Coliform Bacteria	Present	1.Collect another sample to test for *E.-coli.* 2. Discontinue using water directly from the tap until the results of the *E. coli* test are received. 3. If the presence of *e.coli* is confirmed, consult a water treatment professional immediately, as a treatment system may be necessary. *Do not consume the tap water directly*, either boil the water first, or use bottled water until the problem is resolved. 4. If *E. coli* is not detected, investigate and eliminate possible sources of contamination and disinfect the well. 5. Retest the well. If recurrent problems persist, consult a water treatment professional.
Nitrate/Nitrite(total)	>10 mg/L	Collect a re-sample to confirm. If contamination is confirmed, install a water treatment system or find an alternate water supply. Consult a water treatment professional for guidance.

“>” means “more than”
“mg/L” means milligrams per liter

Table 11 : Recommended Water Quality Testing - Annual Basis

A positive *E.coli* result is much more serious than one for coliform bacteria because it indicates that water contaminated with human or animal waste is entering the well. If the contamination is just in the well or the water system, it should be removed by disinfection. It can take several disinfection attempts before the coliform bacteria are eliminated.

In some wells, coliform bacteria levels may slowly return over time, and periodic “shock “disinfection (see Disinfection section on page 72) may be necessary to keep the problem under control.

Possible sources of coliform bacteria include:

- Absence of a well cap or seal which could allow vermin to get into the well
- Old, rusty or damaged well casings
- Improper well casing installation
- Faulty pump installation

If any of the above are thought to be the cause of the bacterial contamination, then proper repairs must be made by a certified well driller.

Recommended Test	Interpreting Your Result		
	If the lab report shows:	**Then you may want to consider:**	**In addition**:
Arsenic	>0.010 mg/L	1.Collect a re-sample to confirm. 2. Compare to previous results 3. Contact your BOH or water quality professional for guidance. 4. Depending upon contaminant and concentration, options may include installing a treatment system or finding an alternate water supply. The appropriate water treatment system depends on your overall water chemistry and the constituents that need to be removed.	Information on probability of arsenic and uranium in well water in MA communities is available on the MassDEP website. If radon is detected in water, test indoor air. Lead and manganese are of particular concern to young children.
Lead	>0.015 mg/L		
Manganese	>0.3 mg/L		
Copper	>1.3 mg/L		
Fluoride	>4 mg/L		
Sodium	>20 mg/L		
Gross Alpha Screen	>15 pCi/L		
Radon-222	>10,000 pCi/L		
Radium 226 &228	>5 pCi/L		
Uranium	>0.03 mg/L		
Volatile Organic Compounds	Above MA Maximum Contaminant Levels (MMCL)		
PFAS6	Above 20 ng/L for the combined total of all six MassDEP regulated PFAS chemicals		
PFOA	> 4.0 ng/L		
PFOS	> 4.0 ng/L		
PFHxS	> 10 ng/L		
PFNA	> 10 ng/L		
HFPO-DA (GenX Chemicals)	> 10 ng/L		
Mixures of two or more PFHxS, PFNA, HFPO-DA, and PFBS	Above EPA Hazard Index of 1*		
Chloride	>250 mg/L	These parameters effect water taste and odor.	Measurement necessary for efficient design of water treatment system
Hardness	<50 mg/L or >200 mg/L		
Iron	>0.3 mg/L		
pH	<6.5 or >8.5		

"<" means "less than"
"mg/L" means milligrams per liter
"ng/L" means nanograms per liter or parts per trillion (ppt)
"pCi/L" means picocuries per liter

*Information on how to calculate EPA Hazard Index for PFAS can be found here:
https://www.epa.gov/system/files/documents/2024-04/pfas-npdwr_fact-sheet_hazard-index_4.8.24.pdf

Table 12 : Recommended Water Quality Testing - Initially and Every 10 years

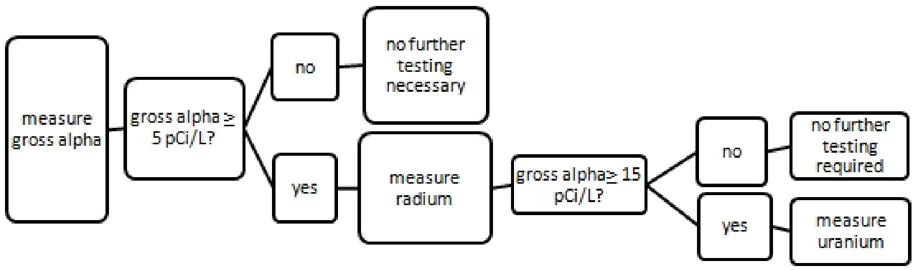

Figure 18 : Radionuclide Testing Decision Diagram

The Board of Health may require more frequent testing, or testing for additional parameters, where other water quality problems are known or suspected to exist. The Board can also require the use of an unbiased third party to take water quality samples.The Board can reserve the right to require retesting of the above parameters, or testing for additional parameters when, in the opinion of the Board, it is necessary due to local conditions or for the protection of public health, safety, welfare and the environment. In any case where a private drinking water well does not meet such Standards or Guidelines, the Board may require the property owner to treat the water or provide an alternative source of drinking water.

Exceedence of the recommended limit for sodium noted in Table 12 is primarily of concern to persons on low sodium diets. If road salt is suspected as the source of high sodium levels, the well owner or Board of Health should contact the Massachusetts Department of Transportation's (MassDOT) Salt Remediation Program if the road is maintained by the state, or the local Department of Public Works (DPW) if it is maintained by the town.

Some well owners may have specific issues or problems with their well water. Table 13 outlines several common problems in drinking water and substances you can test for. Not every problem and possible cause is a health risk. Less frequently encountered water quality issues are listed in Table 13; consult a water treatment professional if your particular water quality problem is not listed or for a more thorough discussion of the causes of water quality problems.

Problem	Possible Cause
Water is orange or reddish brown	High levels of iron
Porcelain fixtures or laundry are stained brown or black	High levels of iron or manganese
Blue stains on plumbing fixtures and laundry	Corrosive water (low pH) leaching copper from plumbing
White spots on dishes or white encrustation around fixtures	Hardness caused by high levels of calcium,magnesium, and sulfates which leaves spots.
Water smells like rotten eggs	Hydrogen sulfide, sulfate–reducing or sulfur bacteria
Water has salty brackish taste	Saltwater intrusion, road salt contamination

Water heater is corroding	Water can be corrosive. Very corrosive water can damage metal pipes and water heaters
Water appears cloudy, frothy, or colored	Suspended particulates, detergents,dissolved gases and sewage can cause these conditions
Your home's plumbing system has lead pipes, fittings, or solder joints	Corrosive water can cause lead, copper, cadmium, and zinc to leach from lead pipes and solder joints

Table 13 : Possible Causes of Common Taste, Odor, and Appearance Problems in Well Water

The Drinking Water Standards in Appendix A (with the exception of the Office of Research and Standards Guidelines (ORSGs)) are the Primary Standards that have been adopted by MassDEP for Public Water Systems (PWS). For establishing ORSGs for drinking water, MassDEP uses methodology similar to that used by the EPA's Office of Groundwater and Drinking Water for establishing Primary Standards. These limits have been determined by either the U.S. Environmental Protection Agency or the MassDEP Office of Research and Standards (ORS) to be protective of human health. For information on the derivation of the recommended concentration limits, and general information on the health effects of water contaminants, please contact ORS at (617) 556-1158.

RECOMMENDED USE OF APPROVED METHODS AND CERTIFIED LABORATORIES

MassDEP has an ongoing laboratory certification program administered by its Wall Experiment Station (Regulation 310 CMR 42.00, "**Certification and Operation of Environmental Analysis Laboratories**") which establishes certification requirements for laboratories conducting analytical measurements of chemical, radiochemical, and microbiological parameters in environmental samples, including drinking water. It is important to note, however, that a laboratory that is certified for one type of analysis may not be certified for another type. In addition, since the certification process is ongoing, a laboratory may, at any time, lose its certification for a particular analysis. Thus, prior to contracting a laboratory for a particular analysis, verify that the laboratory has current certification by the state to perform such an analysis by consulting a list of laboratories that are certified for specific analyses at the following MassDEP web page: https://www.mass.gov/certified-laboratories.

Public water suppliers are required to use MassDEP-certified laboratories for water analysis. MassDEP recommends that local Boards of Health also require the use of DEP certified labs for private well testing. While homeowners are not required to use MassDEP-certified laboratories when testing their private well water, MassDEP strongly encourages them to do so.

All water quality analyses should be conducted utilizing methods approved by the U. S. Environmental Protection Agency for analyzing drinking water (https://www.epa.gov/dwanalyticalmethods) and **not** methods used for analyzing wastewater.

RECOMMENDED WATER QUALITY INFORMATION

It is recommended that the local Board of Health require the well owner to submit to the Board a water quality report anytime a private water supply is tested. The report should include the following information:

(1) Location of well (if no street address is available, location should be provided in lat/long or UTM)

(2) Name, address and phone number or other contact information for the individual who performed the sampling (i.e., BOH member, BOH agent, lab personnel, well owner, well owner's agent);

(3) where in the system the sample was obtained (at the wellhead, prior to treatment, or at the tap) and, if sampled at the tap, whether or not the system was flushed prior to sampling;

(4) existence of water treatment and, if so, what type of water treatment used (chemical or special device e.g., disinfection, reverse osmosis unit, filter, etc.);

(5) date and time of sample collection;

(6) date and time sample received by the laboratory;

(7) a copy of the laboratory's test results which includes the MassDEP laboratory certificate number and the EPA approved methods used in the analysis.

Results that indicate no contamination are as important as those that indicate water quality problems because these results provide background data in case of future contamination. A complete record of all testing results is also useful when designing local water quality testing programs.

Each laboratory will have its own method of reporting results, so each laboratory report will look different. However, for each substance that is tested, the amount of that substance found in the water sample should be reported and compared to the health-protective drinking water quality standard or guideline established by the Commonwealth. Frequently the lab report will list the standard or guideline for eachanalyte tested . These values can be found on the MassDEP website at https://www.mass.gov/guides/drinking-water-standards-and-guidelines

Most substances in water are measured and reported as a concentration. Depending on the substance, the results may be reported as:

- Parts per million (ppm) = milligrams per liter of water = mg/L
- Parts per billion (ppb) = micrograms per liter of water = ug/L
- CFU/100 mL= colony - forming units per 100 mL of water.

Upon receiving the laboratory report, the following information should be located on the report for each parameter tested:

- The laboratory method detection limit (MDL).
- The Massachusetts Maximum Level (MMCL) or ORSGL (MassDEP Office of Research and Standards Guidelines). Sometimes a Secondary Maximum Contaminant Level (SMCL) is listed for those contaminants causing aesthetic problems.
- The level of contaminant measured.

Compare water test results to the established guidance levels to determine if a particular substance is exceeding the respective guidance level. The results should be at or below the guidance value listed for that substance. If any of the test results are above the guidance value, then a problem exists that needs to be addressed. If the result is above the health-based – MMCL or ORSG, then the issue should be addressed quickly. The important part about interpreting test results is to determine whether the substance is considered a health threat at the particular concentration found in the water sample.

PRIVATE WELL CERTIFICATE

The issuance of a Private Well Certificate by the Board of Health certifies that the private well may be used as a drinking water supply. A Private Well Certificate should be issued for the use of a private well prior to the issuance of an occupancy permit for an existing structure or, in the case of new construction, prior to the issuance of a building permit for the dwelling to be served by the well (MGL Chapter 40, sec 54). In the case where a well requires installation of a treatment system in order to meet primary drinking water standards, the Board of Health should condition their approval of the building permit so that the treatment system must be installed and tested before occupancy occurs.

The following should be submitted to the Board of Health in order to obtain a Private Well Certificate:

(1) a copy of the Well Completion Report (which should include pumping test results) as required by the MassDEP Well Driller Program; and,

(2) a copy of the water quality report.

Upon the receipt and review of the above documents, the Board of Health may:

(1) issue a **Private Well Certificate** if the test indicates that the water is considered potable without any required treatment;

(2) deny the applicant a **Private Well Certificate** and specify the reasons for the denial; or,

(3) issue a **Private Well Certificate With Conditions**, specifying those conditions that must be met or maintained which the Board deems are necessary to ensure the fitness, purity, and quantity of the water derived from that private well. The conditions may include, but are not limited to requiring treatment or additional testing of the water. Boards of Health that approve wells that require treatment to meet Primary Drinking Water Standards should ensure that the approved treatment system is recorded as a deed notice attached to the records for that property at the Registry of Deeds. If the **Private Well Certificate With Conditions** lists the type of treatment deemed necessary, the owner may record the Certificate as a deed notice. The owner must submit an additional water quality report(s) proving that the installed treatment system, if maintained properly, provides a potable source of water. Proof of potability and of the deed notice recording should be submitted to the Board of Health prior to the issuance of a Certificate of Occupancy by the Building Commissioner.

WATER TREATMENT

Locating Treatment Systems: POE vs POU

The type of treatment chosen, point of entry (POE) for the whole household versus point of use (POU) for an individual tap, will depend upon the nature of the problem. For taste and odor problems, POU devices will suffice. Minerals that cause scaling on water heaters or staining of laundry should be removed by entry-devices. POE devices should also be used to remove or disinfect health related contaminants such as bacteria, organic chemicals and radon.

Table 14 summarizes the types of treatment available for specific contaminants.

	Treatment Device								
Contaminants	UV Light	Ion Exch.	Sediment Filter	Actd. Carbon	Actd. Alum	Reverse Osmosis	Distillation	Aeration	Chlorination
Aluminum						•	•		
Arsenic					•	•	•		
Bacteria and Viruses	•					•	•		•
Cadmium		•				•	•		
Chloride					•	•	•		
Chromium						•	•		
Copper		•				•	•		
Fluoride		•		•	•	•	•		
Giardia* and *Crytosporidium	•		•			•	•		
Hardness		•				•	•		
Iron and Manganese		•		•		•	•		•
Lead		•		•	•	•	•		
Mercury				•		•	•		
Nitrate		•			•	•	•		
Pesticides				•		•	•		
PFAS		•		•		•			
Radium		•				•	•		
Radon		•		•				•	
Sediment/ Turbidity			•	•		•			
Selenium		•			•	•	•		
Silver						•	•		
Sodium						•	•		
Sulfate		•			•	•	•		
Taste and odor				•		•	•		
Total Dissolved Solids						•	•		
Uranium		•			•	•	•		
VOCs				•		•		•	
Zinc						•	•		

Table 14 : Treatment Device Options

Ultraviolet

Ultraviolet (UV) light systems provide continuous disinfection treatment. UV radiation disrupts the bacteria's genetic material, making reproduction impossible. While UV radiation is effective for bacteria and viruses, it is less effective for *Giardia* or *Crytosporidium*. In a typical whole house (POE) UV system, untreated water enters the UV unit and is exposed to the UV radiation as it flows through the device.

To effectively disinfect a water supply, the UV lamp must emit light at the correct intensity. The age of the lamp and the characteristics of the water being treated both affect intensity. UV lamps weaken over time and must be changed according to manufacturer's recommendations.

Water that is cloudy or contains sediment will limit UV light penetration. As a result, the UV disinfection system is typically the last device in a household water treatment system, preceded by other devices designed to filter or otherwise clarify the water supply. Finally, the concentration of bacteria in the water supply can also affect UV treatment effectiveness. If the water supply contains large concentrations of bacteria (more than 1,000 total coliforms per 100 millimeters or more than 100 fecal coliforms per 100 millimeters), an alternative disinfection method is recommended.(VA Cooperative Ext, 2013)

Ion Exchange

Ion Exchange (IE) is a water treatment method where one or more undesirable contaminants are removed from water by exchange with another less objectionable substance. This activity is achieved by using an organic resin as the exchange media. Both the contaminant and the exchanged substance (resin) must be dissolved and have the same type of electrical charge. Pretreatment may be needed to remove any solids. There are two types of ion exchange; cation and anion.

A Cation Exchange Treatment System, also called a water softener, is primarily used to remove positive, divalent metals from water that are typically associated with hardness such as iron, manganese, calcium and magnesium, which make the water 'hard'. Hard water can cause scale build up in appliances, plumbing, and in showers and tubs. On the other hand, an Anion Exchange System can remove nitrate, arsenic, sulfate, bicarbonate, uranium and selenium.

Ion exchange systems are designed to treat all the water used in the household (POE). The major part of these systems is a large tank that contains mineral beads (resins), which can remove unwanted substances from the water flowing through it. The electrical charge of the ions in the mineral beads reacts with the electrical charge of the unwanted substances. The unwanted ions, like iron, are exchanged for another substance that is in the mineral beads. For iron removal, sodium or potassium chloride ions are commonly used in the mineral beads and exchanged for iron. In order for the unit to function properly the unit must be backwashed in accordance with the manufacturer's instructions. (URI, 2013)

Sediment Filtration

Sediment filters are typically used to remove suspended particles found in water (e.g., sand, silt, clay, and oxidized iron and manganese). Sediment filters remove impurities by passing the water through a filter material that is rated or sized according to the smallest particle it can trap (Figure 19).

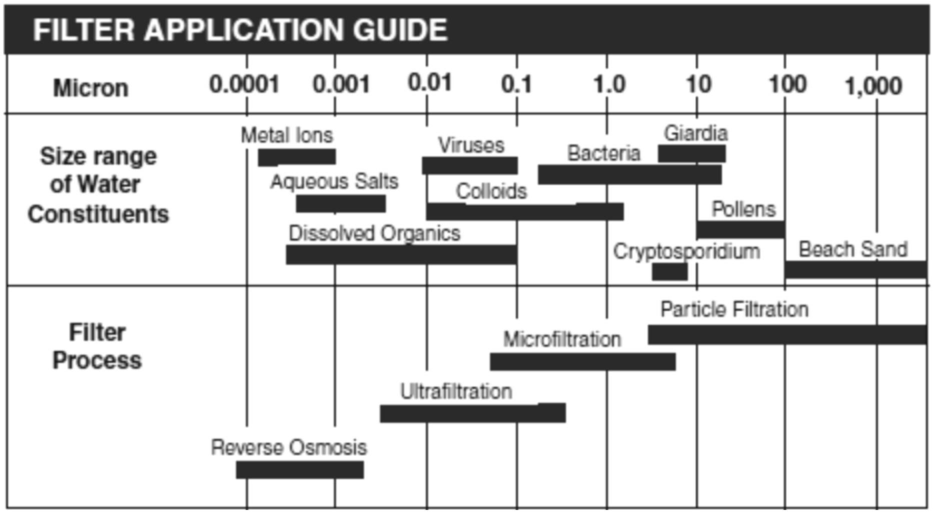

Figure 19 : Filter Appplication Guide
[from Arizona Cooperative Water Facts: Home Water Treatment Options *(AZ 1498, 2009)*]

Sediment filters come in many sizes and varieties. The simplest are the very small cartridge filters commonly installed ahead of UV lights, reverse osmosis and other treatment units to remove sediment that might interfere with the treatment processes. These simple, inexpensive cartridge filters remove large sediment and metal particles, but they have very limited capacity. Typical cartridge filter media types include pleated paper, cellulose, wound string, and spun polypropylene.

Larger whole house (POE) sediment filters are also available to treat much larger amounts of water and remove much smaller particles. They may even be constructed of very fine media capable of trapping small organisms like *Giardia* and *Cryptospordium* cysts. Sand, diatomaceous earth, spiral wound fabric, ceramic and activated carbon are common media for filtration.

In order for these filters to be effective, they must be properly maintained and operated. As sediment filters become saturated, water pressure is reduced in the home, an indication that maintenance is required. Large sediment filters must be routinely backwashed to clean and refresh the filter media. Cartridge type filters must be changed periodically, as they are also susceptible to bacteria growth.

Activated Carbon Filter

Activated carbon filtration as a point of use (POU) treatment, may be selected to reduce unwanted taste and odor through the removal of chlorine and low concentrations of organic chemicals. Larger whole house (POE) treatment units can be installed to remove organic contaminants like fuel oil, gasoline, chlorine, solvents, some pesticides, and radon. Carbon filters will not remove bacteria or major inorganic ions (e.g., sodium, calcium, chloride, nitrate, fluoride or metals). However, some carbon filters can reduce lead, copper, and mercury.

The effectiveness of an activated carbon filter device depends on the design of the filter, the type and concentration of the impurities and the amount of time the water is in contact with the activated carbon media. To function properly, these filters must be changed according to the manufacturer's recommendations. The water should be tested periodically to ensure that the filter is working properly. When using the filter to remove hazardous materials, a contaminated (or radioactive, in the case of radon) carbon media is created that must be disposed of properly.

The use of an activated carbon filter for radon is not recommended since radioactivity can build up on the carbon media. At radon concentrations above 5,000 pCi/L, the carbon in the canister will be too radioactive to be located in the basement or other occupied areas of the house, and would also result in expensive disposal costs.

Activated Alumina

Activated Alumina (AA) filtration involves the passage of the water through an alumina media. Activated alumina filters have been used to remove fluoride, arsenic, and lead from drinking water. Since there are several different types of activated alumina, the filter selected should be one specifically designed to remove the contaminant of concern. Large AA treatment devices can de used to treat the whole house (POE), or smaller point of use (POU) filters can be used to remove arsenic at the tap. AA is the preferred treatment method if your water is high in total dissolved solids (TDS) or high sulfate concentrations. A disadvantage of AA filters is that they must be regenerated using strong acid and base solutions that are undesirable for home storage and handling. In addition to periodic regeneration, the alumina filter material must be replaced every one to two years.

Reverse Osmosis

Reverse Osmosis (RO) units are typically POU devices that can effectively remove most dissolved and suspended impurities (such as arsenic, barium, cadmium, sodium, chloride, copper, fluoride, lead, manganese, mercury, sulfates and nitrate), but they are not recommended for removal of organic impurities, including bacteria. With RO systems, impurities are removed as water is forced through a semi-permeable membrane with microscopic holes that are large enough to allow water molecules to pass through but small enough to block most dissolved and suspended impurities. RO will strip the minerals from the water, which may affect the water's taste, giving it a "flat" taste, and making it more corrosive.

Care must be taken not to clog the filter; hard water can foul the membrane. A sediment prefilter is frequently used to remove particles before the water encounters the RO membrane, and an activated carbon is often included after the membrane to polish the water and remove any taste or odor problems. In some modular systems, these components may be included in a single unit. Maintenance involves periodically replacing the RO membrane and associated filters in accordance with the manufacturer's recommendations. Ten to 20 % of the water entering the RO system exits as treated water. The other 80 to 90 % is wastewater that is diverted to a drain.

Distillation

Distillation units boil water to create steam, which is then condensed and collected as distilled water. Distillation can be used to disinfect water, remove many organic and inorganic contaminants, and reduce the concentration of toxic metals. Distillation completely removes all dissolved solids from the water, which may affect the water's taste, giving it a "flat" taste, and make it more corrosive.

Distillation units are typically POU devices that treat comparatively small volumes of water. Home distillation units tend to be energy intensive, making them expensive to operate and produce a considerable amount of heat. Periodic maintenance and cleaning of the distillation unit is required because minerals and other impurities accumulate in the evaporation chamber and can potentially interfere with the operation.

Aeration

Home aeration systems remove dissolved gases such as radon, carbon dioxide, methane, hydrogen sulfide, as well as volatile organic compounds, like MTBE or industrial solvents. EPA has listed aeration as the best available method for removing radon from water. Aeration prior to filtration can be used for the precipitation and removal of iron and manganese. These systems treat all the water entering the home (POE) and range from simple systems, with spray aerators enclosed in a tank, to packed tower aerators, which collect and release the accumulated gas.

Aeration treatment consists of passing large amounts of air through water and then venting the air to the atmosphere. The air causes dissolved gases or volatile compounds to release from the water into the air. Waste air from the aerators needs to be disposed of outside of the home. In the case of iron and manganese, the air causes the minerals to precipitate out of solution. Aeration raises the pH of the water by removing carbon dioxide.

Maintenance costs are low for aeration units, but the initial purchase costs are often higher than other treatment options. Regardless of the quality of the equipment purchased, it will not perform satisfactorily unless maintained in accordance with the manufacturer's recommendations for maintenance, cleaning, and parts replacement.

Disinfection of aerated water is recommended. Bacterial slime will grow in aerators and storage tanks, requiring continuous or periodic chlorination. Chlorination may oxidize iron and other metals, and cause them to precipitate out, requiring the need for a filter to remove the metal particles. The storage tank needs occasional cleaning as precipitated sulfur, iron sulfide, rust and algae collect.

Continuous Chlorination

Chlorination treatment systems (POE) are basically composed of a feed system that injects a chlorine solution (sodium hypochlorite or calcium hypochlorite) into the water ahead of a storage tank. The chlorine that is injected into the water is consumed as it kills the bacteria. The chlorine is also consumed by impurities in the water such as iron, hydrogen sulfide and organic materials. The amount of chlorine needed to kill bacteria and oxidize all the impurities in the water is known as the chlorine demand. The goal of continuous chlorination is to provide enough chlorine to satisfy the chlorine demand and still allow for a residual amount of chlorine in the water. The residual chlorine is then available to kill any bacteria that may enter the water after the chlorinator.

A sediment or media filter may be required following a chlorination system to filter out oxidized impurities. If chlorine taste or odor is an issue, an activated carbon filter may be needed to remove residual chlorine from the treated water. Maintenance of continuous chlorination systems involves ensuring that the metering device is feeding the correct amount of chlorine to the system and having a sufficient supply of chlorine available. Both liquid and solid forms of chlorine are poisonous and irritants that must be handled according to specific safety measures.

Acid Water Neutralizing Filter

The EPA recommended pH range for drinking water is between 6.5 and 8.5, a pH less than 7.0 is considered acidic. Acidic water can be corrosive and can dissolve metals such as copper and lead in the household plumbing. Consuming dissolved lead and copper in drinking water can be a health hazard. Some dissolved metals can also cause staining of plumbing fixtures and water to have a metallic taste.

An acid neutralizing filter is a relatively simple treatment device that raises the pH of water by adding a neutralizing material. The most common type of neutralizing filter is a tank type, in which water flows through a neutralizing media composed of calcium carbonate (limestone), crushed oyster shells, marble chips, or synthetic magnesium oxide material. As the water flows through the neutralizing media, the media is dissolved and the pH of the water increases.

Frequent maintenance is required for neutralizing filters. The tank must be routinely refilled with neutralizing media as it is dissolved. Backwashing is recommended to remove trapped particles and oxidized metals unless a sediment filter is installed ahead of the unit.

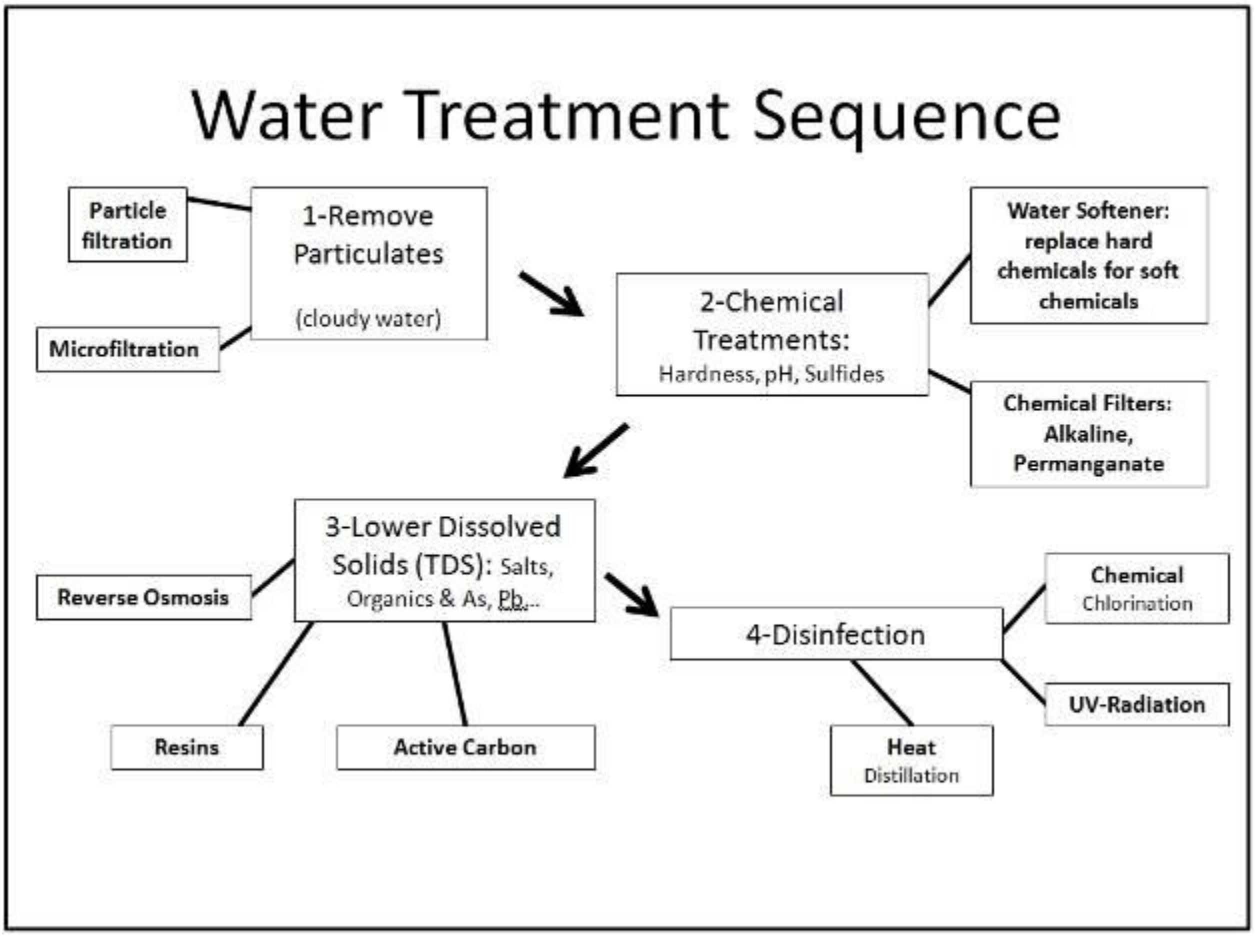

Figure 20. Typical Treatment Sequence

The typical sequence for water treatment devices used for household systems is outlined in Figure 20. Some type of sediment filter is usually first in the treatment train to eliminate any particulates in the well water that may clog subsequent treatment devices. Chemical treatments to modify pH, or a water softening unit, if necessary, would be installed next in the treatment sequence. If inorganic contaminants or other undesirable dissolved solids are present in the water, treatment devices such as RO, AC, or resin beds may be installed after any necessary chemical treatment. Finally, if bacteria is an issue, some type of disinfection treatment device should be installed prior to distributing the water to the household taps.

Performance Certifications: NSF and WQA Certifications

Several independent associations provide testing of water treatment equipment to determine its effectiveness. Two such organizations are the National Sanitation Foundation (www.nsf.org) and the Water Quality Association (www.wqa.org). Water treatment systems vendors should provide written proof of these certifications for the treatment equipment installed in the house.

WELL MAINTENANCE AND REHABILITATION

All materials and construction practices used in the maintenance, or repair of any well should be the same as those required for the construction of a new well. All maintenance, repair, and reconstruction work to the well should be done only by a MassDEP certified well driller.

Upon completion of any alteration of a well, or maintenance or repair work done on a well or its pumping equipment, the contractor should disinfect the well, the pumping equipment and the distribution system before the well is returned to service. Appropriate disinfection procedures are discussed in the section entitled "Disinfection".

WELL MAINTENANCE

The well owner should be responsible for;

(1) maintaining the well in a sanitary condition

(2) maintaining the well in a manner that prevents surface water or contaminants from entering the well

(3) maintaining the well in a manner that conserves groundwater resources

(4) maintaining the well so that it is accessible for rehabilitation and repairs

(5) ensuring that an abandoned well is properly plugged

Temporary Abandonment

When a well is not abandoned, but is out of use for an extended period of time, it is the owner's responsibility to properly maintain the well and to prevent the development of defects which may facilitate the impairment of water quality in the well or in the water bearing formations penetrated by the well. Until a well is permanently abandoned by plugging procedures, as described in the following section entitled "Decommissioning Abandoned Wells, Test Holes, and Dry or Inadequate Borings", all provisions for protection of the water from contamination and for maintaining sanitary conditions around the well should be carried out to the same extent as though the well were in routine use.

To temporarily abandon a well, the top of the well casing should be sealed with a watertight threaded cap or with a steel plate welded watertight to the top of the casing. If the pump or well seal is water tight, the pump may be left in place.

WELL REHABILITATION

Well rehabilitation is defined as restoring a well to its most efficient condition by various methods of treatment or reconstruction. The necessity for well rehabilitation depends on the effectiveness of the maintenance program and how faithfully it has been followed. In some cases, a major reconstruction of the well may be necessary, such as replacing the screen or lining a portion of the casing. Timely maintenance designed to overcome specific problems can sustain well performance, thereby prolonging well life.

It is important to take note of any changes in the operating characteristics of the well and pump, because both can deteriorate to the point where rehabilitation is difficult, if not impossible. Experience indicates that if the specific capacity of a well declines by 25 %, it is time to initiate rehabilitation procedures. Further neglect significantly increases maintenance costs.

Major Causes of Deteriorating Well Performance

(1) Incrustation and Biofouling of the Screen and Surrounding Formation
(2) Physical Plugging of the Screen and Surrounding Formation
(3) Onset of Sand Pumping
(4) Structural Collapse of the Well Casing or Screen

Incrustation and Biofouling of the Screen and Surrounding Formation

Well yield may be reduced by chemical incrustation or biofouling of the well screen and the formation materials around the intake portion of the well. Water quality chiefly determines the occurrence of incrustation. The surface of the screen itself may also play a part in regulating the rate at which incrustation occurs. Screens constructed of rough-surface metal may be more prone to incrustation. The kind and amount of dissolved minerals and gases in natural waters determine their tendency to deposit mineral matter as incrustation. The incrustation often forms a hard, brittle, cement like deposit similar to the scale found in water pipes. Under different conditions, however, it may be a soft, paste like sludge of a gelatinous material. The major forms of incrustation include;

(1) incrustation from precipitation of calcium and magnesium carbonates or their sulfates;

(2) incrustation from precipitation of iron and manganese compounds, primarily their hydroxides or hydrated oxides;

(3) plugging caused by slime producing iron bacteria or other slime-forming organisms (biofouling).

Prevention and Treatment of Incrustation Problems

For most wells where incrusting materials cannot be removed before reaching the well, several actions can be taken to delay incrustation and make it a less serious problem. First, the well screen should be designed to have the maximum possible inlet area to reduce the flow velocity to a minimum through the screen openings. Second, the well should be developed thoroughly. Third, the pumping rate may be reduced and the pumping period increased, thereby decreasing entrance velocities.

Chemical incrustation can best be removed by treating the well with a strong acid solution that chemically dissolves the incrusting materials so they can be pumped from the well. The acids most commonly used in well rehabilitation are hydrochloric (HCL), which is prepared commercially under the name muriatic acid, and is one of the most effective acids for mineral scale removal; sulfamic (H_3NO_3S), a dry white, granular material that produces a strong acid when mixed with water; and hydroxyacetic ($C_2H_4O_3$), also known as glycolic acid, which is a liquid organic acid available commercially in 70% concentrations.

Provisions should be made to neutralize acids and other chemicals used to rehabilitate a well. For example, acid solutions should be pumped to waste through agricultural lime or other suitable material.

Great care should be taken in placing liquid acid into a well. Only experienced personnel with specialized equipment should attempt to use it in rehabilitating a well. When using any liquid acid, the following precautions should be followed;

(1) wear protective rubber clothing and goggles

(2) a breathing respirator should be used by all personnel handling the acid and by persons near the well

(3) all mixing tanks, chemical pumps, and piping (tremie pipes) should be constructed of plastic or black iron to minimize reaction to acid

(4) a large quantity of water, or a water tank with a mixture of sodium bicarbonate, should be available in the event that an accident occurs

(5) proper ventilation must be maintained because the fumes released from the well treatment are lethal

Liquid acid should be introduced into the well through a small diameter pipe. If the screen is more than 5 feet long, enough acid should be added to fill the lower 5 feet of screen. Then the pipe should be raised and the next 5 feet of screen filled with acid, continuing in this manner until the entire screen is full.

After the acid is placed in the well (or the pellets dissolve), a volume of water equal to that standing in the well screen should be poured into the well to force the acid solution through the screen into the formation. Some form of mechanical agitation, such as surging, should be employed while the acid is in the well to help break up the incrustation and improve the overall efficiency of the process. This step is particularly important because it exposes the incrustant to the acid, thereby assuring maximum removal. The use of surge blocks or jetting tools are effective methods of agitating the well. The agitation time will depend on the amount of incrustant in the well

Another method available for the removal of incrustants is by mechanical means. This method is useful in either the preparation for acid treatment or as a primary method of removing incrustants. Bristle brushing or other means of mechanical scraping can remove incrustants that have been deposited on the inside of the well screen. The loosened material is then removed from the well by bailing, airlift pumping, or other means. Removal of these incrustants minimizes the quantity of acid that must be used in any subsequent acid treatment, enhances the effectiveness of this treatment, and reduces the time required for the acidizing process.

Well Failure Caused by Physical Plugging of the Screen and Surrounding Formation

It can be expected that over time, almost all screened wells will experience some loss in specific capacity. This loss may be partially due to the slow movement of fine formation particles into the area around the screen. Many of these particles may partially plug the screen itself, depending on the type of screen slot opening, or even erode the slot openings under certain conditions. In summation, the movement of small particles reduces the yield, increases the drawdown, and may damage the screen.

The movement of these fine particles may be the result of a number of factors including (1) improper screen placement, poor slot selection, or inaccurate aquifer sampling techniques, (2) insufficient or improper development before the well was placed in service, (3) removal of cement holding the sand grains together around the well screen, (4) corrosion of the screen or casing, (5) increase in the pumping rate beyond the designed capacity, and (6) excessive pump cycling, although this may pertain more to high yield wells than small yield private wells.

Thorough development of the well during its completion can greatly decrease the movement of sediment into the formation around the well screen. The application of an appropriate development technique for a sufficient length of time will stabilize the formation material so that subsequent pump cycling and higher discharge rates will not result in sediment movement.

Onset of Sand Pumping

Some wells always pump sand, a condition attributable to poor well design or inadequate development. Other wells may begin to pump sand after months or years of service. Localized corrosion of the well screen or casing, or incrustation on only a portion of the screen, can produce higher velocities through either the corroded opening or the nonincrusted areas of the screen. Thus corrosion and incrustation are major factors in sand pumping problems that develop over time. In some well-cemented sandstones, removal of the cement by water passing into the well can weaken the sandstone to the point where sand particles begin to move into the well.

Structural Collapse of the Well Casing or Screen

Corrosion of the well screen, casing or pumping equipment can severely limit the useful life of the well. Most natural waters are either corrosive or incrustive in nature. The rate at which corrosion takes place depends on several factors such as the acidity of the groundwater, presence or absence of oxidizing agents, movement of the water over areas being corroded, electrolytic effects, formation of films or protective deposits and temperature of the corrosive reactions. The effects of corrosion can be reduced by the proper choice of well construction materials and the use of a corrosive resistant pump.

DECOMMISSIONING ABANDONED WELLS, TEST HOLES, AND DRY OR INADEQUATE BORINGS

Private water supply wells are removed from service for a number of reasons, including construction of a replacement well, failure of the well to produce safe water, extension of a municipal water system to an area formerly served by individual private wells, or destruction of the building being served. When private wells are removed from service, they are seldom used again and are often forgotten after a property transfer. Over time, they may be covered by vegetation, a parking lot, or a building and they may act as a conduit, or channel, for the vertical movement of contamination from the ground surface to the groundwater or from one aquifer to another.

All abandoned private water supply wells, test holes, and dry or inadequate borings associated with private well installation and not used for water quality monitoring should be sealed in a manner that will permanently prevent vertical movement of water within the borehole, the well, and the annular space between the well casing and the wall of the boring. Improperly sealed wells, test holes, and dry or inadequate borings constitute a potential hazard to public health and a danger to groundwater supplies used for drinking water and other beneficial purposes.

Proper sealing will:

(1) eliminate physical hazards

(2) prevent the groundwater from being contaminated by flooding, or the accidental or intentional disposal of waste materials

(3) prevent the intermingling of potable and non-potable groundwater

(4) conserve the yield and hydrostatic head of confined aquifers

(5) prevent localized surface flooding in the vicinity of artesian wells

(6) prevent cross migration of water between 2 or more aquifers separated by confining layers

CRITERIA FOR ABANDONING A PRIVATE WATER SUPPLY WELL

A private water supply well should be abandoned and properly sealed if the well meets any of the following criteria;

(1) construction was terminated prior to completion of the well

(2) the well owner has notified the local Board of Health that the use of the well has been permanently discontinued

(3) the well has, after extended use, been out of service for at least three years

(4) the well is a potential hazard to public health or safety and the situation cannot be corrected

(5) the well is in such a state of disrepair that its continued use is impractical

(6) the well has the potential for transmitting contaminants from the land surface into an aquifer or from one aquifer to another and the situation cannot be corrected

RESPONSIBILITY

It is the responsibility of the property owner to ensure that all abandoned wells and test holes or borings associated with private well installation are properly sealed. Landowners should have the property inspected for wells that are no longer in use before purchase, and/or prior to the construction of new buildings. Any person having knowledge of the location of any unplugged abandoned wells, test holes, or dry or inadequate borings should inform the local Board of Health.

Only MassDEP certified well drillers can seal abandoned wells, test holes, and dry or inadequate borings. In addition, when an old well is replaced by a new well, it is generally more economical to have the well driller plug the old well at the same time that the replacement is being constructed. In the case of new well construction, it is required that any test holes and dry or inadequate borings be sealed before the well driller completes work at the site

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DECOMMISSIONING REPORT

Within 30 days following the completion of the sealing procedure, the MassDEP certified well driller who sealed the abandoned well, test hole, or dry or inadequate boring must submit a decommissioned Well Completion Report to the MassDEP DWP Well Driller Program and should submit a decommissioned Well Completion Report to the owner of the property where the well, test hole, or boring is located. It is recommended that the local Board of Health require that the property owner file a copy of the decommissioned Well Completion Report with the appropriate Registry of Deeds or Land Court as part of the chain-of-title. Another copy of the decommissioned Well Report should be submitted to the Board of Health. It is recommended that the copy submitted to the Board of Health include the Book and Page reference and the name of the Registry of Deeds where the report was filed or, in the case of registered land, the appropriate Land Court reference.

The following information concerning the decomissioning should, when available, be included in the Well Completion Report;

(1) name and address of the property owner

(2) name and certification number of the certified well driller who performed the sealing

(3) reason for abandonment

(4) location of the well, test hole, or boring referenced to location coordinates or decimal degrees

(5) all information known about the well, test hole, or boring including but not limited to:

   a. depth
   b. diameter
   c. type of casing

(6) static water level before sealing

(7) types of sealing material used

(8) quantity of each type of sealing material used

(9) description of the sealing procedure including, but not limited to, notes regarding;

   a. removal of pump and other obstructions
   b. removal of screen
   c. perforation or removal of casing
   d. method used to place plugging material(s)

(10) a copy of the original well driller's report, when available

(11) a copy of the abandonment permit, if a permit is required by the local Board of Health.

Massachusetts Department of Environmental Protection
Bureau of Resource Protection
DECOMMISSIONED WELL REPORT

Note: GPS coordinates must be in WGS84 datum, in degrees decimal degree format.

1. WELL LOCATION GPS (Required) North ___ ___ ° . ___ ___ ___ ___ ___ West ___ ___ ° . ___ ___ ___ ___ ___

Address at Well Location ______ ☐ Property Owner ______

Subdivision/Property Description: ______ ☐ Engineering Firm ______

City/Town ______ In public right-of-way? ☐ Mailing Address ______

Assessors Map ______ Assessors Lot # ______ City/Town ______ State ______

Board of Health permit obtained ☐ Yes ☐ Not Required Permit Number ______ Date Issued ______

2. WELL INFORMATION

Date decommissioned	Depth of decommissioned well
Number of wells decommissioned in group	Area of group (sq. ft)

3. ADDITIONAL INFORMATION (IF AVAILABLE)

Well Type Prior to Decommission ☐ ☐ ☐ ☐ | Original WCR # for Decommissioned Well

Well ended in formation type ☐ Overburden ☐ Bedrock | Was a new well drilled? ☐ Yes ☐ No | WCR # for New Well

DEP 21E Site # | DEP Groundwater Discharge #

4. CASING

Casing Type ☐ ☐ ☐ | Casing Diameter

Was casing left in place? ☐ Yes ☐ No From To | Was casing ripped or perforated? ☐ Yes ☐ No

Were obstructions left in the well? ☐ Yes ☐ No If yes, what type?

5. WATER LEVEL | **6. SURFACE SEAL**

Date Measured | Static Depth BGS (ft) | Flowing Rate (gpm) | ☐ ☐

7. DECOMMISSIONING MATERIAL

From (ft BGS)	To (ft BGS)	Material 1	Weight	Material 2	Weight	Water (gal)	Batches	Method of Placement
		☐ ☐		☐ ☐				☐ ☐
		☐ ☐		☐ ☐				☐ ☐
		☐ ☐		☐ ☐				☐ ☐
		☐ ☐		☐ ☐				☐ ☐

8. COMMENTS

9. WELL DRILLERS STATEMENT

This well was decommissioned under my direct supervision, according to the applicable rules and regulations, and this report is complete and accurate to the best of my knowledge.

Driller ______ Supervising Driller Signature ______ Certification # ☐☐☐☐

Company ______ Date Job Complete ______

NOTE: Well Completion Reports must be filed by the registered well driller within 30 days of well completion.

Figure 21: Well Decommissioning Report

SEALING PROCEDURE

Preparation Prior to Placement of Sealing Materials

The first step in preparing to seal a well is to obtain information regarding the construction of the well. The construction details are critical for determining whether or not an effective well seal was emplaced during well construction. This, in turn, determines whether or not it is necessary to remove or perforate the well casing prior to emplacement of the sealing materials. A copy of the Well Completion Report may be obtained from the well owner or from the MassDEP DWP Well Driller Program, which maintains records dating back to 1965. Information on wells constructed prior to 1965 may be available from the well owner or from the well driller.

The next step is to check the well or boring, from the land surface to the completed depth, for any debris or obstruction which may interfere with effective placement of the sealing materials: wells should be disconnected from the water system and all pumping equipment and associated piping should be removed from the well. In some instances, when pumps cannot be removed, they should be pushed to the bottom of the well if possible, or left in place if it is not possible to push it to the bottom of the well. Explosives, however, should not be used. After the well has been properly sealed, the property owner should have the interior piping physically disconnected between the well and the household distribution system by a licensed plumber.

Once the well or boring has been cleared of obstructions, the static water level should be measured and recorded. It is important to know where the static water level is because certain types of sealing materials should be placed only above the water level in the well or boring. Also the well depth and diameter must be measured in order to calculate the necessary volume of sealing materials.

In order to ensure a proper seal, the volume of grout used to seal the well or boring must equal or exceed the volume of the casing or borehole being sealed. By knowing in advance the minimum volume of grout required to fill the well or hole, it will not be necessary to stop the grouting process in order to prepare more grout. In addition, if the well or boring appears to be filled before the minimum volume of grout has been placed, the contractor knows immediately that the seal is not continuous and is, therefore, inadequate.

The volume of the casing or borehole can be calculated using the cylindrical volume formula, $\pi r^2 h$; where r is the radius of the well or borehole, in feet, and h is the depth. For example, the volume of a well constructed with six-inch diameter casing and a depth of 100 feet can be calculated as follows;

$$\begin{aligned} \text{volume} &= \pi r^2 h \\ &= 3.142 \text{ x } 0.25 \text{ feet x } 0.25 \text{ feet x } 100 \text{ feet} \\ &= 20 \text{ cubic feet} \end{aligned}$$

If neat cement is used as the sealing material, the number of bags of cement needed to fill the well or boring can be calculated using the assumption that a 94 pound bag of cement plus 5 to 6 gallons of water yields 1.1 cubic feet of material. The following formula can be used to calculate the number of bags of cement needed to fill the well or boring;

$$\text{number of bags of cement needed} = \frac{\text{volume of well or borehole (cubic feet)}}{\text{cubic feet of material produced per bag}}$$

For the preceding example,

$$\text{number of bags of cement needed} = \frac{20 \text{ cubic feet}}{1.1 \text{ cubic feet}} = 18 \text{ bags}$$

Due to borehole irregularities, however, it is advisable to have on hand 25-50 % more sealant than the calculated volume. Also, when a borehole or uncased well penetrates cavernous limestone or highly fractured bedrock, it should be kept in mind that grout is often lost to the formation.

Sealing Materials

It should be noted that the U.S. Environmental Protection Agency (1975) and the guidelines and regulations for several states recommend or require an abandoned well to be sealed in a manner that restores, to the extent feasible, the hydrogeologic conditions existing before the well was constructed. Some states, for example, recommend that sand and gravel be placed opposite more permeable subsurface zones and clay be placed opposite less permeable zones. While restoration to preexisting hydrogeologic conditions is an admirable goal, it is, in the opinion of MassDEP, unattainable in practice.

It is recommended that an abandoned well or boring be completely filled with a material that, after curing, has a permeability of less than $1x10^{-7}$ cm/sec. There are a variety of materials which may be used and each has distinct properties which may make one material more appropriate than another for sealing a given well or boring. The selection of the most appropriate material or combination of materials depends primarily on the construction of the well and the geologic and hydrologic nature of the formation or formations penetrated by the well or boring.

For a fluid type grout the material;

(1) should be sufficiently fluid so that it can be applied through a tremie pipe from the bottom of the well upward,

(2) should remain as a homogeneous fluid when applied to the subsurface rather than disaggregating by gravity into a two-phase substance,

(3) should be resistant to chemical or physical deterioration, and

(4) should not leach chemicals, either organic or inorganic, that will adversely affect the quality of the groundwater where it is applied.

For bentonite chips, the sealing material should be capable of being introduced to the well via a tremie pipe or via gravity without bridging.

The following types of materials are acceptable sealing materials. Comments regarding their use are also noted.

(1) **Bentonite** grout is a mixture of bentonite (API Standard 13A) and water in a ratio of not less than one pound of bentonite per gallon of water. Bentonite grout should not be used where it will come in contact with water having a pH below 5.0 or a total dissolved solids concentration greater than 1,000 mg/l, or both.

(2) **Bentonite cement grout** is a mixture of a maximum of 5% sodium bentonite per 94 lb. bag of cement. For each 1% of bentonite, an additional 0.65 gal. of water should be added. 1% to 2% bentonite addition is the preferred amount. Bentonite increases the set volume, reduces shrinkage, decreases density, and decreases the water loss from the cement.

(3) **Bentonite chips** can be used for filling and sealing wells or portions of wells by applying directly into the well through the top at a rate no greater than 3 minutes per bag. When hydrated, bentonite will swell up to 12 to 13 times their dry volume to fill voids, exerting pressure against all surfaces to create a flexible low

permeability seal, and effectively seal the well. If the chips are applied at a rate greater than 3 minutes per bag, bridging can occur within the well and the well will not be filled completely. Since the chips are introduced in a “dry” state, shrinkage cannot occur and there is a reserve expansion capacity. Generally hydration takes 1 to 2 hours.

(4) **Sand cement grout** is a mixture consisting of Portland cement (ASTM Standard C150, Type I or API Standard 10, Class A), sand, and water in the proportion of one part cement to 3 or 4 parts sand, by volume, and not more than 6 gallons of water per bag (94 pounds) of cement. Up to 5%, by weight, of bentonite (API Standard 13A) shall be added to reduce shrinkage.

(5) **Neat cement grout** is a mixture consisting of one bag (94 pounds) of Portland cement (ASTM Standard C150, Type I or API Standard 10, Class A) to not more than six gallons of clean water. Bentonite (API Standard 13A), up to 2% by weight of cement, shall be added to reduce shrinkage. Other additives, as described in ASTM Standard C494, may be used to increase fluidity and/or control setting time. Although one bag of cement to 6 gallons of water produces a very fluid mixture, it sets up like concrete when it hardens. Neat cement grout may be used in all geologic formations and is ideal for sealing small openings, for penetrating annular space outside of casings, and for filling voids in the surrounding formation. When applied under pressure, it is favored for sealing wells under artesian pressure or borings that penetrate more than one aquifer. Unlike many other grouts, neat cement will not separate into a two-phase substance.

(6) **Concrete** is a mixture consisting of Portland cement (ASTM Standard C150, Type I or API Standard 1OA, Class A), sand, gravel, and water in a proportion of not more than 5 parts of sand plus gravel to one part cement, by volume, and not more than 6 gallons of water. One part cement, two parts sand, and three parts gravel are commonly used with up to six gallons of water. When a tremie pipe is used to place the concrete, the gravel size should not be greater than 1/3 the inside diameter of the tremie pipe. Concrete may be used in all geologic formations but should never be used below the static water level in the well or boring. Concrete is generally used where extra strength or bulk are required.

The advantages and disadvantages of bentonite-based grouts and cement-based grouts are summarized below;

(1) Bentonite-Based Grouts:

(a) Advantages

- suitable permeability with high solid grouts
- non-shrinking
- low density
- no curing time required

(b) Disadvantages

- Usage instructions vary with each bentonite product
- difficult mixing
- premature swelling and high viscosity result in difficult pumping
- subject to washout in fractured bedrock
- equipment cleanup difficult
- high density results in loss to formations
- -prompt equipment cleanup essential

(2) Cement-Based Grouts:

(a) Advantages

- suitable for most types of geologic formations
- easily mixed and pumped
- hard, positive seal; sets up like concrete
- properties can be altered with additives
- proven effective over decades of use

(b) Disadvantages

- mix water must contain less than 500 mg/l of total disolved solids
- separation of constituents (can be overcome by using correct proportion of water to cement)
- high density results in loss to formations
- shrinkage (can be overcome by adding bentonite to the cement slurry)
- saline groundwater may cause flash set
- long curing time
- prompt equipment cleanup essential

Placement of Sealing Materials

The sealing materials should be introduced at the bottom of the well or boring and placed progressively upward to a level approximately four feet below the ground surface. An improperly sealed well or boring can be as much of a threat to groundwater quality as an unused open well or boring.

The preferred method of well abandonment is by tremie grouting. Methods of placement that utilize a grout pipe or tremie tube, either with or without a grout pump, are recommended. To avoid breaking the seal, however, it is important to ensure that the discharge end of the grout pipe or tremie tube is submerged in grout at all times during the placement procedure. Although dump bailers are generally not recommended for placing sealing materials, they may be appropriate when sealing a dug well. Regardless of the method of placement used, care should be taken to prevent segregation or dilution of the sealing materials. When neat cement or cement grout is used, it should be placed in one continuous operation. It should be noted that when bentonite based grout is used, it should be capped by at least 6 feet of neat cement terminating 4 feet below the ground surface. The neat cement cap reduces the potential for desiccation cracks in the seal. The entire screened section of a gravel packed well should be pressure grouted so that the seal extends into the gravel pack materials. When it is necessary to use pressure grouting, the pressure should be maintained for the length of time that is necessary for the grout to set.

It should be noted that the entire uncased portion of a bedrock well should be sealed. When zones of lost circulation are encountered such as highly fractured bedrock or cavernous limestone, it is recommended that the grout be pumped until it is certain that it is being lost to the formation. Grouting should then be stopped and the material that has been placed should be allowed to set. Generally, three hours is sufficient time for the grout to set. If grout continues to be lost when placement resumes, 3/8 inch to ½ inch diameter pea gravel may be inserted, judiciously, from the surface while simultaneously inserting grout through the tremie pipe. The pea gravel, which floats on top of the cement, should restrict the flow of grout into the formation enough to permit completion of the sealing operation.

In some cases where the decommissioning of a bedrock well by grouting may negatively impact a nearby well or highly fractured or cavernous zones exist which would make it impractical to grout, it is acceptable to use large diameter fill material such as gravel or pea gravel. When large diameter fill material is used, the borehole should be filled no higher than the bottom of the casing. The casing shall then be filled with a mixture of neat cement and 6% bentonite by weight of which the upper four feet shall be filled with neat cement. The plugging material shall be allowed to flow out and along the sides of the casing to assure that a proper seal is established. The upper 4 feet of soil from the top of the casing to the surface shall be properly compacted.

For wells completed in artesian aquifers, it is important to ensure that the groundwater is confined to the aquifer in which it occurs. In order to prevent surface or subsurface leakage from the artesian zone, it is recommended that the entire zone be pressure grouted using a bentonite or cement based grout. The remainder of the well or boring may be grouted with or without pressure, as warranted by conditions. Flowing artesian wells that are not contained by existing casing should be made static before sealing. For wells in which the hydrostatic pressure producing the flow is relatively low, the well casing may be extended high enough above the artesian pressure surface to stop the flow. For wells in which extension of the casing is not feasible, flow may be restricted by placing an inflatable packer at the bottom of the confining formation immediately above the artesian zone. After the artesian zone has been grouted, the packer should be deflated and removed prior to plugging the remainder of the well. Flow may also be contained by introducing high-specific-gravity fluids at the bottom of the well or boring and filling the hole with fluids until flow ceases. Specific procedures for this method vary with the depth and artesian pressure of the well or boring.

A less preferred alternative method involves pouring bentonite chips into the well. This method should be used with extreme care, and patience to avoid bridging of the bentonite. The smaller the diameter of the well or the deeper the well, the greater the chance for bridging, resulting in inadequate filling of the entire well. If this method is to be used, the information given by the driller in the decommissioning section of the WCR must substantiate that the proper volume was used to completely fill the borehole with bentonite.

Bentonite chips come in two basic ranges (¼" - ⅜" and ½"- ¾" chips). Medium grade (¼" -⅜") chips should be used for 4- inch diameter wells. Bentonite chips should not be used in wells 2 inches or less in diameter, as the chips can too easily bridge in the casing pipe.

When pouring medium- sized bentonite chips, the chips should be poured over a coarse mesh screen (1/4" openings) to allow the fines to drop out before the bentonite reaches the well opening. (These particles swell upon contacting water and can bridge in the upper part of the well.) The rate of pouring should be no greater than one 50-pound bag every three minutes. The level of the sealing material should be measured frequently to confirm bridging has not occurred. The bentonite should be poured into standing water. If insufficient water is in the well to hydrate the chips, water should be added at appropriate intervals during the filling process. No more than 2 or 3 feet of dry bentonite chips should ever be in the well during the filling process. Wetting dry bentonite after the entire well has been filled is not recommended. *(NDSUES, 2011)*

When sealing standard type dug wells, the cover and upper four feet of curbing should be removed before placement of the plugging materials. The curbing may be caved into the well, but only when it is done in a manner that will not prevent any blockage of plugging materials part way down the well. The dug well pit should be filled with clean fill material consisting of clay, silt, sand, gravel, crushed stone or any combination of these materials. A 6-inch concrete grout seal should be placed such that it covers the entire excavated area. It is recommended that a dump bailer be used to place the plugging materials below the water table in a standard type dug well. The remainder of the well, above the water table, may be sealed using either a dump bailer or a tremie pipe. Use of a dump bailer is not recommended, however, for sealing dug wells constructed with a buried slab.

Surface Seal

In order to allow time for settlement of the sealing materials, the contractor should emplace the surface seal no sooner than 6 hours after the well or boring has been sealed. Before the surface seal is formed, the casing remaining in the hole should be cut off at or below ground surface. The remaining 4 feet (2 feet for dug wells) at the top of the well or boring should then be filled with concrete.

Appendix A
Recommended Analytes, Concentration Limits, and Monitoring Frequency

Concentrations are in milligrams per liter (mg/l) or nanograms per liter (ng/l); to convert milligrams per liter (mg/l) to micrograms per liter (ug/l) multiply concentration in mg/l by 1000.

PARAMETER	Recommended Concentration Limit	Recommended Sampling Frequency
Inorganic Compounds		Monitor initially for all compounds and then once every ten years if no detects, or as otherwise determined by the local Board of Health.
Antimony	0.006 mg/l	
Arsenic	0.010 mg/l	
Asbestos	7 million fibers/l	
Barium	2 mg/l	
Beryllium	0.004 mg/l	
Cadmium	0.005 mg/l	
Chromium (total)	0.1 mg/l	
Cyanide (as free cyanide)	0.2 mg/l	
Fluoride	4 mg/l	
Lead (action level)	0.015 mg/l	
Copper (action level)	1.3 mg/l	
Manganese[1]	0.3 mg/l	
Mercury	0.002 mg/l	
Nitrate (N)	10 mg/l	Note: Nitrate and Nitrite should be monitored once every year.
Nitrite (N)	1 mg/l	
Total Nitrate & Nitrite (N)	10 mg/l	
Perchlorate	0.0020 mg/l	
Selenium	0.05 mg/l	
Sodium[2]	20 mg/l[3]	
Thallium	0.002 mg/l	
Turbidity		As determined by the local Board of Health.
Turbidity[4]	1 NTU[5]	

Appendix A Continued on next two pages

[1] EPA has set a lifetime Health Advisory value of 0.3 mg/l for Manganese to protect against concerns of potential neurological effects. This advisory is based on the health risks posed to children under the age of 1 and infants on formula by the ingestion of Maganese.

[2] Sodium guideline is based on an eight (8) ounce serving. This guideline was established to protect persons on sodium restricted diets. If the sodium concentration is above the guideline and a person using the water is on a sodium-restricted diet, that person's physician should be consulted as to whether the water should be consumed.

[3] **ORSG**: Office of Research and Standards Guideline.

[4] See the table and associated footnotes provided by EPA at https://www.epa.gov/ground-water-and-drinking-water/national-primary-drinking-water-regulations for a discussion of the concern for turbidity in drinking water and the recommended concentration limit.

[5] NTU = Nephelometric turbidity unit.

Appendix A Continued:

Parameter	Recommended Concentration Limit	Recommended Sampling Frequency
Synthetic Organic Compounds (SOC)[6]		To reduce cost it is best to perform a monitoring screen initially using analytical method 505 or 508 and then once every ten years if no detects or as specified by the local Board of Health. The recommended monitoring screen won't provide analytical results for all of the SOC listed in Appendix A. Monitoring for the remaining SOC should be considered if contaminants are detected in the monitoring screen. This approach is consistent with what MassDEP requires for SOC monitoring at public water supplies. Owners of wells in agricultural areas are encouraged to conduct more frequent testing. If private well owners decide to request laboratory analysis of all of the SOC listed in Appendix A, MassDEP encourages them to request that the laboratory include analytical results for other synthetic organic compounds that the laboratory may normally include with the analysis of the synthetic organic compounds listed in this table at no additional cost.
Alachlor	0.002 mg/l	
Atrazine	0.003 mg/l	
Benzo(a)pyrene	0.0002 mg/l	
Carbofuran	0.04 mg/l	
Chlordane	0.002 mg/l	
Dalapon	0.2 mg/l	
Di(2-ethylhexyl)adipate	0.4 mg/l	
Di(2-ethylhexyl) phthalate	0.006 mg/l	
Dinoseb	0.007 mg/l	
Diquat[6]	0.02 mg/l	
1,2-Dibromo-3-chloropropane (DBCP)	0.0002 mg/l	
2,4-D (2,4-Dichlorophenoxyacetic acid)	0.07 mg/l	
Endothall	0.1 mg/l	
Endrin	0.002 mg/l	
Ethylene Dibromide (EDB)	0.00002 mg/l	
Glyphosate[6]	0.7 mg/l	
Heptachlor	0.0004 mg/l	
Heptachlor epoxide	0.0002 mg/l	
Hexachlorocyclopentadiene	0.05 mg/l	
Lindane	0.0002 mg/l	
Methoxychlor	0.04 mg/l	
Oxamyl(Vydate)	0.2 mg/l	
Polychlorinated biphenyls (PCBs)	0.0005 mg/l	
Pentachlorophenol	0.001 mg/l	
Picloram	0.5 mg/l	
Simazine	0.004 mg/l	
2,3,7,8-TCDD (Dioxin)	$3x10^{-8}$ mg/l	
Toxaphene	0.003 mg/l	
2,4,5-TP (Silvex)	0.05 mg/l	

[6] The SOC monitoring requirements for public water supply wells typically only involve screening by analytical method 505 or 508. The screening analysis does not test for all SOC listed in this table.

Appendix A Continued:

Parameter	Recommended Concentration Limit	Recommended Sampling Frequency
Bacteria		
Total Coliform Bacteria	Positive sample	Monitor once every year, or as otherwise specified by the local Board of Health.
Enterococci	Positive sample	
Cryptosporidium	Positive sample	Initial monitoring for *Cryptosporidium* and *Giardia lamblia* is only recommended if the source is surface water (e.g. spring) or a well located within 100 feet of a surface water body or is prone to flooding. It is recommended that additional monitoring occur after any flooding event in which the flood waters reach the well location, or as otherwise specified by the local Board of Health.
Giardia lamblia	Positive sample	
Radionuclides		Monitor for radionuclides initially in wells completed in granite formations or in areas known to have high radionuclide levels and determine future sampling frequency based upon the results. If the gross alpha result is greater than 15 pCi/l then uranium testing should be performed. If the gross alpha result is greater than 5 pCi/l then Radium-226 and Radium-228 testing should be performed.
Gross Alpha Activity	15 pCi/l	
Radium –226 & 228	5 pCi/l	
Uranium	0.03 mg/l	
Volatile Organic Compounds (VOC)		Monitor initially for VOC and then once every 10 years if no detects, or as otherwise determined by the local Board of Health. Owners of wells in industrial or densely developed residential areas are encouraged to conduct more frequent testing. MassDEP encourages private well owners to request that the laboratory include analytical results for other volatile organic compounds that the laboratory may normally include with the analysis of the volatile organic compounds listed in this table at no additional cost.
Benzene	0.005 mg/l	
Carbon Tetrachloride	0.005 mg/l	
Dichloromethane (methylene chloride)	0.005 mg/l	
1,2-Dichlorobenzene (o-DCB)	0.6 mg/l	
1,4-Dichlorobenzene (p-DCB)	0.005 mg/l	
1,2-Dichloroethane	0.005 mg/l	
1,2-Dichloroethylene (cis)	0.07 mg/l	
1,2-Dichloroethylene (trans)	0.1 mg/l	
1,1-Dichloroethylene	0.007 mg/l	
1,2-Dichloropropane	0.005 mg/l	
Ethylbenzene	0.7 mg/l	
Methyl Tertiary Butyl Ether (MTBE)	0.07 mg/l[7]	
Monochlorobenzene (chlorobenzene)	0.1 mg/l	
Styrene	0.1 mg/l	
Tetrachloroethylene (PCE)	0.005 mg/l	
Toluene	1 mg/l	
Trichloroethylene (TCE)	0.005 mg/l	
1,1,1-Trichloroethane (1,1,1-TCA)	0.2 mg/l	
1,2,4-Trichlorobenzene	0.07 mg/l	
1,1,2-Trichloroethane	0.005 mg/l	
Vinyl Chloride (VC)	0.002 mg/l	
Xylenes (total)	10 mg/l	

Appendix A Continued:

Parameter	Recommended Concentration Limit	Recommended Sampling Frequency
Per- and polyfluoroalkyl substances (PFAS)		Monitor initially for PFAS and then once every 10 years if no detects, or as otherwise determined by the local Board of Health. Owners of wells in industrial or densely developed residential areas are encouraged to conduct more frequent testing. MassDEP encourages private well owners to request that the laboratory include analytical results for other PFAS chemicals that the laboratory may normally include with the analysis of the PFAS chemicals listed in this table at no additional cost.
perfluorooctane sulfonic acid (PFOS)	4.0 ng/l	
perfluorooctanoic acid (PFOA)	4.0 ng/l	
perfluorohexane sulfonic acid (PFHxS)	10 ng/l	
perfluorononanoic acid (PFNA)	10 ng/l	
perfluoroheptanoic acid (PFHpA)	20 ng/l	
perfluorodecanoic acid (PFDA)	20 ng/l	
PFAS6 (total of all six of the above PFAS substances	20 ng/l	
HFPO-DA (commonly known as Gen X chemicals)	10 ng/l	
Mixures of two or more of the following: PFHxS, PFNA, HFPO-DA, and PFBS*	EPA Hazard Index of 1 **	

*"PFBS" means Perfluorobutane sulfonate
**Information on how to calculate EPA Hazard Index for PFAS can be found here:
https://www.epa.gov/system/files/documents/2024-04/pfas-npdwr_fact-sheet_hazard-index_4.8.24.pdf

Appendix B
Land Use/Associated Contaminants Matrix

This matrix links land use activities to potential contaminants of concern in drinking water that have MassDEP ORS Standards or Guidelines. Owners of wells in commercial or agricultural areas are encouraged to conduct more frequent sampling. If any of these land uses are (or were) present in proximity to the drinking water well, then testing for the chemicals associated with these activities in this matrix should be considered. The abbreviations in **Bold** represent the types of contaminants associated with the land use activity.

MIC = Microbial organisms
SURF = Surfactants
RAD = Radionuclides
VOC = Volatile organic compounds
IOC = Inorganic compounds
SOC = Synthetic organic compounds
PFAS = Per- and polyfluoroalkyl substances

Many of the contaminants associated with agricultural uses are SOCs used in pesticides, which are expensive to test for. To reduce costs, it is best to perform a monitoring screen initially using EPA analytical methods 505 or 508. These screening methods do not provide analytical results for all of the SOCs listed in Appendix A. Monitoring for the remaining SOCs should be considered if contaminants are detected in the screening.

In the following table, references to PFAS indicate that one or more of the following PFAS chemicals is potentially related to the activity: perfluorooctane sulfonic acid (PFOS), perfluorooctanoic acid (PFOA), perfluorohexane sulfonic acid (PFHxS). perfluorononanoic acid (PFNA), perfluoroheptanoic acid (PFHpA), perfluorodecanoic acid (PFDA), HFPO-DA (commonly known as PFAS GenX Chemicals), and Perfluorobutane sulfonic acid (PFBS).

ACTIVITIES	Potential Contaminants of Concern*		
AGRICULTURAL			
Livestock Operation	**MIC/IOC**	nitrite	nitrate
Dairy Farms	**MIC/IOC** nitrate nitrite	lindane methoxychlor 2,4-D	glyphosate
Fertilizer Storage or Use	**IOC/PFAS** cyanide	nitrate nitrite	Fluoride PFAS
Forestry Operations	**VOC** turbidity benzene	toluene ethylbenzene xylene	naphthalene lindane
Manure Spreading or Storage	**MIC/IOC**	nitrate	nitrite
Land Application of Sludge from Wastewater Treatment Plants	**VOC/IOC/MIC/PFAS** nitrite nitrate arsenic barium cadmium	chromium cyanide lead copper mercury selenium	silver zinc sulfate 1,2,3 trichlorobenzene PFAS
Nurseries	**SOC**	methoxychlor	

Pesticide/Herbicide Storage or Use	**SOC/IOC/PFAS** alachlor aldicarb aldicarb sulfoxide aldicarb sulfone atrazine carbofuran 2,4 -D lindane methoxychlor diquat	glyphosate hexachlorobenzene hexachlorocyclopentadiene oxamyl picloram simazine metolachlor dalapon DBCP Endrin EDB dinoseb	1,3 dichloropropene dichlorobenzenes bromomethane selenium arsenic copper toxaphene 2,4,5-TP Heptachlor PCP Chlordane PFAS
Slaughterhouses	**MIC/IOC** nitrate	nitrite	arsenic

COMMERCIAL	Contaminants of Concern		
Airports	**VOC/SOC/IOC/PFAS** PFAS benzene toluene ethylbenzene xylene naphthalene acetone MEK MIBK MTBE	2,4-D 2,4,5-TP dalapon diquat glyphopsate carbon tetrachloride o-dichlorobenzene 1,2 DCE chlorobenzene 1,1,1 TCA	1,1 DCA 1,2 DCA PCE TCE methoxychlor heptachloroepoxide cadmium mercury beryllium nickel 1,4 dioxane
Auto Repair Shops	**VOC/IOC/SOC/PFAS** benzene toluene ethylbenzene xylene naphthalene acetone MEK MIBK MTBE EDB	arsenic barium cadmium chromium lead mercury zinc PCBs o-dichlorobenzene 1,2 dichloropropane chlorobenzene	tetrachloroethylene 1,1,1 TCA TCE 1,1 DCA 1,2 DCA 1,2,3 trichlorobenzene benzo(a)pyrene dichlorodifluoromethane fluorine 1,4 dioxane PFAS
Boat Yards/Builders	**VOC/SOC/IOC** toluene benzene ethylbenzene xylene naphthalene acetone MEK MIBK MTBE EDB	arsenic barium cadmium chromium lead mercury zinc PCBs o-dichlorobenzene 1,2 dichloropropane chlorobenzene	tetrachloroethylene 1,1,1 TCA TCE 1,1 DCA 1,2 DCA 1,2 trichlorobenzene benzo(a)pyrene dichlorodifluoromethane fluorine 1,4 dioxane

Bus and Truck Terminals	**VOC/SOC/IOC** toluene benzene ethylbenzene xylene naphthalene acetone MEK MIBK MTBE EDB	arsenic barium cadmium chromium lead mercury zinc PCBs o-dichlorobenzene 1,2 dichloropropane chlorobenzene	tetrachloroethylene 1,1,1 TCA TCE 1,1 DCA 1,2 DCA 1,2,3 trichlorobenzene benzo(a)pyrene dichlorodifluoromethane fluorene 1,3 dichloropropane 1,4 dioxane
Car Washes	**SURF/VOC/SOC/PFAS** toluene benzene	ethylbenzene xylene naphthalene	EDB MTBE sodium PFAS
Cemeteries	**SOC/IOC** arsenic atrazine 2,4-D	methoxychlor glyphosate simazine picloram	pentachlorophenol nitrate nitrite
Dry Cleaners	**VOC** PCE	TCE 1,2 dichloropropane	1,1,1 TCA 1,4 dioxane
Funeral Homes	**VOC**	pentachlorophenol	chloroform
Furniture Stripping and Refinishing	**VOC/IOC/PFAS** benzene chlorobenzene o-dichlorobenzene 1,2 DCA 1,1 DCA 1,2 DCE 1,1 DCE 1,2 dichloropropane	1,1,1 TCA TCE toluene xylene carbon tetrachloride MEK MIBK acetone pentachlorophenol	antimony barium cadmium mercury lead zinc chromium ethylbenzene 1,4 dioxane PFAS
Gas/Service Stations	**VOC/SOC/IOC/PFAS** toluene benzene ethylbenzene xylene naphthalene acetone MEK MIBK MTBE EDB	arsenic barium cadmium chromium lead mercury zinc PCBs o-dichlorobenzene 1,2 dichloropropane chlorobenzene	tetrachloroethylene 1,1,1 TCA TCE 1,1 DCA 1,2 DCA 1, 2,3 trichlorobenzene benzo(a)pyrene dichlorodifluoromethane fluorine 1,4 dioxane PFAS
Golf Courses	**SOC/IOC/PFAS** atrazine 2,4-D methoxychlor glyphosate	simazine picloram nitrate nitrite arsenic	cadmium mercury cyanide PFAS

Junk Yards and Salvage Yards	**VOC/SOC/IOC** benzene toluene ethylbenzene xylene naphthalene acetone MEK MIBK MTBE EDB	arsenic barium cadmium chromium lead mercury zinc PCBs o-dichlorobenzene 1,2 dichloropropane chlorobenzene	tetrachloroethylene 1,1,1 TCA TCE 1,1 DCA 1,2 DCA 1,2,3 trichlorobenzene benzo(a)pyrene dichlorodifluoromethane fluorine 1,4 dioxane
Laundromats	**MIC/SURF/VOC/PFAS** PFAS xylene	carbon tetrachloride benzene	TCE 1,1,1 TCA 1,4 dioxane
Medical Facilities	**MIC/RAD/IOC/VOC** legionella arsenic benzene bromoform chloroform chromium 1,1 DCA mercury selenium	silver toluene TCE zinc pentachlorophenol 1,1 dichlorobenzene p-dichlorobenzene styrene thallium acetone	1,2 DCE dichlorodifluoromethane epichlorohydrin 1,3 dichloropropane radium iodine manganese MTBE
Nursing Homes	**MIC**	*legionella*	
Paint Shops	**VOC/IOC/SOC/PFAS** acetone benzene chlorobenzene o-dichlorobenzene 1,2 DCA 1,1 DCA 1,2 DCE 1,1 DCE 1,2 dichloropropane 1,1,1 TCA	TCE toluene xylene carbon tetrachloride MEK MIBK pentachlorophenol antimony barium cadmium	mercury lead zinc chromium PCE ethylbenzene cyanide di(2-ethylhexyl) phthalate hexylphthalate 1,4 dioxane PFAS
Photo Processors	**VOC/IOC/SOC/PFAS** cyanide	cadmium silver	Selenium PFAS
Printer and Blueprint Shops	**VOC/IOC/PFAS** barium cadmium chromium cobalt lead selenium MEK MIBK	silver TCE PCE ethylbenzene antimony cyanide xylene 1,1,1 TCA 1,1,2 TCA	benzene toluene acetone naphthalene ethylbenzene nitrate zinc 1,4 dioxane PFAS

Railroad Tracks and Yards	**VOC/SOC/IOC/PFAS** 2,4-D glyphosate picloram diquat ethylbenzene xylene naphthalene acetone MEK MIBK	MTBE EDB arsenic barium cadmium chromium lead mercury zinc PCBs o-dichlorobenzene 1,2 dichloropropane	chlorobenzene tetrachloroethylene 1,1,1 TCA TCE 1,1 DCA 1,2 DCA 1,2,3 trichlorobenzene benzo(a)pyrene dichlorodifluoromethane fluorine 1,4 dioxane PFAS
Repair Shops (Small Engine, Appliances, etc.)	**VOC** benzene carbon tetrachloride o-dichlorobenzene 1,2 dichloropropane chlorobenzene	1,1,1 TCA TCE toluene 1,1 DCA 1,2 DCA dichlorodifluoromethane	acetone naphthalene mercury thallium antimony 1,2,4 trichlorobenzene 1,4 dioxane
Research Laboratories	**VOC/SOC/ MIC/RAD/IOC** silver acetone thallium selenium	arsenic benzene 1,1 DCA styrene toluene TCE	pentachlorophenol dichlorodifluoromethane uranium manganese
Rust Proofers	**VOC/IOC**	zinc	
Sand and Gravel Mining/Washing	**VOC** benzene	toluene ethylbenzene	xylene naphthalene

INDUSTRIAL	Contaminants of Concern		
Asphalt, Coal Tar, and Concrete Plants	**VOC/SOC/PFAS** TCE 1,1,1 TCA 1,2 DCE chloroform	MEK toluene ethylbenzene xylene naphthalene	benzo(a)pyrene dichlorodifluoromethane fluorene sulfate 1,4 dioxane PFAS
Glass and Ceramics Manufacturing	**IOC/PFAS** lead	aluminum zinc	PFAS

Chemical Manufacture or Storage	**VOC/SOC/IOC/PFAS** benzene toluene xylene TCE hexachlorobenzene dioxin o-dichlorobenzene 1,2 DCA 1,1 DCA 1,2 DCE 1,2 dichloropropane ethylbenzene PCE vinyl chloride mercury acetone silver 1,1,2 TCA chromium sodium	MEK MIBK naphthalene nickel nitrate chlorobenzene MTBE antimony barium chromium lead tert butylbenzene sec butylbenzene 1,2,3 trichlorobenzene p-dichlorobenzene 1,3 dichloropropene chlorobenzene acrylamide epichlorohydrin hexachloropentadiene di(2-ethylhexyl)phthalate	bromodichloromethane dibromomethane 1,1,1 TCA toluene nitrate antimony barium nickel alumimum chromium nickel zinc cyanide styrene bis 2 chloroethylether p-chloroaniline methyl mercury sodium 1,4 dioxane PFAS
Electronics Manufacture	**VOC/IOC/SOC/PFAS** carbon tetrachloride TCE PCE arsenic mercury antimony beryllium thallium	acetone MEK toluene xylene styrene lead barium arsenic silver	selenium zinc nickel cyanide chromium cadmium nitrate di(2-ethylhexyl)phthalate PFAS
Electroplaters	**VOC/IOC/PFAS** carbon tetrachloride 1,2 dichloropropane chlorobenzene PCE	1,1,1 TCA TCE o-dichlorobenzene 1,1 DCA 1,2 DCA	cadmium chromium cyanide nickel 1,4 dioxane PFAS
Food Processors	**MIC/IOC** nitrate nickel	barium xylene zinc	bromomethane
Foundries or Metal Fabricators	**VOC/IOC/SOC/PFAS** carbon tetrachloride 1,2 DCA 1,1 DCA 1,2 dichloropropane chlorobenzene PCE 1,1,1 TCA 1,1,2,2 TCA naphthalene arsenic cadmium chromium	antimony cyanide selenium nickel antimony zinc barium silver lead acetone TCE toluene MEK MIBK	xylene ethylbenzene nitrate hexachlorobenzene di(2-ethylhexyl)phthalate styrene sodium manganese aluminum o-dichlorobenzene 1,1,2 TCA pyridine 1,4 dioxane PFAS

Fuel Oil Distributors	**VOC/SOC/IOC** fluorene benzo(a)pyrene naphthalene benzene xylene ethylbenzene	toluene arsenic cadmium chromium lead nickel	zinc MTBE MIBK MEK TCE 111 TCA PCE
Gasification Plants (Oil or Coal)	**VOC/SOC/IOC** benzo(a)pyrene naphthalene barium cadmium chromium	nitrate selenium antimony cyanide nickel benzo(g,h,i)perylene	fluorothene fluorene sulfate zinc
Hazardous Waste Storage, Treatment and Recycling	**VOC/SOC/IOC/PFAS** PCBs pentachlorophenol hexachlorobenzene benzene carbon tetrachloride o-dichlorobenzene p-dichlorobenzene 1,2 DCA 1,1 DCA 1,2 DCE 1,1 DCE 1, 2 dichloropropane ethylbenzene chlorobenzene styrene	PCE 1,1,1 TCA TCE toluene vinyl chloride xylene naphthalene asbestos arsenic barium cadmium chromium mercury selenium antimony beryllium cyanide	nickel thallium lead acetone di(2-ethylhexyl)phthalate fluorene MEK MIBK silver 1,2,4 trichlorobenzene 1,1,2 trichloroethane zinc p-chlorotoluene 1,2,3 trichlorobenzene n-butyl benzene 1,4 dioxane PFAS
Industrial Lagoons and Pits	**VOC/SOC/IOC/PFAS** PCBs pentachlorophenol hexachlorobenzene benzene carbon tetrachloride o-dichlorobenzene p-dichlorobenzene 1,2 DCA 1,1 DCA 1,2 DCE 1,1 DCE 1,2 dichloropropane ethylbenzene chlorobenzene	styrene PCE 111TCA TCE toluene vinyl chloride xylene naphthalene asbestos asenic barium cadmium chromium mercury selenium	antimony beryllium cyanide nickel thallium lead acetone di(2-ethylhexyl)phthalate fluorene MEK MIBK silver 1,2,4 trichlorobenzene 1,1,2 trichloroethane zinc PFAS

Industrial Parks	**VOC/SOC/IOC/PFAS** PCBs pentachlorophenol hexachlorobenzene benzene carbon tetrachloride o-dichlorobenzene p-dichlorobenzene 1,2 DCA 1,1 DCA 1,2 DCE 1,1 DCE 1,2 dichloropropane ethylbenzene chlorobenzene styrene PCE 1,1,1 TCA	TCE toluene vinyl chloride xylene naphthalene asbestos asenic barium cadmium chromium mercury selenium antimony beryllium cyanide nickel thallium	lead acetone di(2-ethylhexyl)phthalate fluorene MEK MIBK silver 1,2,4 trichlorobenzene 1,1,2 trichloroethane zinc nitrate aluminum acrylamide 1,3 dichloropropane epichlorohydrin aluminum 1,4 dioxane PFAS
Jewelry or Metalplating	**VOC/IOC/PFAS** carbon tetrachloride 1,2 dichloropropane chlorobenzene PCE 1,1,1-TCA TCE o-dichlorobenzene 1,1 DCA 1,2 DCA	cadmium chromium cyanide nickel barium aluminum lead silver zinc nitrate	toluene xylene MEK MIBK acetone ethylbenzene o-dichlorobenzene 1,1,2 TCA Pyridine 1,4 dioxane PFAS
Machine/ Metalworking Shops	**VOC/IOC/PFAS** carbon tetrachloride 1,2 DCA 1,1 DCA 1,2 dichloropropane chlorobenzene PCE 1,1,1 TCA naphthalene arsenic cadmium	chromium antimony cyanide selenium nickel silver barium lead zinc nitrate styrene ethylbenzene	MEK MIBK toluene acetone PCE TCE xylene o-dichlorobenzene 1,1,2 TCA Pyridine 1,4 dioxane PFAS

Metal and Drum Cleaning/Reconditioning	**VOC/SOC/IOC/PFAS** PCBs pentachlorophenol hexachlorobenzene benzene carbon tetrachloride o-dichlorobenzene p-dichlorobenzene 1,2 DCA 1,1 DCA 1,2 DCE 1,1 DCE 1,2 dichloropropane ethylbenzene chlorobenzene	styrene PCE 1,1,1 TCA TCE toluene vinyl chloride xylene naphthalene asbestos asenic barium cadmium chromium mercury selenium antimony	beryllium cyanide nickel thallium lead acetone di(2-ethylhexyl)phthalate fluorene MEK MIBK silver 1,2,4 trichlorobenzene 1,1,2 trichloroethane zinc 1,4 dioxane PFAS
Nuclear Power Plants	**MIC/RAD/IOC** radium 226 radium 228	radium 222 Gross Beta Gross Alpha	cadmium uranium beryllium
Paper Manufacture	**VOC/IOC/PFAS** aluminum antimony	zinc MEK xylene	Toluene PFAS
Pharmaceutical Manufacture	**VOC/SOC** dichlorodifluoromethane	1,3 dichloropropan manganese	
Plastic Manufacture	**VOC/SOC/IOC/PFAS** aluminum antimony barium epichlorohydrin ethylbenzene lead MEK	MIBK nitrate styrene toluene xylene zinc PCE TCE	cyanide nickel chromium cadmium silver acetone PFAS
RCRA TSDF Facilities	**VOC/SOC/IOC/PFAS** PCBs pentachlorophenol hexachlorobenzene benzene carbon tetrachloride o-dichlorobenzene p-dichlorobenzene 1,2 DCA 1,1 DCA 1,2 DCE 1,1 DCE 1,2 dichloropropane ethylbenzene chlorobenzene	styrene PCE 1,1,1 TCA TCE toluene vinyl chloride xylene naphthalene asbestos asenic barium cadmium chromium mercury selenium antimony	beryllium cyanide nickel thallium lead acetone di(2-ethylhexyl)phthalate fluorene MEK MIBK silver 1,2, 4 trichlorobenzene 1, 1, 2 trichloroethane zinc 1,4 dioxane PFAS
Tanneries	**VOC/IOC/SOC/PFAS** benzene o-dichlorobenzene p-dichlorobenzene toluene	naphthalene arsenic chromium di(2-ethylhexyl)phthalate zinc	pentachlorophenol cyanide cadmium PFAS

Textile Manufacture	**VOC/IOC/PFAS** antimony chromium barium	lead zinc xylene MIBK	TCE MEK Toluene PFAS
Wood Preserving Facilities	**SOC/IOC** pentachlorophenol aldrin	naphthalene cadmium arsenic	chromium

RESIDENTIAL	Contaminants of Concern		
Fuel Oil Storage	**VOC/SOC/IOC** fluorene benzo(a)pyrene naphthalene benzene	ethylbenzene xylene toluene arsenic cadmium chromium	lead nickel zinc MTBE MIBK
Lawn Care	**SOC/IOC/PFAS** atrazine 2,4 -D	methoxychlor glyphosphate arsenic	Mercury PFAS
Septic Systems/Cesspools	**MIC/VOC/IOC/PFAS** nitrate nitrite benzene toluene xylene ethylbenzene MTBE	TCE acetone fluoride sulfate 1,1,1 TCA PCE carbon tetrachloride MEK	MIBK styrene p-dichlorobenzene naphthalene cyanide silver 1,4 dioxane PFAS

MISCELLANEOUS	Contaminants of Concern		
Aboveground Storage Tanks	**VOC/SOC/IOC** fluorene benzo(a)pyrene naphthalene benzene ethylbenzene	xylene toluene arsenic cadmium chromium lead	nickel zinc MTBE MIBK
Aquatic Wildlife	**MIC**		

Clandestine Dumping	**VOC/SOC/IOC/PFAS** PCBs pentachlorophenol hexachlorobenzene benzene carbon tetrachloride o-dichlorobenzene p-dichlorobenzene 1,2 DCA 1,1 DCA 1,2 DCE 1,1 DCE 1,2 dichloropropane ethylbenzene chlorobenzene	styrene PCE 1,1,1 TCA TCE toluene vinyl chloride xylene naphthalene PFAS asbestos arsenic barium cadmium chromium mercury selenium	antimony beryllium cyanide nickel thallium lead acetone di(2-ethylhexyl)phthalate fluorene MEK MIBK silver 1,2,4 trichlorobenzene 1,1,2 trichloroethane zinc 1,4 dioxane
Combined Sewer Outfalls	**MIC/IOC/SOC/VOC/PFAS** nitrate nitrite TCE benzene toluene ethylbenzene	xylene MTBE benzo(a)pyrene naphthalene dichlorodifluoromethane arsenic barium cadmium	chromium cyanide selenium silver mercury lead fluorene PFAS
Composting Facilities	**MIC/IOC/PFAS** PFAS	nitrate	nitrite
Dredge Disposal Facilities	**IOC** arsenic cadmium chromium	copper lead mercury nickel	PCBs zinc
Fire Training Facilities	**VOC/IOC/SOC/PFAS** toluene ethylbenzene xylene benzene naphthalene acetone MEK MIBK MBTE EDB arsenic	barium cadmium chromium lead mercury zinc PCBs o-diclorobenzene 1,2 dichloropropane chlorobenzene tetrachloroethylene 1,1,1 TCA	TCE PCE 1,1 DCA 1,2 DCA 1,2, 3 trichlorobenzene benzo(a)pyrene fluorene chromodibromomethane bromodichloromethane dichlorodifluoromethane 1,4 dioxane PFAS
Fishing/Boating	**VOC/MIC** benzene toluene	xylene ethylbenzene beryllium	MEK MIBK
Landfills and Dumps	**VOC/SOC/IOC/PFAS** styrene nitrate sulfate arsenic barium cadmium chromium cyanide	lead mercury selenium silver TCE carbon tetrachloride 1,1 DCE 1,2 DCE chlorobenzene	1,4 dichlorobenzene MEK MIBK hexachlorobenzene benzene dichlorodifluoromethane PCBs PFAS

Land Application of Sewage Sludge	**IOC/SOC/PFAS** cadmium chromium barium arsenic	lead mercury silver selenium endrin	lindane methoxychlor toxaphene PCBs PFAS
Large Quantity Hazardous Waste Generator	**VOC/SOC/IOC/PFAS** PCBs pentachlorophenol hexachlorobenzene benzene carbon tetrachloride o-dichlorobenzene p-dichlorobenzene 1,2 DCA 1,1 DCA 1,2 DCE 1,1 DCE 1,2 dichloropropane ethylbenzene chlorobenzene styrene PCE 1,4 dioxane	1,1,1 TCA TCE toluene vinyl chloride xylene naphthalene asbestos asenic barium cadmium chromium mercury selenium antimony beryllium cyanide nickel	thallium lead acetone di(2-ethylhexyl)phthalate fluorene MEK MIBK silver 1,2,4 trichlorobenzene 1,1,2 trichloroethane zinc nitrate aluminum acrylamide 1,3 dichloropropane epichlorohydrin aluminum PFAS
Military Facilities	**VOC/SOC/IOC/PFAS** PCBs benzene ethylbenzene TCE PCE 1,1,1 TCA toluene xylene	EDB naphthalene beryllium MEK MTBE MIBK RDX cyanide selenium antimony	acetone zinc lead cadmium chromium barium arsenic alumimum di(2-ethylhexyl)phthalate 1,4 dioxane PFAS
NPDES Locations	**MIC/IOC/VOC/PFAS** nitrate nitrite TCE benzene toluene ethylbenzene xylene	MTBE benzo(a)pyrene naphthalene dichlorodifluoromethane arsenic barium silver cadmium	chromium cyanide mercury lead selenium sulfate fluorene PFAS
Pipelines (Oil and Sewer)	**VOC/SOC/IOC/PFAS** fluorene benzo(a)pyrene naphthalene benzene xylene ethylbenzene	toluene arsenic cadmium chromium lead nickel dioxane zinc	MTBE MIBK MEK TCE 1,1,1 TCA PCE PFAS
Prisons	**MIC/VOC** benzene carbon tetrachloride 1,1 DCE ethyl benzene	1,1,1 TCA toluene xylene TCE 1,1 DCA	1,2 DCA naphthalene acetone MEK MIBK 1,4 dioxane

Road and Maintenance Depots	**VOC/IOC/SOC** benzene toluene ethylbenzene xylene naphthalene acetone MEK MIBK MTBE EDB	arsenic barium cadmium chromium lead mercury zinc PCBs o-dichlorobenzene 1,2 dichloropropane monochlorobenzene	tetrachloroethylene 1,1,1 TCA TCE 1,1 DCA 1,2 DCA 1,2,3 trichlorobenzene benzo(a)pyrene dichlorodifluoromethane fluorine 1,4 dioxane
Schools, Colleges and Universities	**VOC/IOC/SOC** benzene toluene ethylbenzene xylene naphthalene acetone MEK MIBK MTBE EDB arsenic barium	cadmium chromium lead mercury zinc PCBs o-dichlorobenzene 1,2 dichloropropane chlorobenzene tetrachloroethylene 1,1,1 TCA TCE 1,1 DCA	1,2 DCA 1,2 trichlorobenzene benzo(a)pyrene dichlorodifluoromethane fluorene silver thallium selenium manganese uranium styrene pentachlorophenol cyanide 1,4 dioxane
Small Quantity Hazardous Waste Generator	**VOC/IOC/SOC/PFAS** benzene toluene ethylbenzene xylene naphthalene acetone MEK MIBK MTBE EDB arsenic	barium cadmium chromium lead mercury zinc PCBs o-dichlorobenzene 1,2 dichloropropane chlorobenzene tetrachloroethylene 1,1,1 TCA	TCE 1,1 DCA 1,2 DCA 1,2,3 trichlorobenzene benzo(a)pyrene dichlorodifluoromethane fluorene carbon tetrachloride thallium antimony 1,2,4 trichlorobenzene 1,4 dioxane PFAS
Snow Dumps	**IOC/VOC** sodium	benzene toluene	xylene ethylbenzene
Stormwater Drains/ Retention Basins	**MIC/IOC/VOC/SOC** nitrate nitrite TCE benzene toluene ethylbenzene	xylene MTBE benzo(a)pyrene naphthalene dichlorodifluoromethane arsenic barium	cadmium chromium mercury lead fluorene
Tire Dumps	**VOC/SOC** benzene toluene	ethylbenzene xylene naphthalene	benzo(a)pyrene fluorine
Transmission Line Right-of-Ways	**SOC**	glyphosate	picloram

Transportation Corridors	**VOC/IOC/SOC** glyphosate picloram benzene	toluene ethylbenzene xylene naphthalene	benzo(a)pyrene fluorene
Underground Storage Tanks	**VOC/SOC/IOC** fluorene benzo(a)pyrene naphthalene benzene xylene	ethylbenzene toluene arsenic cadmium chromium	lead nickel zinc MTBE MIBK
Utility Substation Transformers	**VOC** PCBs	1,2,3 trichlorobenzene 1,1 biphenyl	1,2,4 trichlorobenzene
Very Small Quantity Generators	**VOC/IOC/SOC/PFAS** benzene toluene ethylbenzene xylene naphthalene acetone MEK MIBK MTBE EDB arsenic	barium cadmium chromium lead mercury zinc PCBs o-dichlorobenzene 1,2 dichloropropane chlorobenzene tetrachloroethylene 1,1,1 TCA	TCE 1,1 DCA 1,2 DCA 1,2,3 trichlorobenzene benzo(a)pyrene dichlorodifluoromethane fluorene carbon tetrachloride thallium antimony 1,2,4 trichlorobenzene 1,4 dioxane PFAS
Waste Incinerators	**SOC/PFAS**	cyanide	PFAS
Waste Transfer Stations	**VOC/IOC/PFAS** styrene nitrate sulfate arsenic barium cadmium	chromium cyanide lead mercury silver TCE carbon tetrachloride	1,1 DCE 1,2 DCE chlorobenzene MEK MIBK benzene PFAS
Wastewater Treatment Plants	**VOC/IOC/MIC/PFAS** nitrite nitrate arsenic barium cadmium	chromium cyanide lead copper mercury selenium	silver zinc sulfate 1,2,3 trichlorobenzene PFAS
Water Treatment Sludge Lagoons	**IOC** manganese	aluminum arsenic	radon

- MassDEP ORS Standards or Guidelines for these contaminants in MA drinking waters can be found at: https://www.mass.gov/guides/drinking-water-standards-and-guidelines

Appendix C

Other Board of Health Responsibilities Related to Drinking Water

BOHs might find the following information useful:

- Annual Notice to Local Boards of Health: https://www.mass.gov/lists/drinking-water-information-for-boards-of-health
- MassDEP Board of Health webpage: https://www.mass.gov/drinking-water-health-safety
- Boil orders and other public health orders: https://www.mass.gov/service-details/consumer-information-on-boil-orders
- Certified Labs: https://www.mass.gov/certified-laboratories
- Certified Well Drillers: https://www.mass.gov/well-driller-program
- Cross Connections: https://www.mass.gov/files/documents/2016/08/nl/cccpman.pdf
- Drinking water regulations (310 CMR 22.00): https://www.mass.gov/regulations/310-CMR-22-the-massachusetts-drinking-water-regulations
- Floor drains: https://www.mass.gov/files/documents/2016/08/om/fdrmod.pdf
- Information for Local Boards of Health on Home Burials and Green Burials: https://www.mass.gov/info-details/information-for-local-boards-of-health-on-home-burials-and-green-burials
- Lead Reduction Act: http://www.gpo.gov/fdsys/pkg/BILLS-111s3874enr/pdf/BILLS-111s3874enr.pdf
- Lead and copper in school drinking water can be found on the MassDEP Lead in Drinking Water web page: https://www.mass.gov/lead-in-drinking-water
- List of certified operators: https://www.mass.gov/info-details/certified-operator-directory
- Local Fairs: https://www.mass.gov/doc/drinking-water-at-local-fairs/download
- Private well guidelines: https://www.mass.gov/service-details/private-well-guidelines
- PWS contact information (city/town, PWS name, PWS ID #, location and mailing address, contact person name, phone and fax #) is available on the Water Supplier Operations web page under the section "Reporting and Public Notification": https://www.mass.gov/water-supplier-operations
- Small Systems guidance: https://www.mass.gov/files/documents/2016/08/qp/tncguide.pdf
- UIC: https://www.mass.gov/underground-injection-control-uic
- Vending machines: https://www.mass.gov/service-details/approval-of-water-vending-machines-by-massdep-and-dph
- Well Completion Reports: https://www.mass.gov/service-details/well-database
- How to contact MassDEP offices: https://www.mass.gov/info-details/massdep-employee-directory-and-topical-contacts

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Central	627 Main St.; Worcester, MA 01608	508-792-7650

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GLOSSARY

Unless the context or subject matter requires otherwise, the following words and phrases shall, for the purposes of this document, have the meanings specified in this section.

Words and phrases used in the present tense include the future; words and phrases used in the masculine gender include the feminine and neuter; and the singular number includes the plural and the singular.

Words and phrases not defined in this section shall have their conventional meanings unless expressly stated otherwise.

Abandoned Water Well - a well that meets any of the following criteria: (1) construction was terminated prior to completion of the well, (2) the well owner has notified the local Board of Health that use of the well has been permanently discontinued, (3) the well has been out of service for at least three years, (4) the well is a potential hazard to public health or safety and the situation cannot be corrected, (5) the well is in such a state of disrepair that its continued use is impractical, or (6) the well has the potential for transmitting contaminants from the land surface into an aquifer or from one aquifer to another and the situation cannot be corrected.

Alter a Well or Well Alteration - change the structural or hydraulic characteristics of a well including but not limited to deepening, decommissioning, performing Well Yield Enhancement, or performing casing extension, replacement, perforation or repair.

Annular Space - the space between two cylindrical objects, one of which surrounds the other. For example, the space between the wall of a drillhole and a casing pipe, or between an inner and an outer well casing.

API - American Petroleum Institute.

Aquifer - a geologic formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs.

Artesian Aquifer - an aquifer that is bounded above and below by impermeable materials or materials of distinctly lower permeability than the aquifer itself. The water in an aquifer confined in this manner will rise in a drilled hole or well casing above the point of initial penetration (above the bottom of the confining, or impermeable, layer overlying the aquifer).

Artesian Well - a well producing from an artesian aquifer. The term includes both flowing wells and nonflowing wells.

ASTM - American Society for Testing and Materials.

AWWA - American Water Works Association.

Bedrock - see "Consolidated formation".

Bentonite - a mixture of swelling clay minerals containing at least eighty-five percent of the mineral montmorillonite (predominantly sodium montmorillonite) which meets the specifications of the most recent revision of API Standard 13A.

Bentonite Grout - a mixture of bentonite (API Standard 13A) and water in a ratio of not less than one pound of bentonite per gallon of water.

Casing - impervious durable pipe placed in a boring to prevent the walls from caving and to serve as a vertical conduit for water, other fluids, or gases in the well .

CMR - Code of Massachusetts Regulations.

Concrete - a mixture consisting of Portland cement (ASTM Standard C150, Type I or API Standard 10, Class A), sand, gravel, and water in a proportion of not more than five parts of sand plus gravel to one part cement, by volume, and not more than six gallons of water. One part cement, two parts sand, and three parts gravel are commonly used with up to six gallons of water.

Confined Aquifer - an aquifer in which the groundwater is under pressure greater than atmospheric pressure: the static water level in a well tapping a confined aquifer rises to a level above the top of the aquifer.

Consolidated Formation - any geologic formation in which the earth materials have become firm and coherent through natural rock forming processes. The term is sometimes used interchangeably with the word "bedrock" and includes, but is not limited to, basalt, granite, limestone, sandstone, and shale. An uncased drillhole will normally remain open in these formations.

Contaminant - any physical, chemical, biological, or radiological substance or matter in water.

Contamination - the presence of any physical, chemical, biological, or radiological substance or matter in water at a concentration and for a duration or anticipated duration which, in the opinion of the regulating agency, would present a threat to the public health, using existing federal and state standards and guidelines where applicable.

Cross Connection - any physical connection or arrangement between two otherwise separate piping systems, one of which contains potable water and the other water of unknown or questionable safety, whereby water may flow from the non-potable to the potable system, depending on the pressure differential between the two systems.

Curbing - either precast or poured-in-place, concrete well casing used to construct dug wells.

Department - Massachusetts Department of Environmental Protection

Drawdown – the amount of decline in the water surface in a Well that results from pumping the Well.

Drive shoe - a forged or tempered steel collar, with a cutting edge, attached to the lower end of a casing by threading or welding, to protect the lower edge of the casing as it is driven.

Flushing - the act of causing a rapid flow of water from a well by pumping, bailing, or similar operation.

Formation - an assemblage of earth materials grouped together into a unit that is convenient for description or mapping.

Ground Source Heat Pump Well, GSHPW or Geothermal Well - a Well used to transfer heat to or from the earth for heating or cooling. This includes Open Loop Ground Source Heat Pump Wells, in which the fluid or gas contents of the well can enter the groundwater in the surrounding aquifer and Closed Loop Ground Source Heat Pump Wells in which the contents of the Well are recirculated in piping or tubing such that no mixing of the fluid or gas contents of the Well with the groundwater in the surrounding aquifer can occur.

Groundwater - subsurface water in the zone of saturation.

Grout - a stable impermeable bonding material which is capable of providing a watertight seal.

Grouting - the process of mixing and placing grout.

Install a Pump or Pump Installation – install, Replace or alter a Pump or any component thereof for a Well.

MGL - *Massachusetts General Laws.*

Neat Cement Grout - a mixture consisting of one bag (94 pounds) of Portland cement (ASTM Standard C150, Type I or API Standard 10, Class A) to not more than six gallons of clean water. Bentonite (API Standard 13A), up to two percent by weight of cement, shall be added to reduce shrinkage. Other additives, as described in ASTM Standard C494, may be used to increase fluidity and/or control setting time.

Overburden - see "Unconsolidated formation.

Person – any agency or political subdivision of the federal government or the commonwealth, any state, public or private corporation or authority, individual, trust, firm, joint stock company, partnership, association, or other entity, and any officer, employee or agent of said person, and any group of said persons

Pitless Adapter - a commercially manufactured device which attaches to a well casing and provides watertight subsurface connections for suction lines or pump discharge and allows vertical access to the interior of the well casing for installation or removal of the pump or pump appurtenances.

Private Water Supply - a system that provides water for human consumption, if such system has less than fifteen (15) service connections and either (1) serves less than twenty-five individuals or (2) serves an average of twenty-five (25) or more individuals for less than sixty (60) days of the year.

Private Water System - "private water supply."

Private Water Well - any hole or shaft drilled into the ground to inject or withdraw water, other fluids, or gases, monitor soil gasses, monitor groundwater levels or water quality, transfer heat, or provide cathodic protection that is not regulated as a public water supply under 310 CMR 22.00.

Private Well Yield – the gallons per minute (gpm) of water that can flow or be withdrawn from a Well, at a sustained rate after a minimum of 2 hours if the water level has stabilized (water level does not fluctuate more than 3 inches) for the last 30 minutes of the test

Public Water System - a system for the provision to the public of piped water for human consumption, if such system has at least fifteen (15) service connections or regularly serves an average of at least twenty-five (25) individuals daily at least sixty (60) days of the year. Such term includes (1) any collection, treatment, storage, and distribution facilities under control of the operator of such a system and used primarily in connection with such system, and (2) any collection or pretreatment storage facilities not under such control which are used primarily in connection with such system.

Pumping (Aquifer) Test - a procedure used to determine the characteristics of a well and adjacent aquifer by installing and operating a pump

Sand Cement Grout - a mixture consisting of Portland cement (ASTM Standard C150, Type I or API Standard 10, Class A), sand, and water in the proportion of one part cement to three or four parts sand, by volume, and not more than six gallons of water per bag (94 pounds) of cement. Up to five percent, by weight, of bentonite (API Standard 13A) shall be added to reduce shrinkage.

Septic Tank - a watertight receptacle which receives the discharge of sewage from a building sewer and is designed and constructed so as to permit the retention of scum and sludge, digestion of the organic matter, and discharge of the liquid portion to a leaching facility.

Static Water Level – the distance from established ground surface to the stabilized water level in a Well which is neither being pumped nor under the influence of pumping.

Structure - a combination of materials assembled at a fixed location to give support or shelter, such as a building, framework, retaining wall, fence, or the like.

Surface Water - water that rests or flows on the surface of the Earth.

Thermoplastic Casing - ABS (acrylonitrile-butadiene-styrene), PVC (poly-vinyl chloride) or SR (styrene rubber) casing specified in the most recent revision of ASTM Standard F480.

Tremie Pipe - a device, usually a small diameter pipe, that carries gravel pack or grouting materials to the bottom of a drillhole or boring and which allows pressure grouting from the bottom up without introduction of appreciable air pockets.

Unconfined Aquifer - an aquifer in which the static water level does not rise above the top of the aquifer.

Unconsolidated Formation - any naturally occurring uncemented, unlithified material such as sand, gravel, clay, or soil.

Water Table - the upper surface of the zone of saturation in an unconfined formation at which the pressure is atmospheric.

Watertight - a condition which does not allow the entrance, passage or flow of water or other fluids under normal operating conditions.

Watertight Casing - a water well casing that has a wall thickness of 1/8 inch or more, has no seams or has welded seams, and has sections that can be joined together by watertight threads, by a weld, rubber gasket, or by cement that is not limestone or clay based that seals the well against the entrance of surface water into the groundwater.

Watertight Construction - cased and grouted construction through firm formations like clay or rock. Through granular material like sand or gravel, it means that the casing pipe is of approved quality and assembled watertight.

Well - any hole or shaft drilled into the ground to inject or withdraw water, other fluids, or gases, monitor soil gasses, monitor groundwater levels or water quality, transfer heat, or provide cathodic protection.

Well Development - a procedure consisting of the removal of fine sand and drilling fluid from the water bearing sand, gravel, or rock materials opposite the well screen.

Well Vent - an outlet at the upper end of a well casing or basement end of a non-pressure conduit to allow equalization of air pressure in a well but at the same time so constructed as to prevent entry of water and foreign material into the well.

Well Yield Enhancement – a process to increase the production of water and Yield by using water under pressure, or another substance the Department has approved for use in the process, to clean out existing fractures in order to allow water to flow into the Well from other areas. .

Yield - the quantity of water per unit of time which may flow or be pumped from a well under specified conditions.

Zone of Saturation - the zone below the water table in which all interstices are filled with groundwater.

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