Drinking Water Operator Certification Training

Module #:2
Groundwater Sources of Supply and Protection

This course includes content developed by the Pennsylvania Department of Environmental Protection (Pa. DEP) in cooperation with the following contractors, subcontractors, or grantees:

The Pennsylvania State Association of Township Supervisors (PSATS)
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Topical Outline

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Unit 1 – Introduction to Groundwater

Learning Objectives

- Define evaporation, transpiration, evapotranspiration, groundwater, and water table.
- List three types of water and explain each.
- Explain the steps in the Hydrologic Cycle.

Evaporation – the change by which any substance is converted from a liquid and carried off as a vapor. It is one of the processes of returning moisture to the atmosphere. Water on any surface (especially ponds, streams, lakes, and oceans) is warmed by the sun until it turns into vapor, or its gaseous form, and rises into the atmosphere.

Evapotranspiration – the combined net effect of evaporation and transpiration.

Groundwater – underground water located in the zone of saturation below the water table.

Hydrologic Cycle – the exchange of water between the earth and the atmosphere through evapotranspiration and precipitation.

Infiltration – the entry of water into the soil through cracks, joints, and pores in the soil and rock structure. This is also referred to as percolation.

Surface Runoff – the movement of water, usually from precipitation, across the land surface toward stream channels, lakes, depressions, or other low spots.

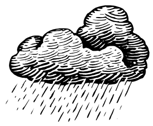
Surface Water – water found on the surface of the land. Usually refers to puddles, ponds, lakes, streams, rivers, and oceans.

Transpiration – the direct transfer of water from the leaves of living plants to the atmosphere. Plants take up water through the roots and then lose some through pores in the leaves. As warm air passes over the leaf surface the moisture evaporates into the air.

Water Table – the boundary below which all of the spaces and cracks in the soil and rock are filled with water.

Zone of Saturation – the area below the groundwater table.

Water is one of earth's basic materials. It can be found around, on, and within the earth.



Atmospheric Water

Atmospheric water is the water that is found in the air ***surrounding*** the earth. It can be seen as clouds, fog, and forms of precipitation like rain, snow, and sleet.

Surface Water

Surface water is water that is ***on top*** of the earth's surface. This water can be fresh water or salt water and can be seen as oceans, lakes, rivers, or streams.

- Fresh water – water which is or can be treated to be drinkable.
- Salt water – water which contains too much dissolved salt and other minerals to be drinkable.

Groundwater

Groundwater is water that is found ***below*** the earth's surface. It includes both fresh water and salt water. Groundwater is found in saturated soil, as shown below, or in fractures in the bedrock.

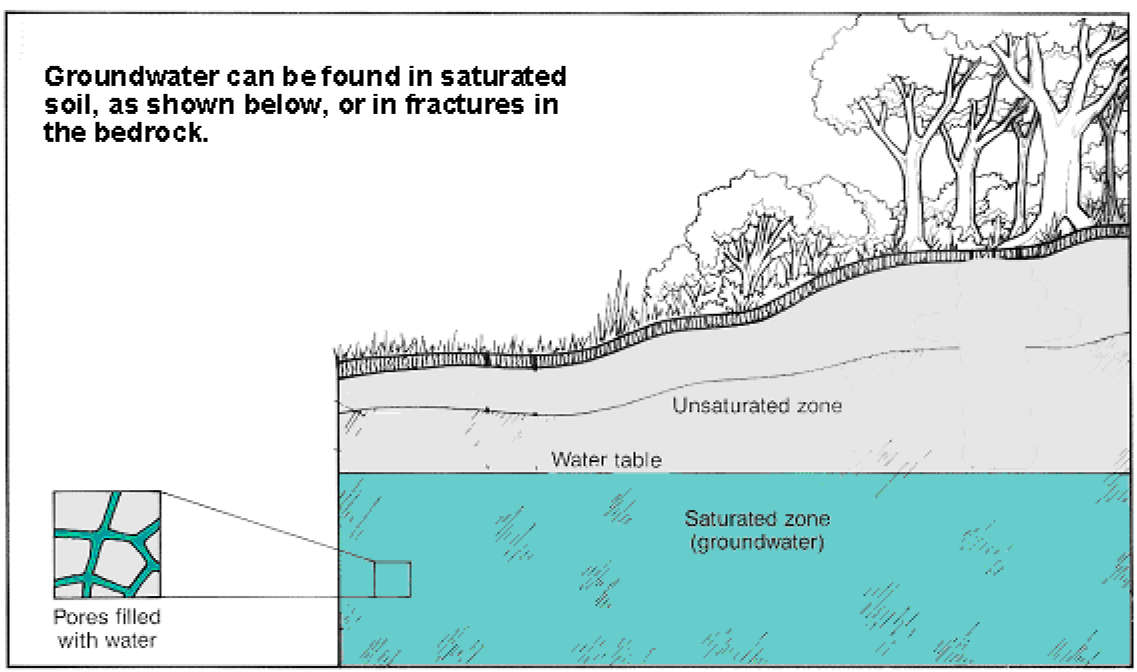


Figure 1.1 - Groundwater

Sources of Groundwater for Drinking Include:

- ► Water obtained from dug, drilled, bored, jetted or driven wells.
- ► Water obtained from Infiltration Galleries and Radial Collectors.
- ► Water obtained from springs.
  - ▪ To be classified as a groundwater source, springs must not come into contact with any potential surface water. Therefore, the spring source must be developed within a "springhouse" to protect the source quality.
  - ▪ Additionally, the spring source must be evaluated and tested to assure that surface water will not directly contaminate the spring.

Groundwater sources are subject to the direct influence of water that has been classified as a surface water source. If it is determined that the groundwater source has been influenced by a surface water, the groundwater source would then require treatment as a surface water.

Overview

The exchange of water between the earth and the atmosphere through evaporation and precipitation is known as the **Hydrologic Cycle**.

The **Hydrologic Cycle** is continuous—no starting or ending point.

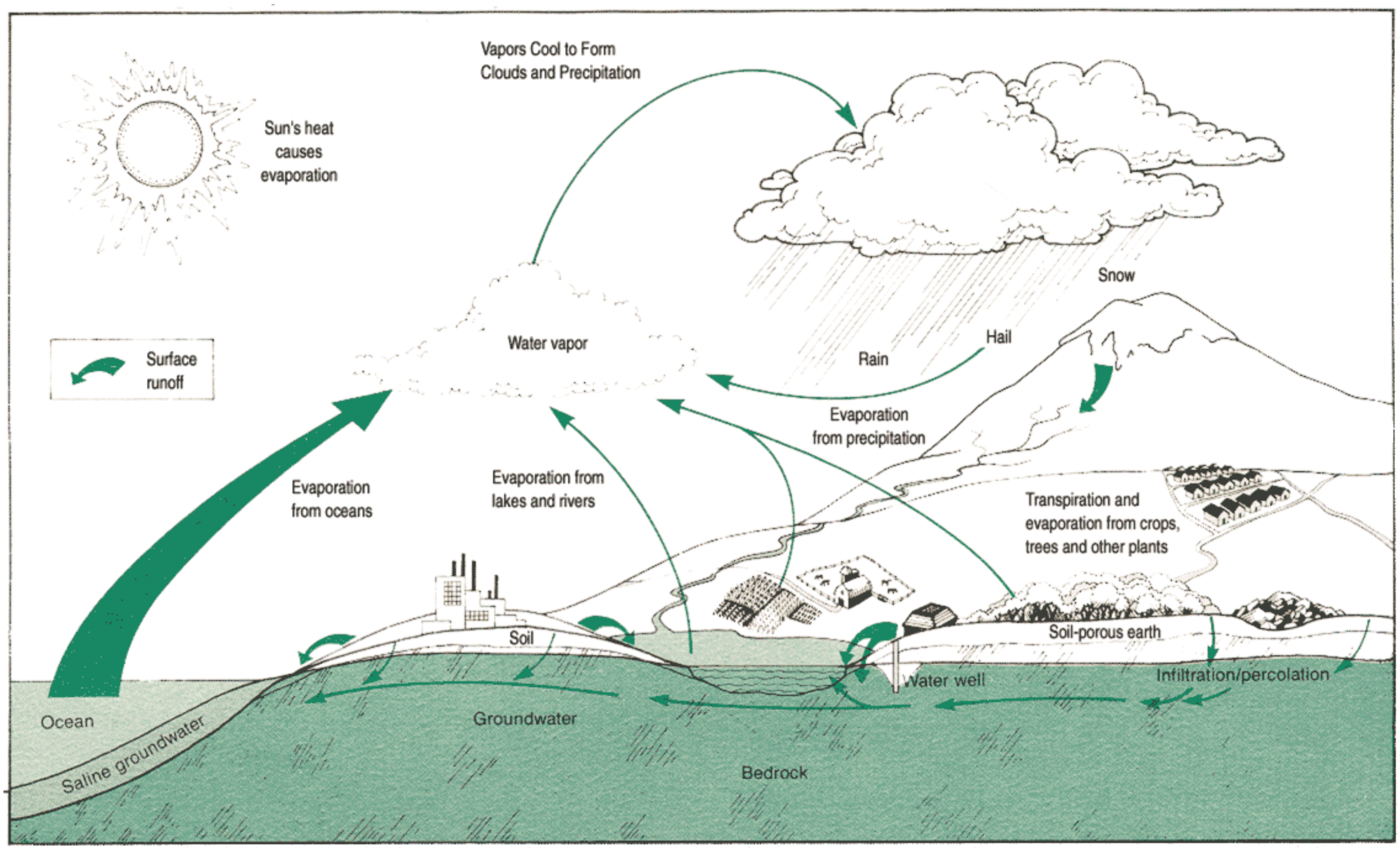


Figure 1.2 - Hydrologic Cycle[1]

Process

Precipitation

Rain or snow falls on the land surface.

- Some of the water flows on the surface to lakes, streams, and wetlands as surface runoff.

Evaporation

Most of the precipitation evaporates back into the atmosphere from the ground surface where it condenses and falls again as precipitation.

Infiltration

The remaining water infiltrates into the ground where one of two things occurs.

① Some water is taken up by plant roots and transpired by plants back into the atmosphere where it condenses and falls again as precipitation. This is known as **Transpiration**.

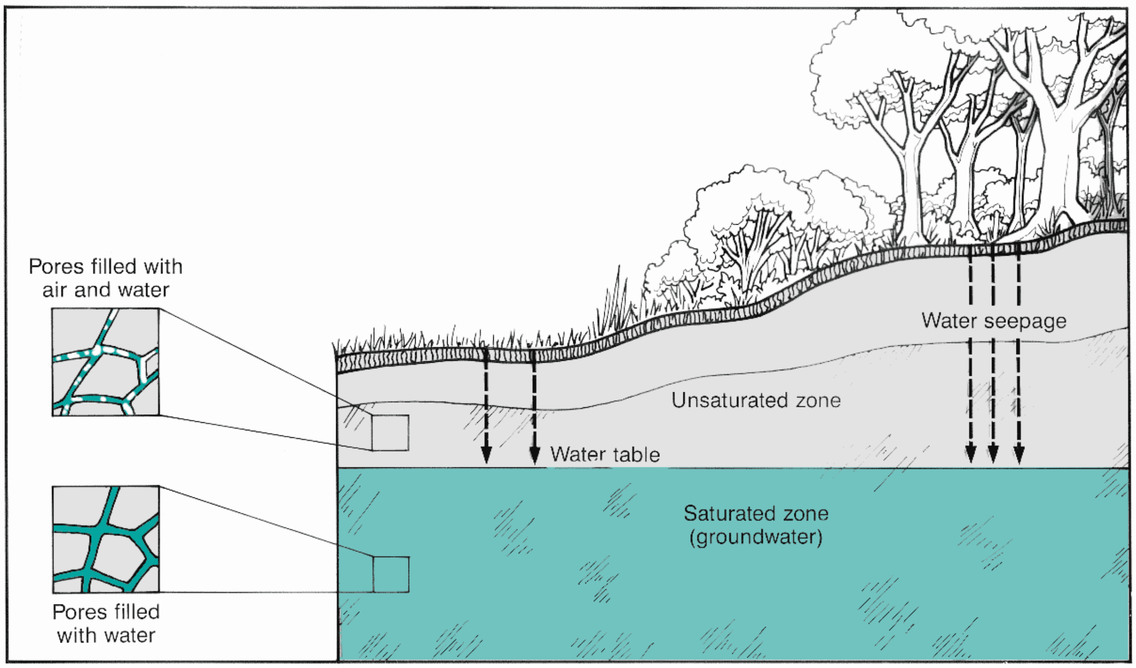


Figure 1.3 - Groundwater Infiltration [2]

② The remaining water filters down through an unsaturated zone where the spaces (pores) between the soil particles and rock contain both air and water.

Eventually water reaches the Water Table—the boundary below which all of the spaces and cracks in the soil or rock are filled with water—recharging the groundwater system.

- Zone of Saturation – area where all pore spaces are filled with water
- Water Table – the top of the zone of saturation
- Water below the water table is in Groundwater Storage

Discharge

The Groundwater moves through the ground, eventually surfacing at an area of discharge—a spring, stream, lake, or wetland.

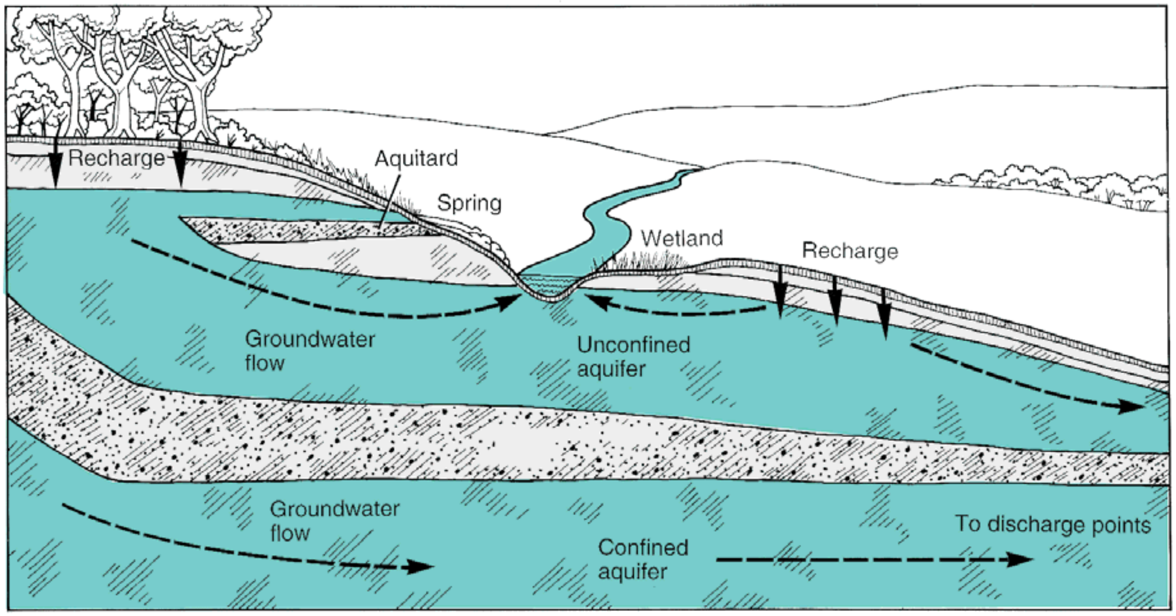
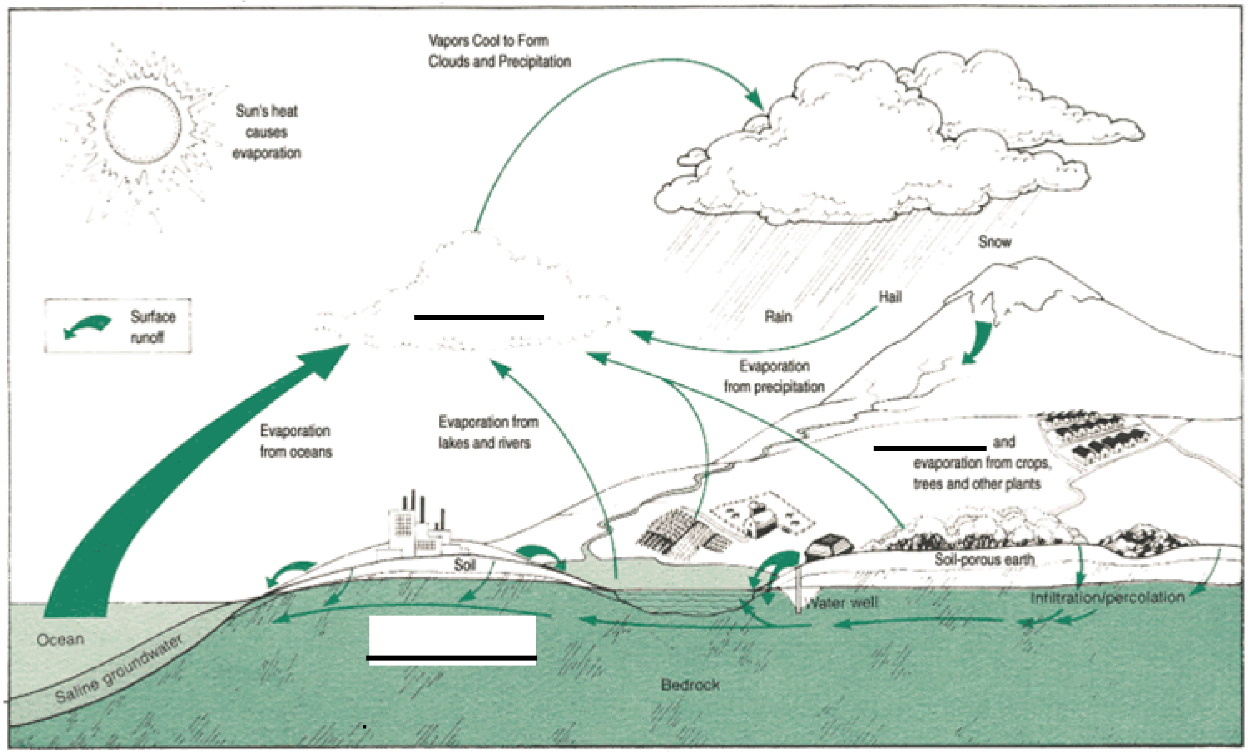


Figure 1.4 - Groundwater Movement [3]

The Water Cycle is complete when **evaporation** from the surface returns this water back to the atmosphere.

Regardless of its origin, water moves between the subsurface, surface, and atmosphere via the Hydrologic Cycle.

Exercise: Fill in the blanks (3 of them) in this Hydrologic cycle:



Hydrologic Cycle in Pennsylvania

Precipitation

Each year, on average, 41 inches of precipitation falls in Pennsylvania.

- 6 inches enters streams and lakes directly either as surface runoff or as flow from the unsaturated zone.
- 20 inches returns to the atmosphere through evaporation and transpiration (evapotranspiration).
- Remaining 15 inches infiltrates and moves downward to the zone of saturation to recharge groundwater.

Groundwater Recharge

In Pennsylvania, most groundwater recharge occurs in the spring.

- Plenty of water from rain and snow melt.
- Plants not yet actively growing and are not taking water from the soil.
- Amount of sunlight is less, so evaporation is less.

Following spring recharge, the water table usually lowers steadily during the summer, fall, and winter.

Recharge Rates

Recharge or infiltration rates vary with type of land cover. Generally,

1. The higher percentage of impervious area in urban areas (sidewalks and roads) results in higher surface runoff and lower infiltration (lower recharge).

2. Forested areas have higher infiltration (higher recharge) due to limited impervious area and therefore less surface runoff.

Groundwater in the United States

According to United States Geological Survey (USGS), in the United States, Groundwater provides:

- ☑ 51% of all drinking water
- ☑ 99% of drinking water for the rural population

Groundwater in Pennsylvania

Pennsylvania groundwater includes both fresh and salt water.

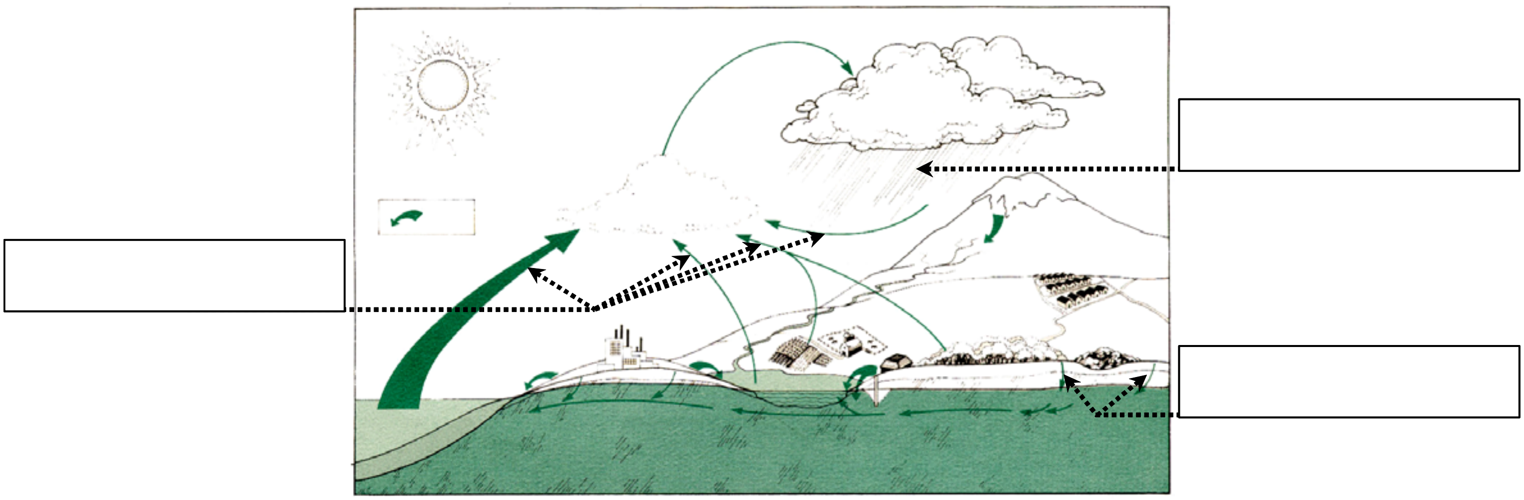
- Salt water can be found beneath fresh water almost everywhere at depths ranging from 200 to over 1000 feet. It contains much more salt than seawater and is called brine or brackish water.
- Pennsylvania has 30 times more groundwater than surface water.
- Groundwater provides two thirds of the water to our surface water streams, lakes, and wetlands.

Pennsylvania Groundwater Statistics

- ☑ Ranks 2nd (after Michigan) for total number of wells, 2nd (after Michigan) for number of household wells, and 3rd (after Wisconsin and New York) for number of public water supply wells.
- ☑ 33.7% of Pennsylvania's population depends on groundwater for its drinking water supply.
- ☑ 978,200 households (2.5 million residents) served by private individual wells.
- ☑ 17,500 public supply wells serving 1.5 million residents.
- ☑ 243 million gallons per day (MGD) of groundwater supplied by public water systems.

Unit 1 Exercise

1. On the diagram below, label the following parts of the Hydrologic Cycle: Precipitation, Evaporation and Infiltration.



2. In addition to surface water, name two other types of water below and briefly describe each.

A. ______________________________

B. ______________________________

3. Match the word with its definition:

Word Pool		
Evapotranspiration	**Transpiration**	**Groundwater**
Evaporation	**Water Table**	

______________	1. When water turns into a vapor and returns to the atmosphere
______________	2. When water travels through a plant and some evaporates directly from plant to air
______________	3. Loss of water by evaporation from the soil and transpiration from plants
______________	4. Water found beneath earth's surface (can be fresh or salt water). This is our largest source of fresh water
______________	5. The boundary below which all of the spaces and cracks in the soil and rock are filled with water

Key points for Unit 1 – Introduction to Groundwater

- The three types of water are: atmospheric water, surface water, and groundwater.
- Surface water can be classified as fresh water or salt water.
- Groundwater can be either fresh water or salt water.
- The water table is the boundary below which all of spaces and cracks in soil and rock are filled with water.
- Springs can be considered a groundwater source if they are protected from coming into contact with surface water.
- Infiltration of surface water through the water table and into the zone of saturation is also called percolation.
- The hydrologic cycle is continuous and involves precipitation, evaporation, infiltration, and discharge of water.
- Most groundwater recharge occurs in the spring in Pennsylvania.
- Groundwater in Pennsylvania can contain both fresh water and salt water.

[1] "Illustration 1—Hydrologic cycle, water is constantly on the move" **http://pa.lwv.org/wren/** (24 March 2003).

[2] "Illustration 2—Groundwater is the water that fills all the spaces in the saturated zone" http://pa.lwv.org/wren/ (24 March 2003).

[3] "Illustration 5—Groundwater generally flows from upland recharge areas to lowland discharge areas" http://pa.lwv.org/wren/ (24 March 2003).

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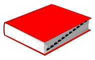
Unit 2 – Aquifers

Learning Objectives

- List four types of groundwater aquifers found in Pennsylvania
- Identify on a map, the location of Pennsylvania's principal groundwater aquifers.
- Describe the geology of each of the four aquifers.
- List three common types of groundwater sources found in Pennsylvania.



Aquifer - A water-bearing stratum of rock, sand, or gravel.

A stratum is a layer of earth. Therefore, an aquifer could be a layer of limestone, which contains or carries water.

There are three types of Aquifers: Unconfined Aquifer, Confined Aquifer, and, Perched Aquifer or Perched Water Table.

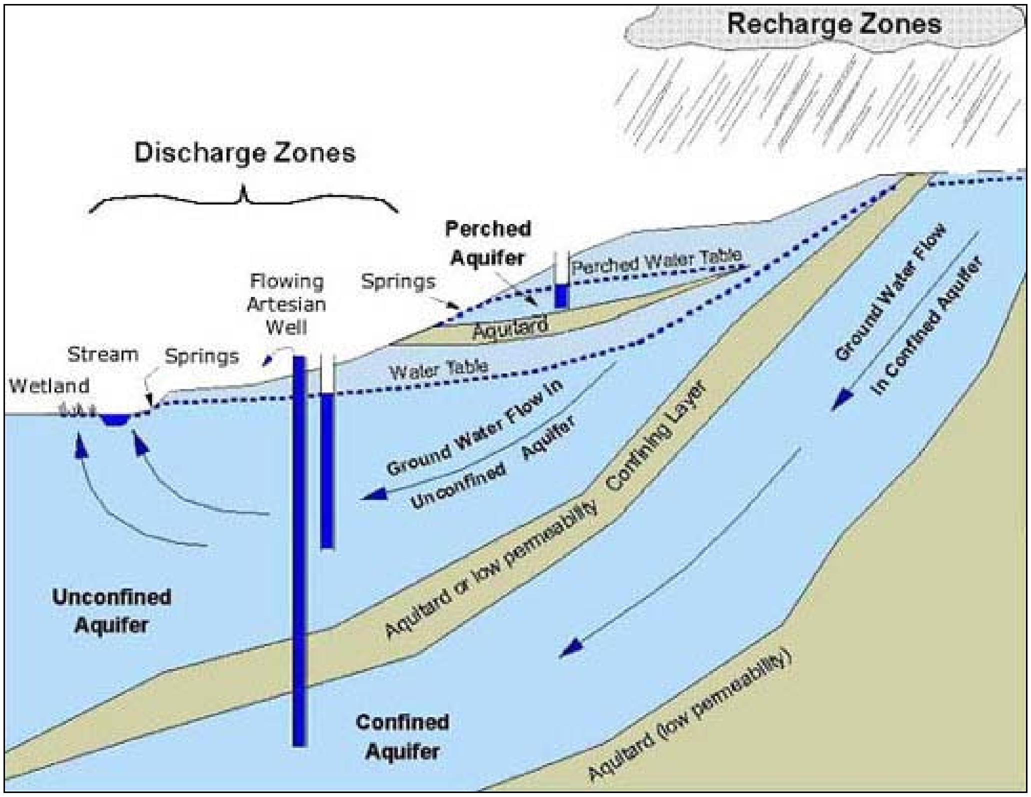


Figure 2.1 - Types of Aquifers

Unconfined Aquifer or Water Table Aquifer

- Groundwater that is not surrounded by soil or rock on all sides.
- Groundwater is under atmospheric pressure.
- This type of aquifer may feed such surface water sources as springs or streams

Confined Aquifer

- Groundwater is sandwiched between two impermeable layers or aquitards.
- Confined Aquifers are under pressure greater than atmospheric.

Perched Water Table

- Groundwater collects above an impermeable layer above the water table.
- The Perched Water Table usually doesn't hold much water.

In Pennsylvania groundwater aquifers are divided into four groups based upon their geology: Sand and Gravel Aquifers, Sandstone and Shale Aquifers, Carbonate Rock Aquifers and Crystalline Rock Aquifers. Each of these has distinct locations, geologies, yields and qualities. The following map and charts help to illustrate these factors.

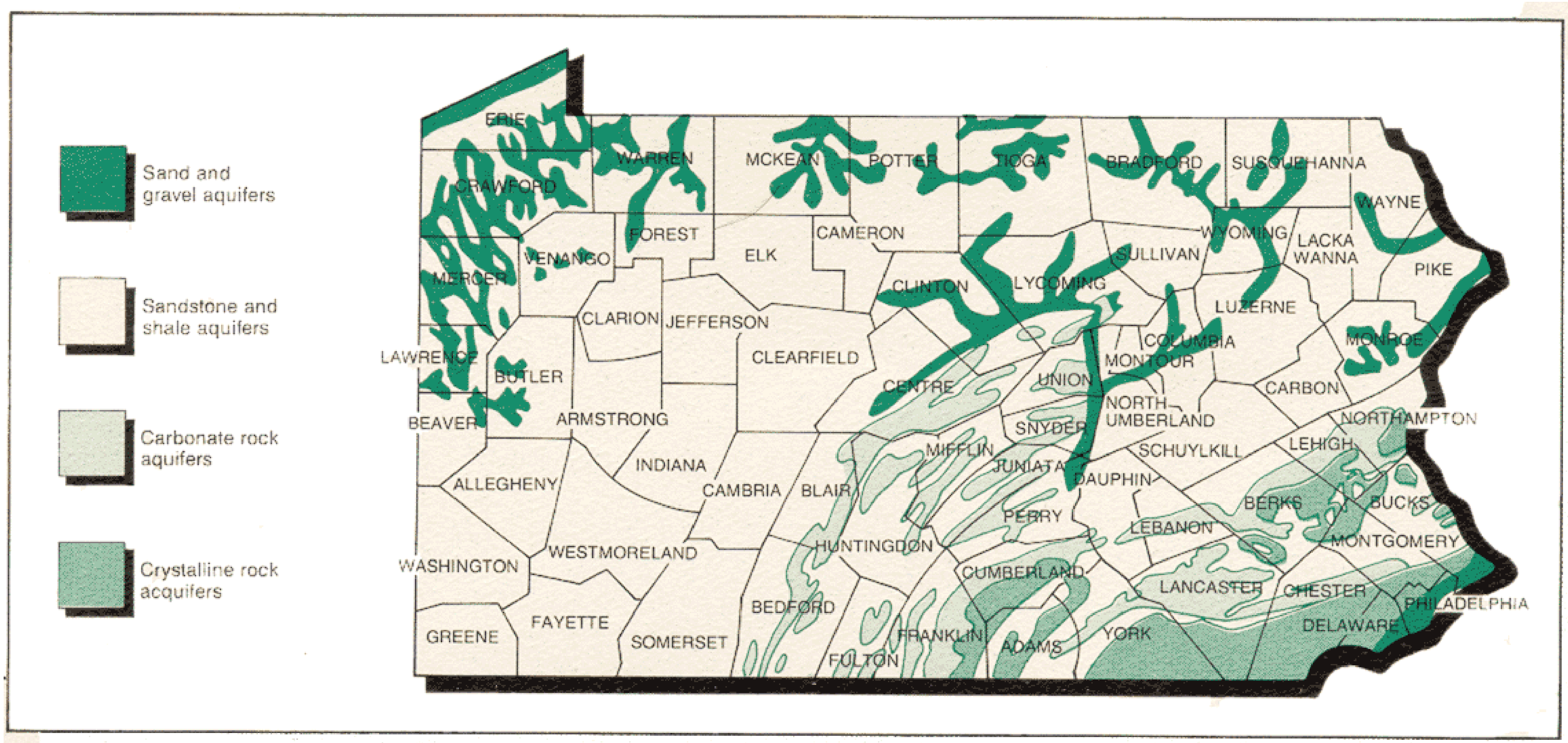


Figure 2.2 - Pennsylvania's Aquifer Distribution[1]

Sand and Gravel Aquifers

Location	• Southeastern coastal plain, along Delaware River • Along Lake Erie shoreline • In most major stream valleys

Geology	• Unconsolidated sand and gravel deposits of various geologic formations
	• Vertically separated by clayey or silty confining layers
	  ▹ retard vertical flow
	  ▹ 60 – 75% of recharge is from upland runoff
	  ▹ Contain saline water in places, especially near salt water coastline

Yields	• Contain large quantities of water • Easily withdrawn • Well yields of 100 – 800 gallons per minute (gpm) ▹ Yield in excess of 1000gpm are common

Quality	• Quality is variable, but generally good to excellent
	• Typical quality:
	  ▹ Dissolved solids – 250 milligrams per liter (mg/l)
	  ▹ Hardness – 140 mg/l (hard)
	  ▹ pH – 7.2
	  ▹ Iron – 0.1 mg/l
	  ▹ Nitrate – if found is generally due to surface contamination by fertilizer, animal wastes, or sewage.
	• Especially susceptible to contamination by human activities.

Sandstone and Shale Aquifers

Location	• Predominant bedrock aquifer in PA • Located in the sandstone, siltstone, and shale areas throughout the state.

Geology	• Consolidated sedimentary rock
	• Almost flay-lying to gently folded
	• Principal coal-bearing formations, consisting of cyclic sequences of sandstone, shale, conglomerate, clay, coal, and minor limestone.
	• Sandstones are the principal water-yielding units
	• Springs common
	  ▹ Low permeability rocks, such as shale, siltstone, or ironstone retard vertical water movement.
	  ▹ Lateral water movement surfaces at intersections with valley wall.

Yields	• Interlayered – can be more than one water bearing zone in a vertical thickness • Well yields are lower than sand and gravel aquifers ▹ Well yields of 20 to 400 gpm • Wells located on fracture intersections can have substantially increased yields

Quality	• Quality of freshwater is somewhat variable but generally satisfactory
	• Typical quality
	  ▹ Dissolved solids – 230 milligrams per liter (mg/l)
	  ▹ Hardness – 95 mg/l (moderately hard)
	  ▹ Water from shale aquifers usually reported to be hard
	  ▹ Water from sandstone aquifers usually reported to be soft
	    ▪ pH – 7.3
	    ▪ Iron – 0.1 mg/l
	• Fresh groundwater circulates only to shallow depths
	• Saline water or brine not far below – separated only by a thin transition zone
	• Improper construction/ plugging of oil and gas wells, and coal mining operations present contamination problems

Carbonate Rock Aquifers

Location	♦ Limestone and dolomite geologic formations located in the valleys of central and southeastern PA ♦ Caves, solution channels, and sinkholes of these regions are caused by water dissolving portions of the carbonate rock
Geology	♦ Complex geologic structure ♦ Sedimentary rock layers are folded and displaced to the northwest ♦ Many fractures, faults, and slippage planes
Yields	♦ Contain large quantities of water ♦ Water movement generally along fractures, bedding planes, and solution channels ♦ Spring yields of 100 to more than 2000 gpm ♦ Well yields of 100 to 1000 gpm, or more, are common ▹ Wells located on fracture intersections can have substantially increased yields
Quality	♦ Quality is somewhat variable, but generally suitable for water supply ♦ Typical quality ▹ Dissolved solids – 330 milligrams per liter (mg/l) ▹ Hardness – 280 mg/l (very hard) ▹ pH – 7.4 ▹ Iron – 0.1 mg/l ♦ Brackish water at depth ♦ Contains relatively large amounts of dissolved solids ♦ In some coal-mining area groundwater is mixed with acidic mine water, resulting in large concentrations of iron, manganese, sulfate, and dissolved solids

Crystalline Rock Aquifers

Location	• Most of southeastern Pennsylvania
Geology	• Dense, almost impermeable bedrock • Complex assortment of metamorphic and igneous rocks • Water yields primarily from secondary porosity and fractures
Yields	• Rock formations have very small fractures • Storage capacity and well yield are relatively low • Almost all recharge is from precipitation • Variable yields – dependent on factors such as type of rock; number, size and spacing of fractures; degree to which fractures are interconnected; and topographic setting of the well • Generally small yields of 5 to 25 gpm

Quality	• Quality is generally suitable for drinking and other uses, but iron, manganese, and sulfate occur locally in objectionable concentrations
	• Typical quality
	  ▹ Dissolved solids – 230 milligrams per liter (mg/l)
	  ▹ Hardness – 160 mg/l (hard)
	  ▹ pH – 7.6
	  ▹ Iron – 0.1 mg/l

Exercise: Answer the following questions for your system's aquifer (use the preceding pages).

1. What is the typical yield in gpm?

2. What is the typical pH

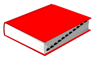
3. What is the quality considered?

4. At your system, have you found similar water quality characteristics? If not, how did they differ?

5. Write down one thing you learned about your aquifer (something you didn't know before):

Types of Groundwater Sources

Groundwater sources are of three types: wells, springs, and infiltration galleries and radial collectors. These three sources provide raw water to a treatment plant.



Raw water is any untreated water source.

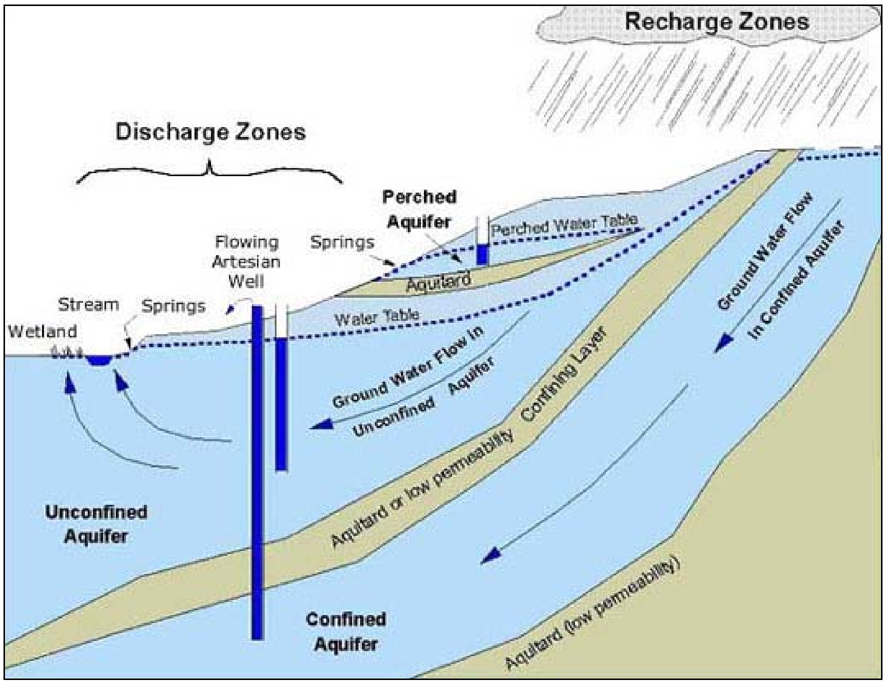


Figure 2.3 - Water Source Placement

Wells

Wells are dug or drilled holes extending below the water table.

Types of Wells

☑ Perched Aquifer Well
- Dry up during dry season
- Aren't good places for wells

☑ Unconfined Aquifer Well
- Water level in well is at the water table level

☑ Confined Aquifer Well
- Artesian wells
- Water level in well higher than water table level because the water is under pressure
  - Water level can be higher than top of well casing – Flowing Artesian

Springs

Springs are groundwater that surfaces where the water table intersects the land surface.

☑ To be considered as groundwater, it must be collected in a spring house or well box before water is exposed to surface conditions.
☑ Springs originate from unconfined or perched aquifers

Infiltration Galleries, Radial Collectors

Both infiltration galleries and radial collectors collect groundwater and are constructed below the water table.

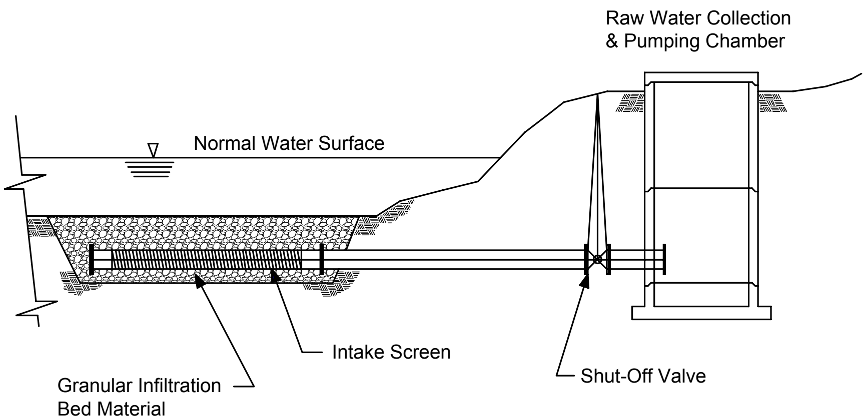


Figure 2.4 – Infiltration Gallery

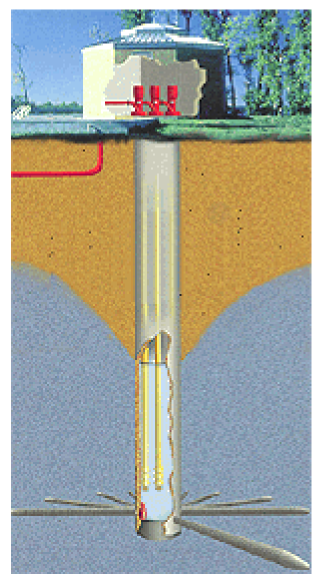


Figure 2.5 – Radial Collector[2]

Unit 2 Exercise

1. List the three types of groundwater sources.

A. ______________________________

B. ______________________________

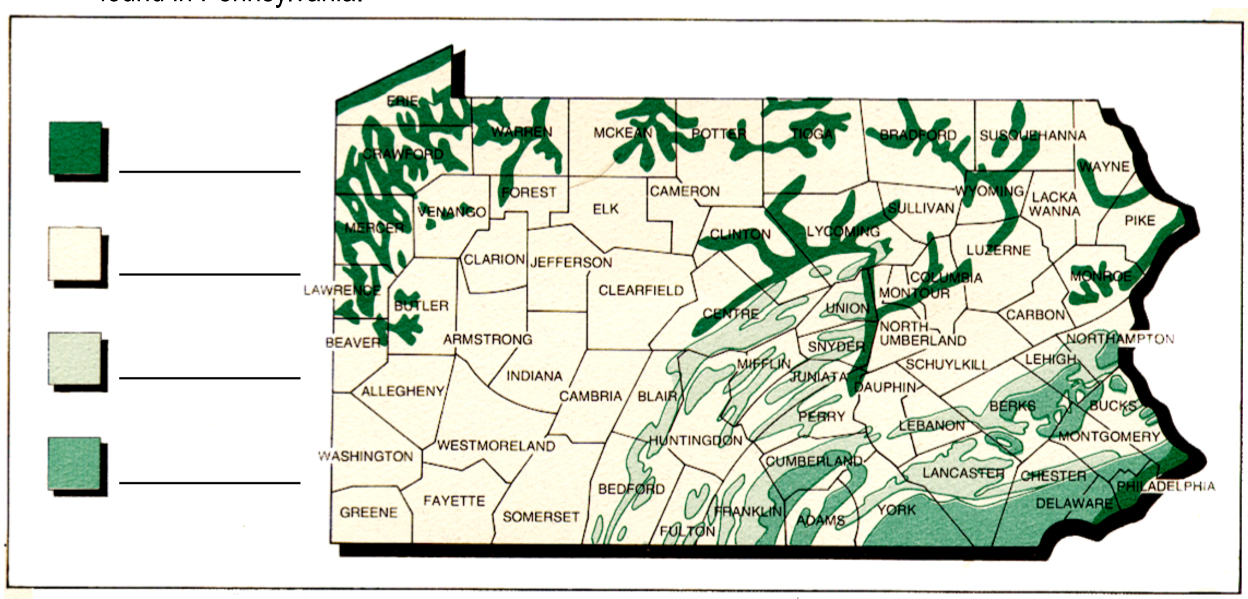
C. ______________________________

2. **True or False:** A stratum is a layer of earth

3. Which one of the following best defines the term ***aquifer***?

a. A low lying area where water pools
b. Water-bearing stratum of rock, sand, or gravel
c. Impervious stratum near the ground surface
d. Treated water leaving the water system

4. On the map below, label the map's key to indicate the geological types of groundwater aquifers found in Pennsylvania.



5. List the three types of aquifers.

A. ______________________________

B. ______________________________

C. ______________________________

6. Based ***solely*** on **quality** of Water and **yield**, which of the four aquifer formations would provide the largest amount of fresh water? Why?

____

____

____

____

Key points for Unit 2 – Aquifers

- An aquifer is a water-bearing layer of rock, sand, or gravel.
- The three general types of aquifers are: unconfined, confined, and perched aquifers.
- Based on their geological properties, Pennsylvania's aquifers are classified into one of four basic groups.
- Pennsylvania's four basic aquifer groupings are:
  - Sand and gravel aquifers
  - Sandstone and shale aquifers
  - Carbonate rock aquifers
  - Crystalline rock aquifers
- Sand and gravel aquifers may contain large amounts of water.
- Sandstone and shale aquifers are the most commonly occurring aquifer in Pennsylvania.
- Carbonate rock aquifers may contain large amounts of water. Caves and sinkholes may be common in these areas. Water hardness may be a problem.
- The three types of groundwater sources are:
  - Wells
  - Springs
  - Infiltration galleries and radial collectors
- A spring can be considered groundwater only if the spring water is collected in a spring house or well box to prevent the spring water being exposed to surface conditions.

[1] ”Illustration 12—Map of Pennsylvania Aquifers” *http://pa/lwv.org/wren/ (24 March 03).*

[2] “Ranney Collector Wells” http://www.laynechristensen.com/ranney_collector_wells.html (05 May 2003).

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Unit 3 – Source Development and Construction

Learning Objectives

- Identify the considerations in new source development
- Define Safe Yield and explain why it is important to groundwater supply sources.
- Explain the basic components of well construction and the importance of proper installation of the well casing.
- Define and explain wellhead protection

Prior to the development and construction of a water supply source there are many factors that need to be taken into consideration.

Water Supply Alternatives

When developing water supply sources, there are three alternatives.

1. Connect to an existing system.
2. Develop surface water resources.
3. Develop groundwater resources.

Facility Location

Considerations

No matter which of the three supply alternatives is used, the following considerations must me made.

- ☑ Anticipated adequacy and reliability of sources.
- ☑ Expected water quality.
- ☑ Monitoring and health requirements.
- ☑ Operation and maintenance costs.
- ☑ Cost of source development.

Sanitary Survey

The purpose of the Sanitary Survey is to discover, investigate, and evaluate conditions that may adversely affect the quantity or quality of the supply source.

Considerations

- ☑ Local geology, topography and size of recharge area, ground slope, and groundwater table.
- ☑ Local sources of pollution (landfills, sink holes, sewage systems, industrial discharges, etc.).
- ☑ Drainage area, population density, land use.
- ☑ Proximity to flood plains or impoundments.
- ☑ Proximity to other wells.

Wellhead Protection Area

Considerations

- ☑ Protect source by ownership, easements, deed restrictions, and zoning.
- ☑ 100 foot radius of source, minimum.

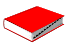
Wellhead protection is an important program in Pennsylvania. Under the program, water systems apply proper management techniques and various preventive measures to protect their ground water supplies. The underlying principle of the whole program is that it is much less expensive to protect ground water than it is to try to restore it once it becomes contaminated. In Pennsylvania, to meet the wellhead protection program, new community water system well permitting requirements, voluntary local wellhead protection programs, and a three-tiered approach to wellhead protection were enacted.

Based on the three-tiered approach, three WHP areas are delineated. All man-made sources that may impact human health are identified. Within these areas, management practices are implemented to manage the sources of contamination.

Testing

Overview

Testing is done for both the capacity (quantity) of water in the prospective well and for its water quality. The goal is to have a well that has a Safe Yield and a water quality that is potable, suitable for human consumption, or can be treated to a potable level.



Safe Yield – The amount of water that can be annually withdrawn from a groundwater basin without adverse impacts. This is the long term sustainable pumping rate.

General Well Hydraulics

☑ When water is pumped from a well, the water table in the vicinity of the well is lowered, creating a cone of depression.

☑ If cone of depression extends to surface water body, water will flow from the surface water body to the groundwater. This is known as Induced Recharge.

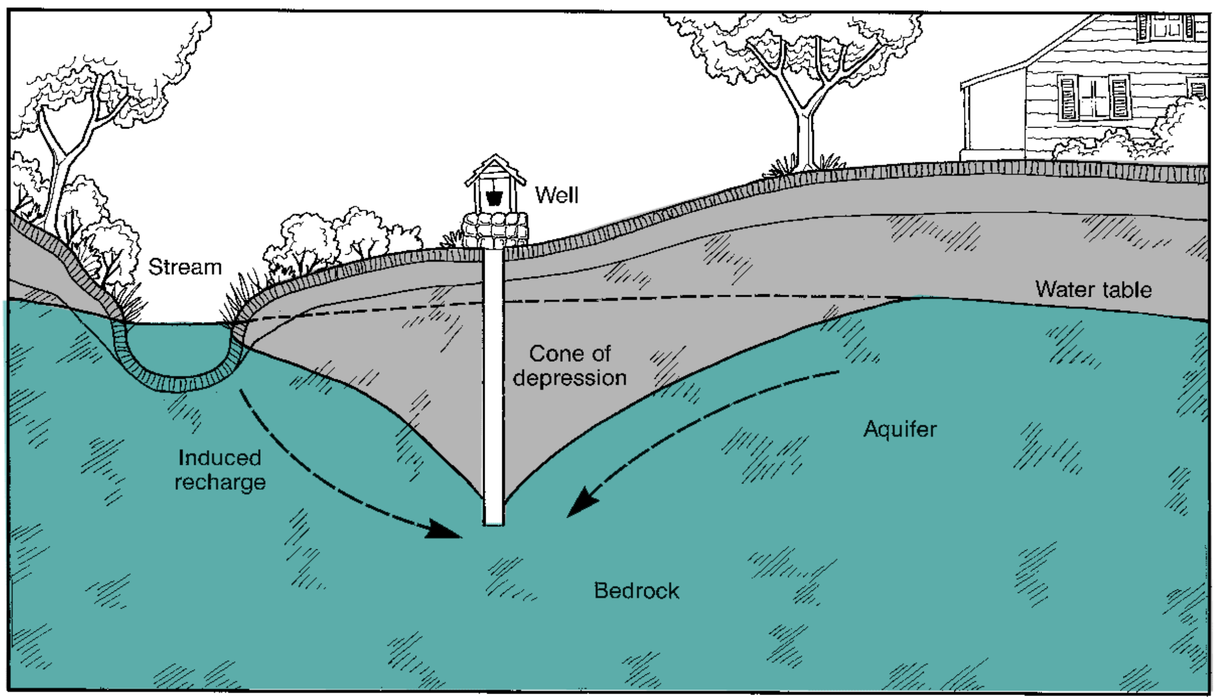


Figure 3.1 - Well Drawdown[1]

Testing Protocol

☑ Drilling Log

- ► Complete DEP drilling report

☑ Plumbness and Alignment

- ► 40-foot long rigid dummy, ½ inch less than well diameter must move freely throughout length of well.
- ► Indicates that pump will not get stuck during installation or removal. A stuck pump could require abandonment of source.

Capacity Testing

The purpose for capacity testing is to determine if the well will be able to supply a Safe Yield.

☑ Step-Drawdown Test

- This test is used to predict the sustainable pumping rate. Although it is not required by regulatory agencies (DEP, SRBC), it is recommended.
- Well is pumped at several successively higher pumping rates and the drawdown for each rate (or step) is recorded.
- Usually conducted in a single day and requires 5 to 8 pumping rates, each lasting approximately 1 hour.

☑ Sustained Yield Test

- This test is used to evaluate aquifer and well capabilities and potential impacts to existing water supplies and the environment.
- Well is pumped continuously for a minimum of 48 hours. A greater length may be required. During this time several things must occur:
    - Static water level, pumping rate(s), drawdown, water recovery rate and level are measured and recorded;
    - Water Quality – measure and record pH, temperature and conductivity every 2 hours; and,
    - Collect water samples for quality determination at end of test period.

Water Quality Testing

☑ Wells

- Water samples are taken upon completion of the sustained yield pumping test, and the analysis is performed by a DEP certified laboratory.
- Testing Requirements—one set of samples required and tested for presence and amount of:
  - Volatile Organic Chemicals (VOCS) - Benzene, TCE, Toluene, etc.
  - Synthetic Organic Chemicals (SOCS) - PCBs, Alachlor, Lindane, Chlordane, etc.
  - Inorganic Chemicals (IOCS) - Arsenic, Chromium, Lead, Nitrates, Nitrites, Mercury, etc.
  - Microbiological Contaminants (Total Coliform) - 3 samples at 15 minute intervals
  - Radionuclides (Gross Alpha emissions and Gross Beta emissions) - the presence of radioactive material
  - Secondary Contaminants and Others - TDS, pH, iron, manganese, hardness, chloride, etc.
  - Turbidity – the clarity of the water sample

☑ Springs

- Water samples are collected minimally over a 6 month time period. At least 1 set is collected a minimum of 6 hours and a maximum of 24 hours after a significant rainfall event. The analysis is performed by a DEP certified laboratory.
- Testing requirements—the types of testing are the same as for wells; however, the number of samples required is different.
  - Volatile Organic Chemicals (VOCS) – 2 samples
  - Synthetic Organic Chemicals (SOCS) – 1 sample
  - Inorganic Chemicals (IOCS) – 2 samples
  - Microbiological Contaminants (Total Coliform) – 6 samples
  - Radionuclides (Gross Alpha and Gross Beta) – 1 sample
  - Turbidity – 6 samples

☑ Surface Water Identification Protocol (SWIP) Testing

- This testing needs to be done on all ground water sources. Special monitoring is required of groundwater sources susceptible to direct surface water influence.
- Direct surface water influence possibilities include:
  - All springs, infiltration galleries, ranney wells, and crib intakes.
  - Wells if they meet one of the following four criteria:
    1. In carbonate aquifer with static water elevation ≤ 100 feet below ground level.
    2. In an unconfined aquifer with static water elevation ≤ 50 feet below ground level.
    3. In a confined aquifer located ≤ 50 feet below ground level.
    4. ≤ 200 feet from a surface water body (not applicable where static water elevation is > 100 feet below ground level).
- Special monitoring requirements
  - Daily sampling for turbidity, pH, specific conductance (or total dissolved solids), and temperature.
  - Daily measurements flow and/or source water level.
  - Weekly total and, if positive, fecal coliform samples.
  - Daily recording of precipitation and local surface water conditions.
  - Monitoring conducted for 6 months.
- If monitoring indicates a correlation between source water quality and precipitation or surface water conditions, DEP to conduct a Microscopic Particulate Analysis (MPA).
  - If results of MPA show presence of surface water organisms or organic debris, source will be considered groundwater under the direct influence of surface water.

Once the location of the water supply facility has been determined, how the well is constructed and the materials used is very important in helping to ensure we have the amount of water we need and that it is of potable quality. In this section, we will explore the components of well construction: 1) Casings, 2) Screens, 3) Upper Well Terminus, 4) Capping and Abandonment, 5) Well Pumps, 6) Discharge Piping, as well as 7) Special Construction Requirements.

Casings

Material

☑ New wrought iron or steel pipe

- ► Minimum weight and thickness to comply with American Water Works Association (AWWA) Standard A100, "Standard for Water Wells"
- ► Equipped with drive shoe when driven
- ► Welded or threaded joints

☑ Non-ferrous (PVC) pipe

- ► Comply with AWWA A100, "Standard for Water Wells"
- ► Shall not be driven

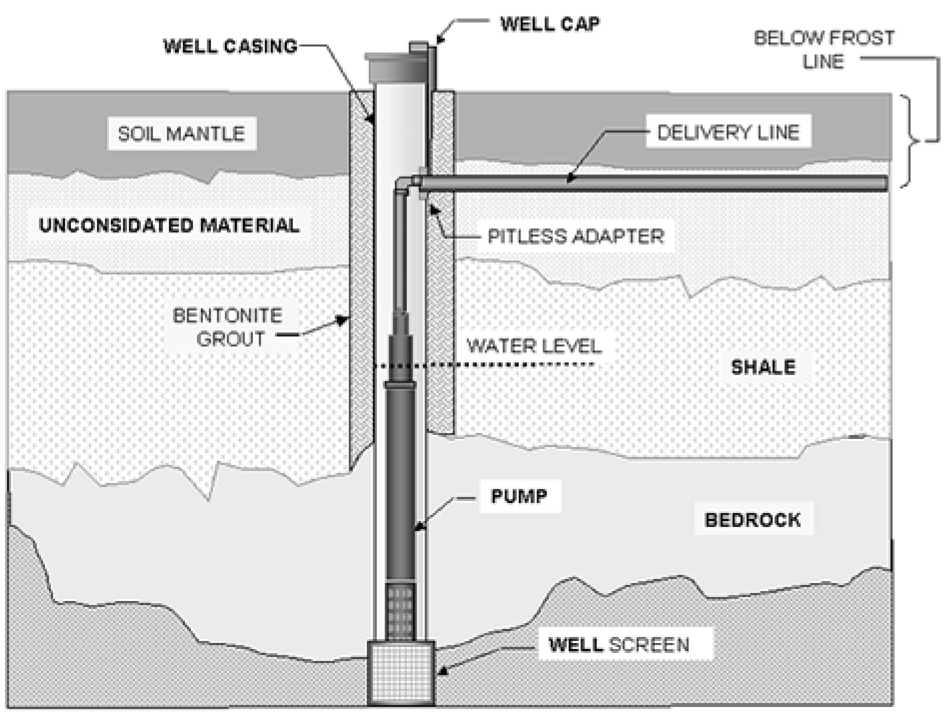


Figure 3.2 Well Components

Grouting

☑ All permanent well casings are to be surrounded by a minimum of 1.5 inches of grout. This is to be done to a minimum depth of 20 feet from the ground surface, or into the impervious subsurface formation which caps the aquifer - whichever is deeper.

☑ Specific grout mixtures can be found in DEP Public Water Supply Manual, Part II, Chapter 3, Section 3.3.5.7.

☑ Grout is to be added from the bottom of the annular opening, in one continuous operation, until opening is filled.

- ► When the annular opening is less than four inches, the grout is to be installed under pressure with a grout pump.

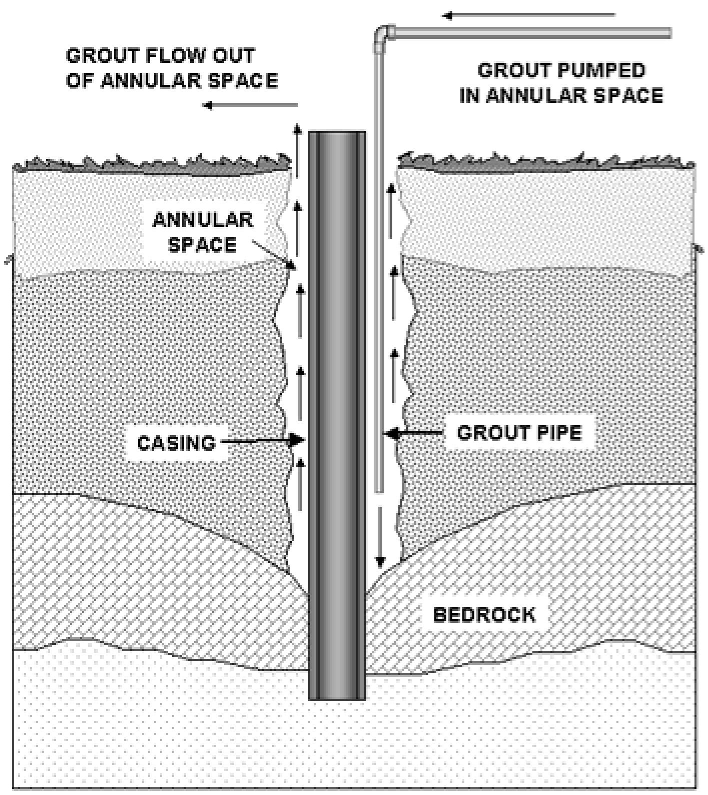


Figure 3.3 Grouting a well

Minimum Protected Depth

DEP has set up standards for Protective Casing Depths. As illustrated in Table 3.1, two factors affect the Protective Casing Depth, the water bearing formation and the overlying materials.

Table 3.1 - Protective Casing Depths[2]

Protective Casing Depths		
Water-Bearing Formation	Overlying Materials	Protective Casing Depth
Sand Or Gravel	Sand, or mixture of sand and gravel	The depth of casing will be governed by the pumping level (level of water during pumping). For pumping levels 30 feet or less, the casing shall extend 10 feet below pumping level. For pumping levels greater than 30 feet the casing shall extend five feet below pumping level.
	Clay or similar material containing layers of sand or gravel.	The casing shall extend five feet below the pumping level, but through the clay. The casing shall extend five feet below the pumping level, but through clay below any sand or gravel above the 30 –foot depth (See Section 3.3.6.2)
	Clay, or similar material only, to a depth of 35 feet or more.	The casing shall extend five feet below the pumping level. (See Section 3.3.6.2)
Limestone, Granite, or Quartzite	Mantle, to a depth greater than 50 feet for a radius of one mile.	The casing shall be firmly seated in the rock formation. (See Section 3.3.6.3)
	Mantle, to a depth less than 50 feet for a radius of one mile.	The casing shall extend 10 feet into uncreviced rock below 40 feet. (See Section 3.3.6.3)
Sandstone	Any material except limestone, to a depth of 35 feet or less.	The casing pipe shall extend 15 feet into firm sandstone or to the 40 foot depth.
	Any material except limestone, to a depth greater than 35 feet.	The casing pipe shall be effective seated into sandstone. Minimum cased depth shall be 40 feet.
	Limestone at variable depth.	The casing pipe shall be extended 15 feet into firm sandstone.

☑ **Activity**

Using the Protective Casing Depths Table – Table 3.1, answer the questions for following scenarios.

1. What is the recommended protective casing depth when the water bearing formation is gravel, overlying material is a mixture of sand and gravel, and the pumping level is 28 feet?

____

2. What is the recommended protective casing depth when the water bearing formation is limestone and the overlying material is mantle to a depth of 52 feet for a radius greater than a mile?

____

3. What is the recommended protective casing depth when the water bearing formation is sandstone and the overlying material is limestone at variable depths?

____

Screens

Requirements

If used, screens shall:

☑ Provide maximum open area while maintaining required structural strength.

☑ Have opening sizes based on a sieve analysis of the surrounding material.
- ► Sieve analysis: Method of determining particles size.

☑ Be constructed of materials resistant to damage from the chemical action of the groundwater or cleaning operations.

Upper Well Terminus

Requirements

☑ The permanent casing is to extend a minimum of 12 inches above the pump house floor or concrete apron, or at least 18 inches above final ground level.

☑ The Well house floor is to be constructed a minimum of 6 inches above final ground level.

☑ The top of the casing is at least 3 feet above the highest known flood level.

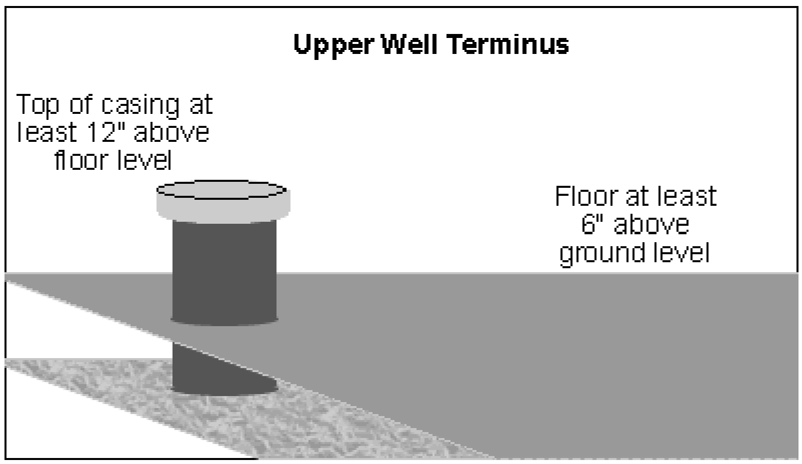


Figure 3.4 Upper Well Terminus

Capping and Abandonment

Capping

All new wells are to be capped until development as a water source or abandoned.

☑ A tight fitting wooden plug or welded metal plate is required.

Abandonment

Abandoned wells are to be sealed. This is required in order to restore the geologic conditions which existed prior to drilling.

☑ Sealing prevents the exchange of water from one aquifer to another.

☑ The preferred method is accomplished by filling the bore hole with neat cement grout.

Well Pumps, Discharge Piping and Appurtenances

Pumps

☑ Line Shaft Pumps

- ► Drive motor located on surface, pumping assembly located in well.
- ► Pump sealed to casing to prevent entrance of surface water.

Figure 3.5 Line Shaft Pumps

☑ Submersible Pumps

- ► Pumping assembly and motor are submerged in the well.
- ► Top of casing is sealed against entrance of water.
- ► Electrical cable is attached to riser pipe.

Figure 3.6 Submersible Pump

Discharge Piping

☑ Check and shutoff valves

☑ Pressure gauge

☑ Flow measuring device

☑ Sample tap

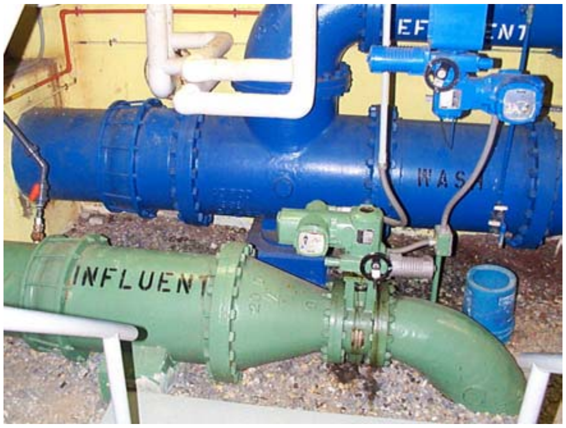


Figure 3.7 Piping

Appurtenances

☑ Pitless well units
- ► Shop fabricated
- ► Threaded or welded to casing pipe
- ► Watertight
- ► Contain facilities to measure water level in well

☑ Water level measurement
- ► Wells are to be equipped with means to measure water level.

Special Construction Requirements

Dug Wells

- ☑ May be considered only when acceptable drilled wells are not possible.
- ☑ Watertight cover required.

Gravel Pack Wells

- ☑ Require gravel packs to be placed in the well to stabilize the borehole. Gravel packs usually consist of a steel screen placed in the hole and the surrounding area is packed with gravel. This prevents the passage of sand into the well.
- ☑ Gravel pack is to be:
  - ► Rounded, sandstone type material.
  - ► Smooth, uniform, properly sized.
  - ► Washed and disinfected immediately prior to placement.

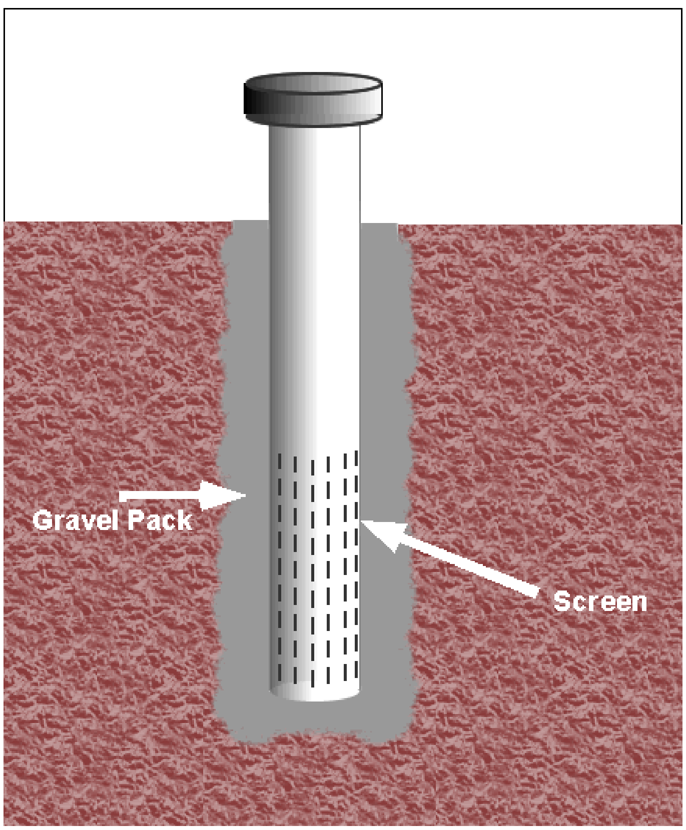


Figure 3.8 Gravel Pack

Sand or Gravel Wells

☑ Permanent casing to extend through clay or hardpan layers above the water bearing formation.

☑ If only permeable materials are above the aquifer, the casing is to extend a minimum of 20 feet below ground surface.

☑ If a temporary outer casing is used, it shall be withdrawn as grout is installed.

Limestone or Sandstone Wells

☑ Where depth of unconsolidated material above the aquifer is more than 50 feet, the casing is to be seated in unbroken rock (Figure 3.9a).

☑ Where depth of unconsolidated material is less than 50 feet, a minimum of 50 feet of casing is required (Figure 3.9b).

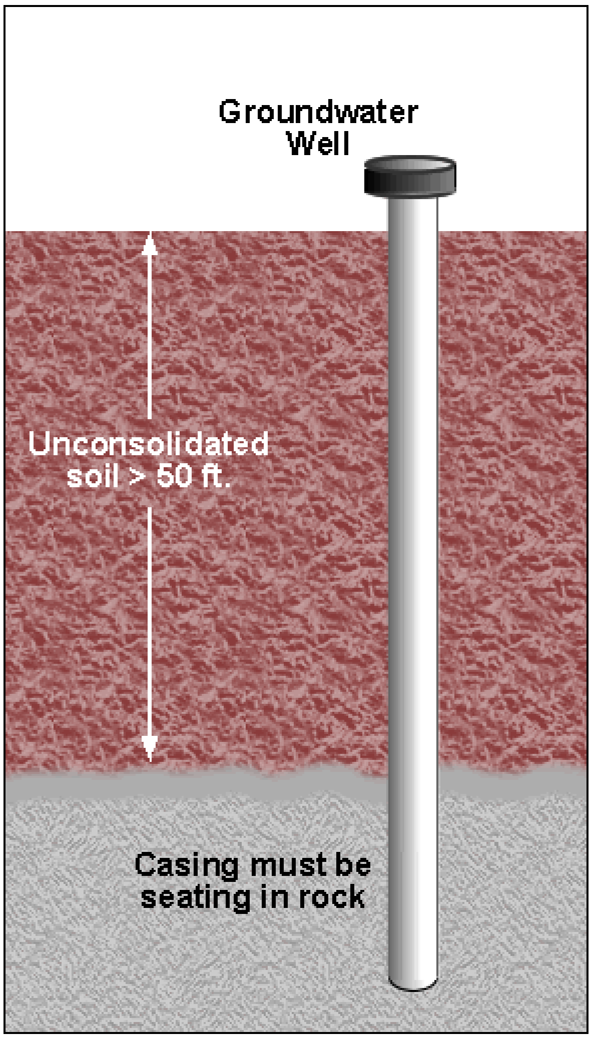


Figure 3.9a

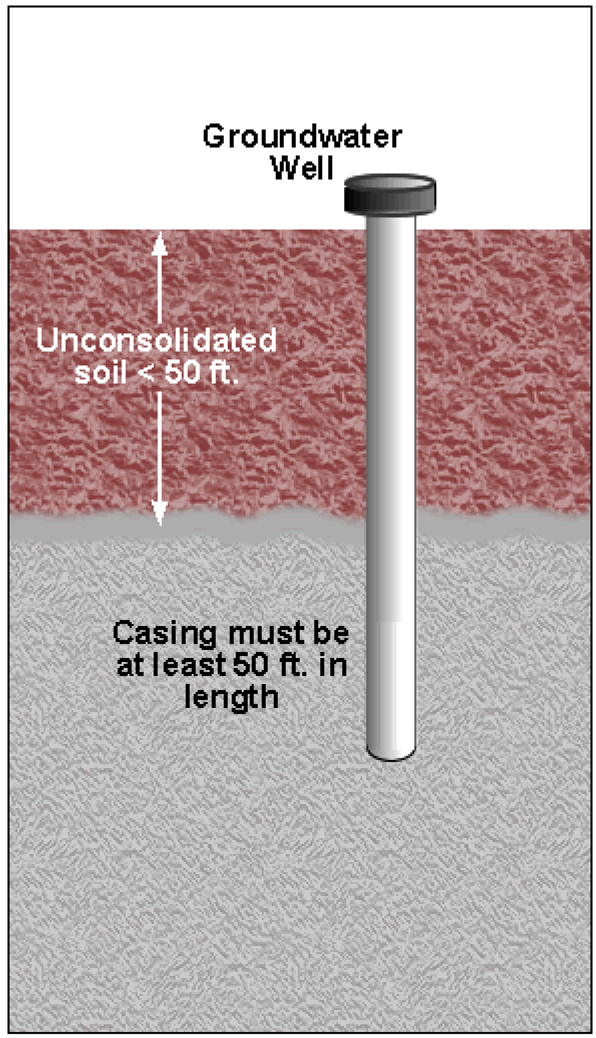


Figure 3.9b

Flowing Artesian Wells

☑ Flow is to be controlled.

☑ If confining layer erosion seems likely to occur, an inner casing is required.

Radial Water Collectors

☑ Radial collectors are to be essentially horizontal.

☑ Top of the caisson is to be covered with a watertight floor.

- ► All openings are to be curbed to prevent entrance of foreign material.

☑ Caisson walls are not to be penetrated by pump discharge piping.

Infiltration Galleries

☑ May be considered only when acceptable drilled wells are not possible.

☑ DEP to establish a minimum area that must be under the control of the source owner.

☑ Gravity flow in lines to collecting well.

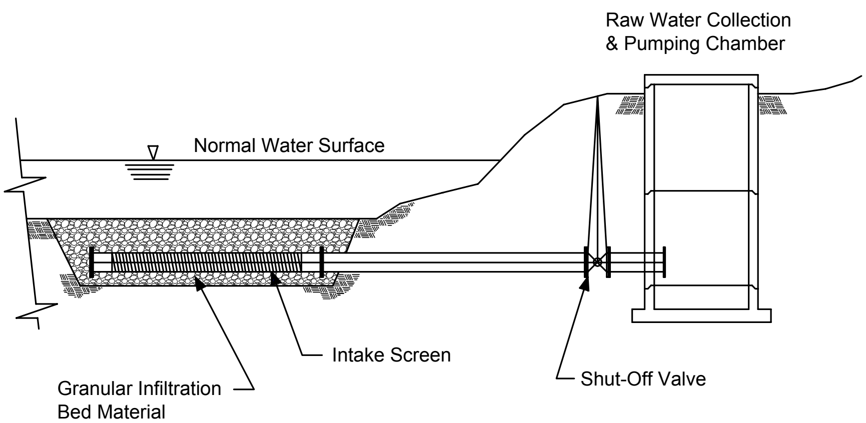


Figure 3.10 – Infiltration Gallery

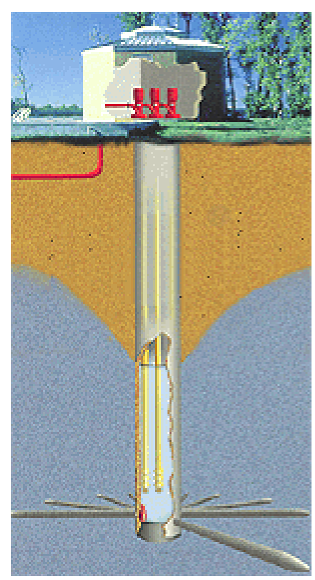


Figure 3.11 – Radial Collector[3]

Unit 3 Exercise

1. In the space below, define Safe Yield and explain why it is important to groundwater supply sources.

____

____

____

____

____

____

2. In the space below, explain the importance of proper installation of the well casing.

____

____

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____

____

____

3. What is the recommended protective casing depth when the water bearing formation is quartzite and the overlying material is 48 feet for a radius of one mile? (Use Table 3.1 – Protective Casing Depths on page 3-9 to answer the following question.)

____

____

Key points for Unit 3 – Source Development and Construction

- The choices for a water supply source may include: connecting to an existing system, develop a new surface water source, or develop a new groundwater source.
- It is very important to understand the current and anticipated future water requirements for the anticipated customers.
- Thorough planning and cost analysis are needed to determine a suitable site, initiate a sanitary survey, develop a wellhead protection plan if groundwater use is planned, and develop an adequate testing plan for ground water or surface water as needed.
- Testing requirements for a proposed well can be extensive and are recommended to include a determination of the safe yield which is the amount of water that can be withdrawn annually from a well without adverse impacts.
- Water from wells and springs must be tested for a variety of organic chemicals, inorganic chemicals, microbiological contaminants, radionuclides, secondary contaminants, and turbidity at a DEP certified laboratory.
- All ground water sources must undergo Surface Water Identification Protocol (SWIP) testing to determine if the groundwater is under the direct influence of surface water.
- Well construction must conform to DEP guidelines for casing depth and grouting around the casing.
- The top of the casing must be at least 3 feet above the highest known flood level.
- Abandoned wells must be properly sealed to restore the geologic conditions which existed before drilling the well.
- New wells must be capped until developed as a water source or abandoned.

[1] "Illustration 7—Pumping from a well lowers the water table near the well creating a cone of depression" http"//pa.lwv.org/wren/(24 March 2003).

[2] "Table II-3.2 Protective Casing Depths" http.//www.dep.state.pa.us/TechnicalGuidance/Draft_ technical_guidance.asp/383-2126-303 (05 May 2003).

[3] "Ranney Collector Wells" http://www.laynechristensen.com/ranney_collector_wells.html (05 May 2003).

Unit 4 – Source Water Protection

Learning Objectives

- Describe a wellhead protection plan and discuss its importance.
- Define Drought Contingency Plan.

Every public water facility in Pennsylvania is required to have a Source Water (Wellhead) Protection Plan. There are not only requirements for **what** is in the plan but also, **who** is involved in the planning as well as **how** the plan is developed.

Minimum Requirements

Who

☑ Local Steering Committee

How

☑ Public Participation

What

☑ Source Water Protection Area Delineation

☑ Contaminant Source Inventory

☑ Protection Area Management Methods

☑ Contingency Planning

☑ New Source Planning

Suggested Additional Components

☑ **Program Promotion** -- This informs the public of a program, rules and/or regulations or potential problems.

☑ **Public Education** -- Is an outcome of the program promotion changing attitude and/or behaviors.

☑ **Integration with Land Use Planning** – This helps prevent future problems.

Each water facility should have a **Drought Contingency Plan**.

Purpose

1. It enhances the Water Supplier's ability to provide adequate supply during moderate to severe drought conditions;

2. It provides suggested actions to extend supplies or reduce usage; and

3. It provides for Public education and awareness that is critical.

Components

Specific Drought Stages Established

☑ **Drought Watch Stage**

- Alert indicating potential future problems
- Focus on monitoring, awareness, and preparation
- Voluntary water conservation (5% reduction in use)

☑ **Drought Warning Stage**

- Coordinated response to imminent conditions
- Potential water supply shortages
- Concerted voluntary water conservation (10-15% reduction in use)

☑ **Drought Emergency Stage**

- Concentrated management phase of operations
- Response to actual emergency conditions
- Mandatory restrictions on nonessential use (15% reduction in consumptive use)
- Ordered by Governor

Local Water Rationing

Requirements

- ☑ Approval from Drought Coordinator
- ☑ Sharing of rapidly dwindling or depleted supplies
- ☑ Specific limits on individual consumption

☑ **Draft a Drought Contingency Plan.** Use the space below and the next page to write contingencies for each stage. Refer to the previous page for descriptions of each stage.

Drought Watch Stage:

____

____

____

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____

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____

Drought Warning Stage:

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____

____

Drought Emergency Stage:

Unit 4 Exercise

1. Two plans that need to be in place to address Source Water Protection. Write the names of each plan below.

   A. ____

   B. ____

2. **True or False:** A local steering committee is recommended, but not a required component of a source water protection program.

3. **Fill-in-the-blank:** The ____________ ______________ ______________ is a list of all the contaminants and where they are found in a source water protection area.

4. List three examples of source water protection public education methods

   a. ________________________________

   b. ________________________________

   c. ________________________________

5. List the three drought stages:

   a. ____

   b. ____

   c. ____

Key points for Unit 4 – Source Water Protection

- All public water facilities in Pennsylvania are required to have a Source Water (Wellhead) Protection Plan.
- There are minimum requirements for what should be in the plan, who is involved in the planning, and how the plan is to be developed.
- Additional optional components to the plan may be program promotion, public education, and land use planning integration.
- Each water facility should have a Drought Contingency Plan.
- The different stages of a drought are:
    - Drought Watch Stage
    - Drought Warning Stage
    - Drought Emergency Stage
- A plan for local water rationing should be put in place so that it can be implemented in the appropriate drought stages.