Wellhead Protection

Tues, May 9, 2023
1pm – 2pm EST
Instructor: Greg Pearson Water/WW Systems Trainer

This program is made possible under a cooperative agreement with US EPA.

www.efcnetwork.org

Certificate of Completion

This training has not been submitted for continuing education credits. We are happy to provide certificates to registered attendees, but cannot guarantee that you will be able to get specific PDH or CEU credit.

You must attend the entire session

- **You must register and attend using your real name and unique email address – group viewing credit will not be acceptable**
- **You must participate in polls**
- **Certificates will be sent via email within 30 days and are for your personal records. Again, we cannot guarantee that our webinars will meet your CEU or PDH requirements.**

If you have questions or need assistance, please contact smallsystems@syr.edu.

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The Environmental Finance Center Network (EFCN) is a university-based organization promoting innovative and sustainable environmental solutions while bolstering efforts to manage costs.

Our Building Technical, Managerial, and Financial Capacity Programs for Small Water and Wastewater Systems provide free training and technical assistance across every state, territory, and tribal nations. Technical assistance is available on a first-come, first-served basis.

Building TMF Capacity for Small Systems

The Small Systems Water and Wastewater Teams

- Southwest Environmental Finance Center at the University of New Mexico
- Syracuse University Environmental Finance Center
- Environmental Finance Center at The University of North Carolina at Chapel Hill
- Environmental Finance Center at Wichita State University
- Environmental Finance Center at Sacramento State
- Michigan Technological University
- New England Environmental Finance Center at the University of Southern Maine
- Environmental Finance Center at the University of Maryland
- Government Finance Officers Association (GFOA)
- National Association of Development Organizations (NADO)
- Mississippi State University Extension
- Environmental Finance Center West
- Great Lakes Environmental Infrastructure Center

Great Lakes Environmental Infrastructure Center
Environmental Finance Center for EPA Region 5

Serves small communities (population of less than 10,000) throughout EPA Region 5

Training and Technical Assistance to increase technical, managerial, and financial capacity of utilities. Focus areas: Asset management, infrastructure funding, & financial management.

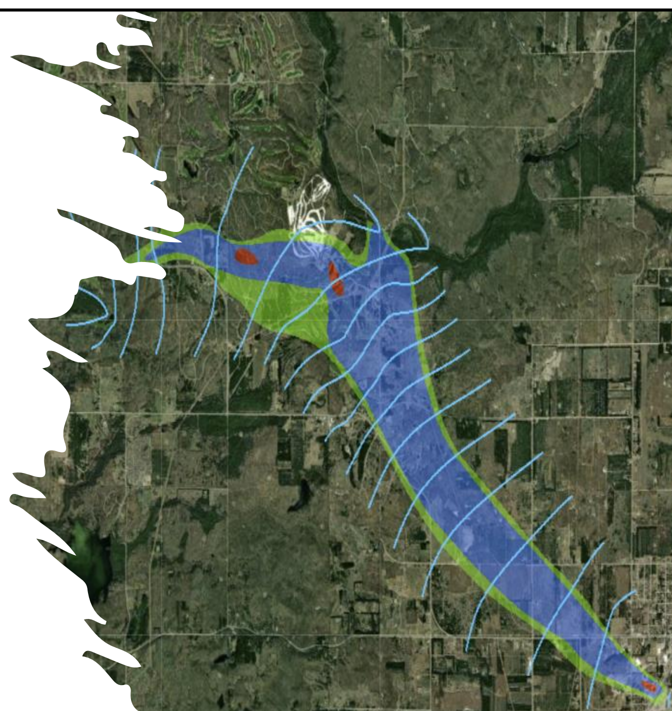
Located: Michigan Technological University (MTU) Center for Technology & Training.

GLEIC Staff
Tim Colling P.E., Director
John Sullivan P.E. , Senior Research Engineer
Greg Pearson, MBA Water & Wastewater Systems Trainer

Wellhead Protection

What we will cover today

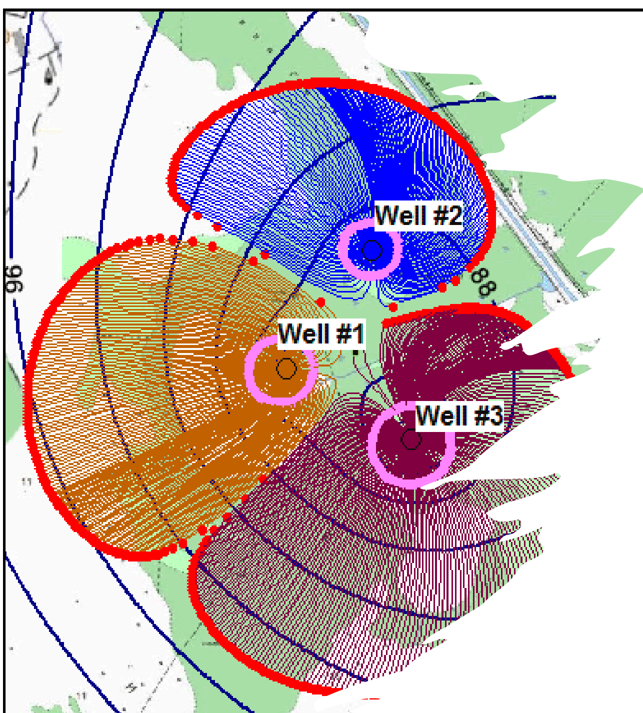
- WHP program components
- Characteristics of aquifers
- Wellhead components
- Delineation methods
- Contaminant plumes
- Remediation
- WHPA management



Great Lakes Environmental Infrastructure Center
Environmental Finance Center for EPA Region 5

Source water protection concepts

- **Multiple barrier approach** – creating multiple protective barriers to contamination of drinking water.
- **Source water assessment** – a study that looks at all water sources, potential and actual contamination sources within a region.
- **Watershed management** – assessing sources that contribute and threats to surface water; creating policies that define acceptable land/water use to protect sources.
- **Wellhead protection** – determining threats to groundwater entering wells, developing ordinances, sanitary construction and maintenance practice.



What are the benefits of a wellhead protection program?

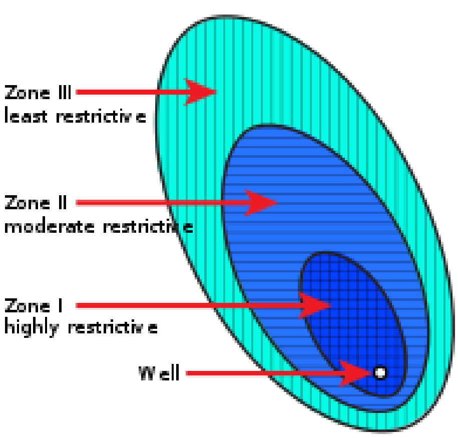
1. Protect public health
2. Source sustainability
3. Economic development
4. Lower long-term costs
5. Protect the aquifer and environment
6. Greater awareness of potential threats
7. Coordination of resources and community involvement

Wellhead protection plan development steps

"It is important to take advantage of the knowledge and expertise that exists within your community to design a plan that will best meet the needs of your community" WI DNR

Form	Form a planning committee.
Delineate	Delineate the wellhead protection area (WHPA)
Inventory	Inventory groundwater contamination sources.
Manage	Manage the wellhead protection area.

Delineate the WHPA



Theoretical wellhead protection zones

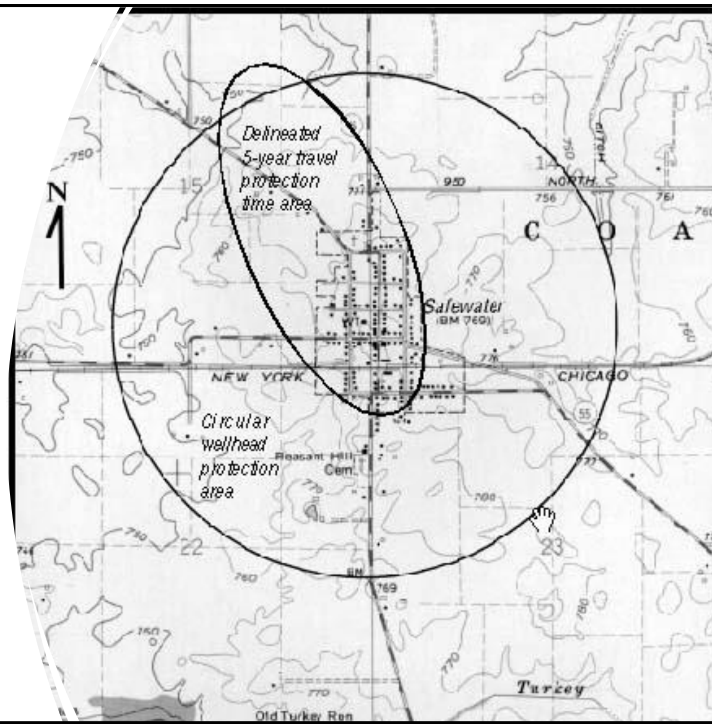
1. Identify the recharge area: the land area which contributes water to a well.
2. Decide what portion of the recharge will be protected to prevent contamination of wells. This area is the (WHPA).

Factors:

- Hydraulic conductivity of aquifer
- Rate of groundwater movement
- Effects of pumping
- Data and technology available

Simple WHPA Delineation

- Primacy agency standards may provide a minimum or suggested pre-prescribed radius (e.g. a 1,200 feet radius)
- Ideally, the WHPA should delineate the recharge area that contributes water within a five-year time of travel (at a minimum)



Calculating a WHPA Radius

$$r = FS\sqrt{\frac{Qt}{7.48nH\pi}}$$

Q = average pumping rate in gallons per year

T = time of travel (enter 2 for 2 years, or 5 for 5 years)

n = porosity

H = Length of well screen in feet

FS = safety factor (either 1.3 or 1.5)

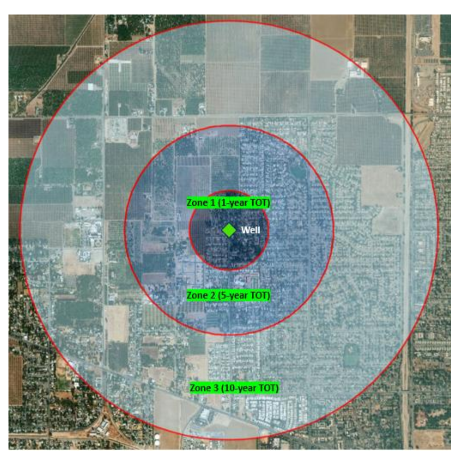
∏ = 3.1416

7.48 gal per cubic foot

METHODS FOR THE DELINEATION OF WELLHEAD PROTECTION AREAS (WHPAs): http://www.wrds.uwyo.edu/wrds/deq/whp/whpappd.html

Can you use this method?

- Can be appropriately used in homogeneous, porous aquifers with minimal GW velocity
- Not suitable for complex aquifers - differences in porosity and permeability are present, and when groundwater flow velocity is significant



Inventory the existing and potential sources of groundwater contamination within the WHPA.

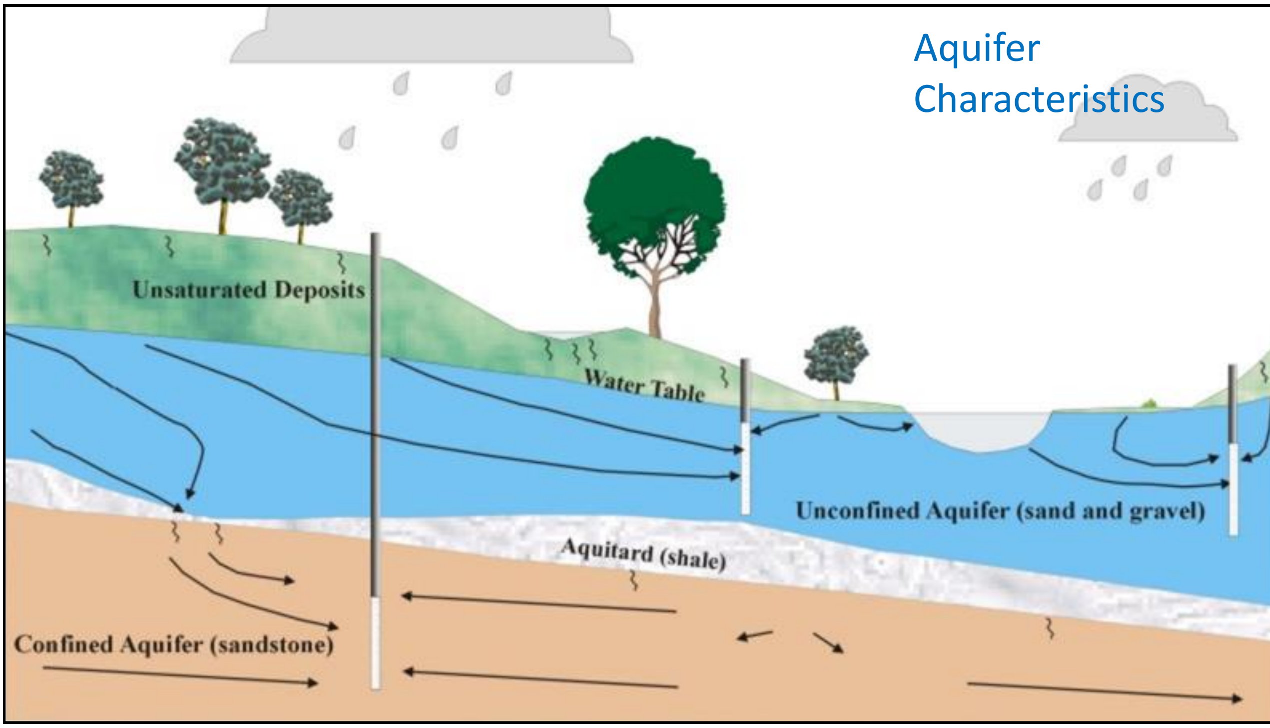
- Record in a database or spreadsheet
- Indicate on map
- Analyze risk
- Determine preventative mitigations

Poorly stored drums are a groundwater pollution risk

Managing the WHPA

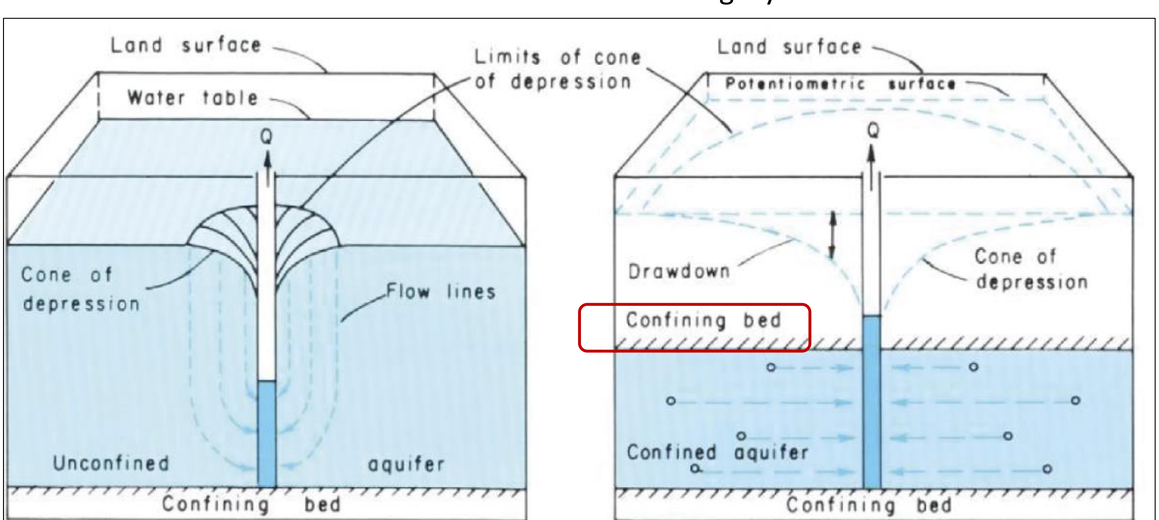
- adoption of zoning restrictions or ordinances
- development of contamination contingency plans
- working with facilities within the WHPA to minimize potential pollution problems
- purchasing property around wells and
- conducting a public educational program

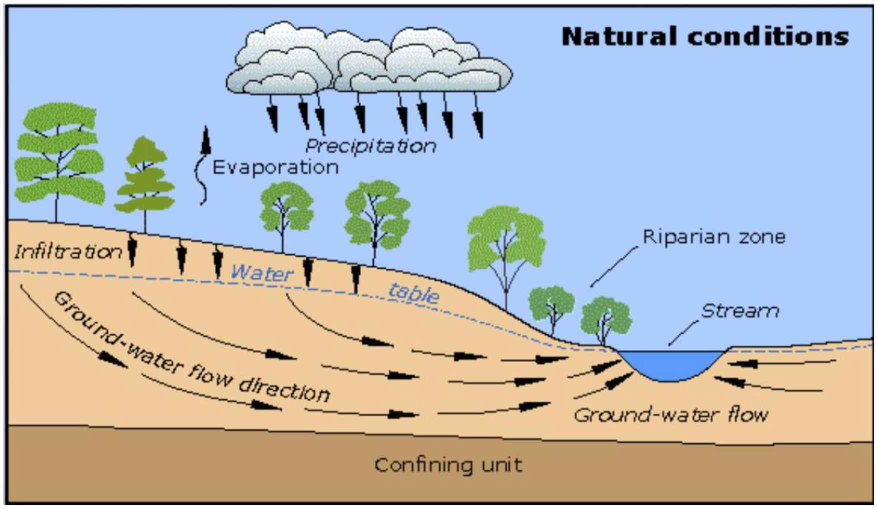
Aquifer Characteristics

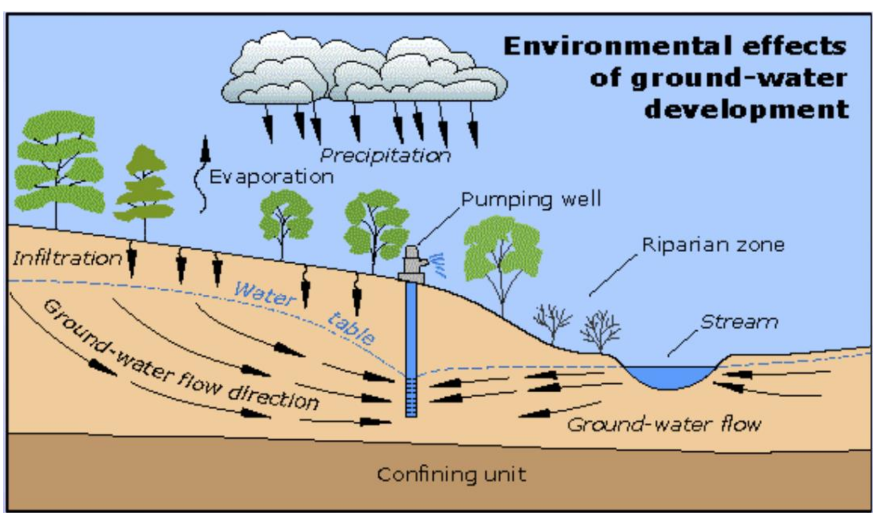


Cone of depression

- Cone of depression in in a confined aquifer is indicated by lower head as you move toward the well. Represented by the potentiometric surface (the level to which water would rise in the absence of a confining layer.




Natural conditions
Precipitation
Evaporation
Infiltration
Water
table
Riparian zone
Stream
Ground-water flow direction
Ground-water flow
Confining unit


Environmental effects
of ground-water
development
Precipitation
Evaporation
Pumping well
Riparian zone
Infiltration
Water
table
Stream
Ground-water flow direction
Ground-water flow
Confining unit

Porosity & Permeability

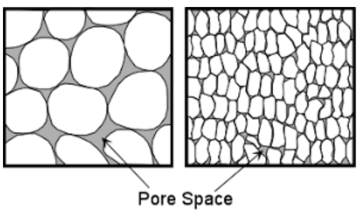
Porosity is a measure of an aquifer material's ability to store water. It is a percent measure of the available space between grains.

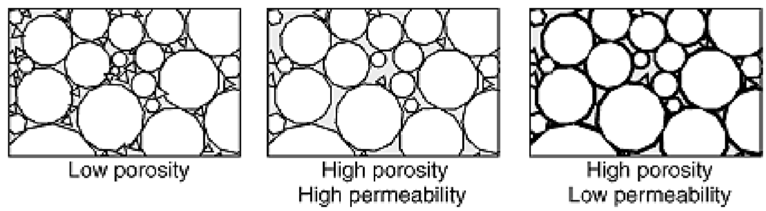
Permeability expresses how well water is able to flow through the aquifer material.

Porosity and Permeability Ranges for Sediments

Sediment Type	Porosity	Permeability
Uniform size sand or gravel	25-50%	High
Mixed size sand and gravel	20-35%	Medium
Glacial Till	10-20%	Medium
Silt	35-50%	Low
Clay	33-60%	Low

Source: U.S. Geological Survey





Hydraulic conductivity is a measure of a material's capacity to transmit water.

- The actual speed of groundwater is usually very slow and depends on the hydraulic gradient and other factors.
- *Porosity, permeability, and hydraulic conductivity can be determined by observing material from well logs or test drilling.*

Unconsolidated Sedimentary Materials	
Material	**Hydraulic Conductivity (m/sec)**
Gravel	3×10^{-4} to 3×10^{-2}
Coarse sand	9×10^{-7} to 6×10^{-3}
Medium sand	9×10^{-7} to 5×10^{-4}
Fine sand	2×10^{-7} to 2×10^{-4}
Silt, loess	1×10^{-9} to 2×10^{-5}
Till	1×10^{-12} to 2×10^{-6}
Clay	1×10^{-11} to 4.7×10^{-9}
Unweathered marine clay	8×10^{-13} to 2×10^{-9}

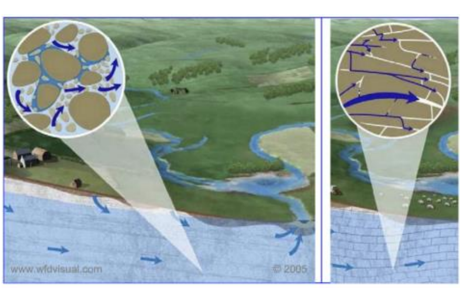
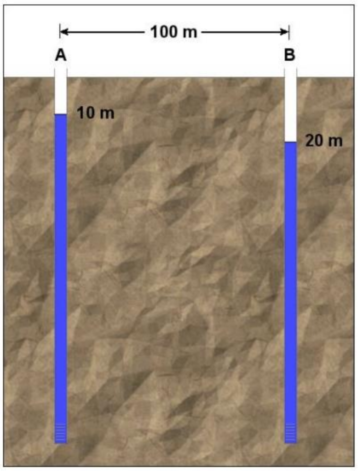


Figure 2-1 Intergranular groundwater flow (left) and fissure flow (right) (Sniffer (2005) www.wfdvisual.com)

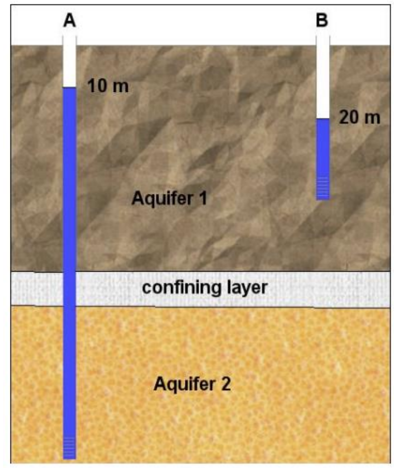
Hydraulic conductivity

Simple Hydraulic Gradient Calculation (2-dimensional)



Concept to practice

- When conducting an actual study, at least three wells would be needed to look at the flow along planes.
- Hydrologists would also make additional calculations that account for wells of different depths and in confined aquifers.
- However, the concept is essentially the same.



Hydraulic gradient $= \frac{10\ m}{100\ m} =$ 0.1 m/m

Hydraulic gradient can't be calculated because the wells are in two different aquifers.

Groundwater velocity

Average Groundwater Velocity can be calculated by the following equation

$$V = \frac{\text{hydraulic gradient} \times \text{hydraulic conductivity}}{\text{effective porosity}}$$

The following calculation was part of the investigation of a PCE contaminant plume for water moving through bedrock.

$$V = \frac{0.0275\ ft/ft \times 0.90\ ft/day}{0.103} = 0.24\ feet/day$$

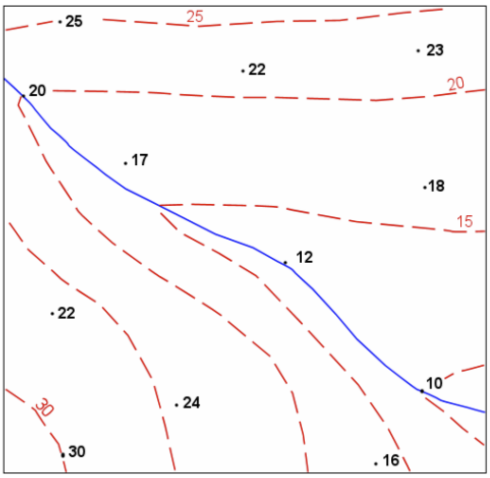
0.24 feet/day x 365 = 87.6 feet per year

Model	Saprolite	Bedrock
Hydrogeology		
Hydraulic Conductivity (ft/day)	0.98	0.90
Hydraulic Gradient (ft/ft)	0.0298	0.0275
Porosity	0.10	0.103
Dispersion		
Longitudinal Dispersivity (ft)	22.2	32.1
Transverse Dispersivity (ft)	2.2	3.2
Adsorption		
Bulk Density (g/cm^3)	1.7	2.2
Partition Coefficient (K_{oc})	318	318
Fraction Organic Carbon	0.001	0.0001
Biodegradation		
Solute Half-Life (years)	4	3.4
Source Half-Life (years)	6	8-9
Initial Source Concentration (µg/L)	25,000	17,000

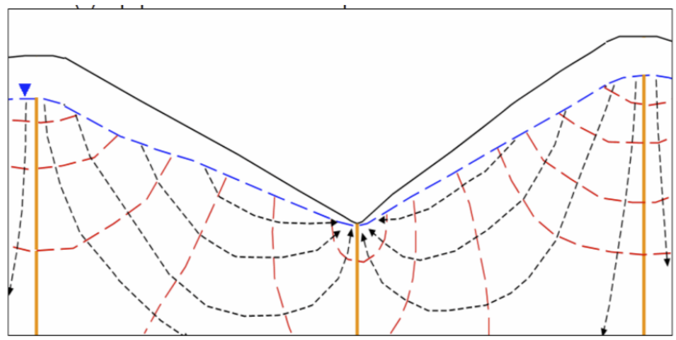
- In practice, the movement of contaminant plumes is affected by chemical and physical interactions and by complexities in material composition of aquifer.
- Adsorption of contaminants onto sand and gravel for example can retard movement of contaminants.

https://www.epa.gov/sites/default/files/2015-06/documents/nbsect5.pdf

Creating diagrams for groundwater flow

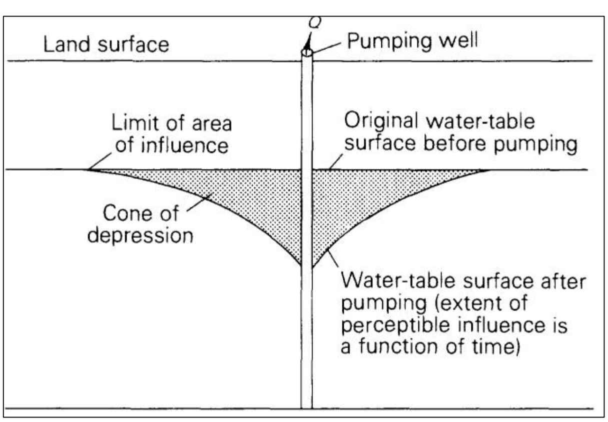


Plan view
Blue = gradient lines of constant head
Red = Flow lines

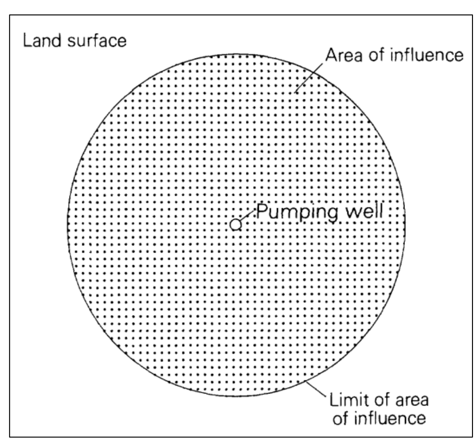


Cross-sectional view
Blue = gradient lines of constant head
Red = Flow lines
Yellow = No flow boundaries (due to confining layers or regions where head does not change.

Area of influence

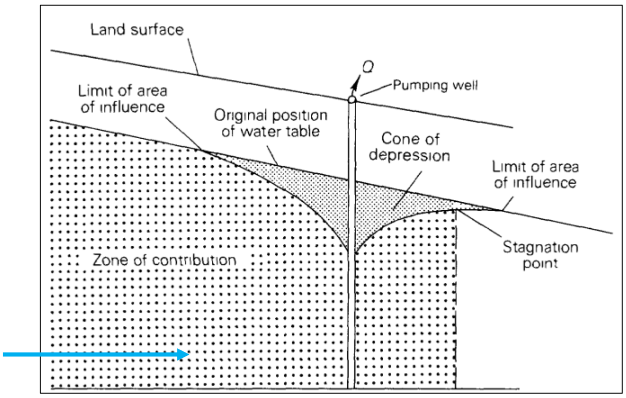


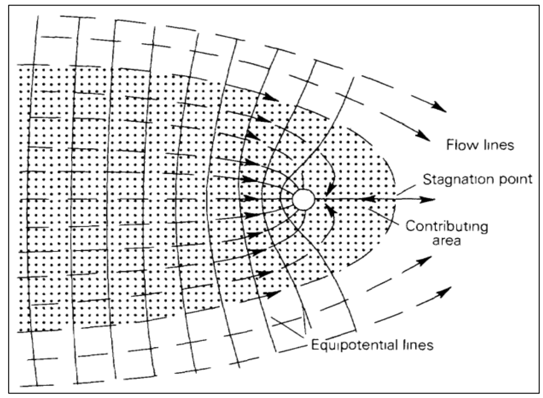
Cross sectional view

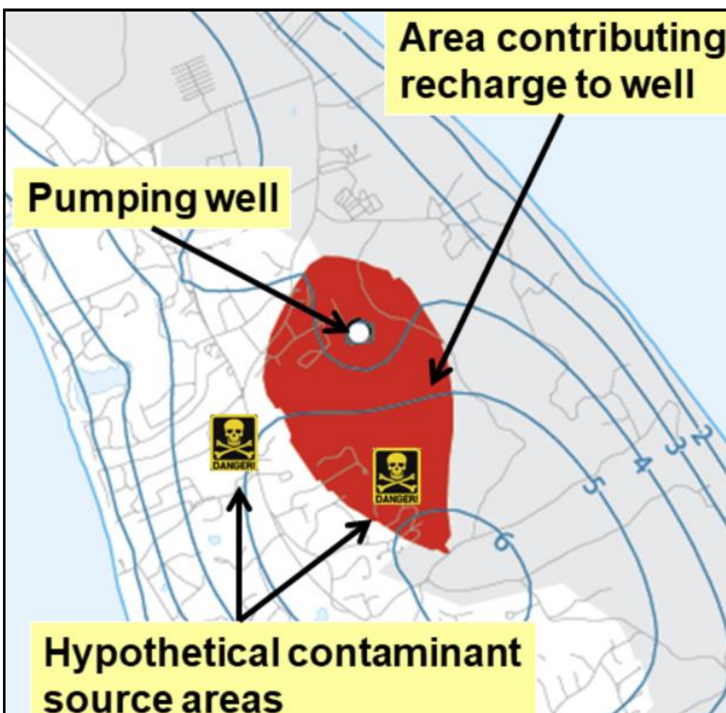


Plan view

Intersection of groundwater flow and area of influence

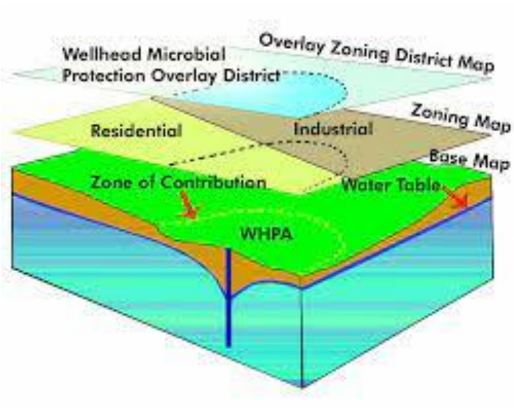


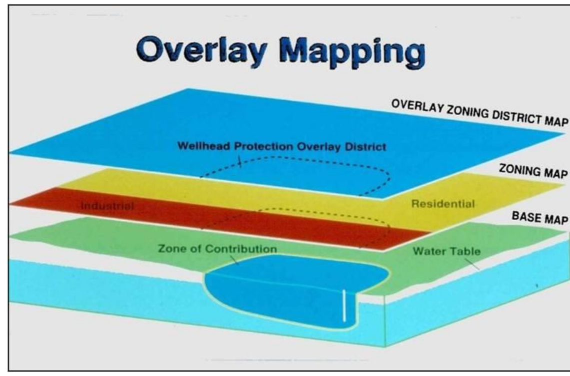




Area of well recharge

- Allows analysis of interaction with potential contamination sites
- Can review intersection with known location of contamination plumes
- Can be overlaid with other types of maps: sewer systems, pipelines, industrial facilities, land usage, roads, etc.





Overlay mapping

Helps to define WHPA in conjunction with roads, railways, industrial, and other features to identify potential threats and guide ordinance development.

Recharge zones map

- Well recharge areas intersection wastewater infiltration beds and lakes
- Blue lines show elevation height of water table

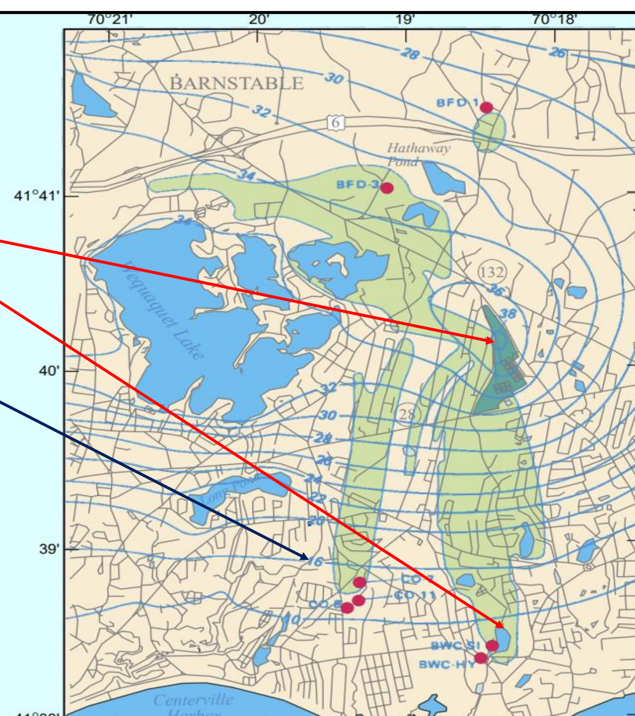
EXPLANATION

Wastewater-treatment-facility infitration beds

Areas contributing recharge to public-supply wells

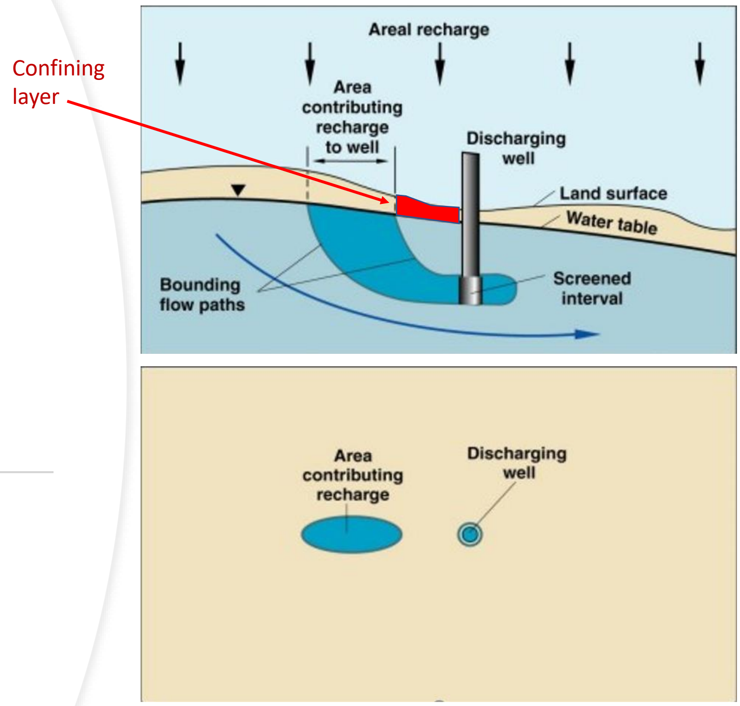
24 — Water-table contour–Shows calculated altitude of water table. Contour interval, in feet, is variable. Datum is sea level

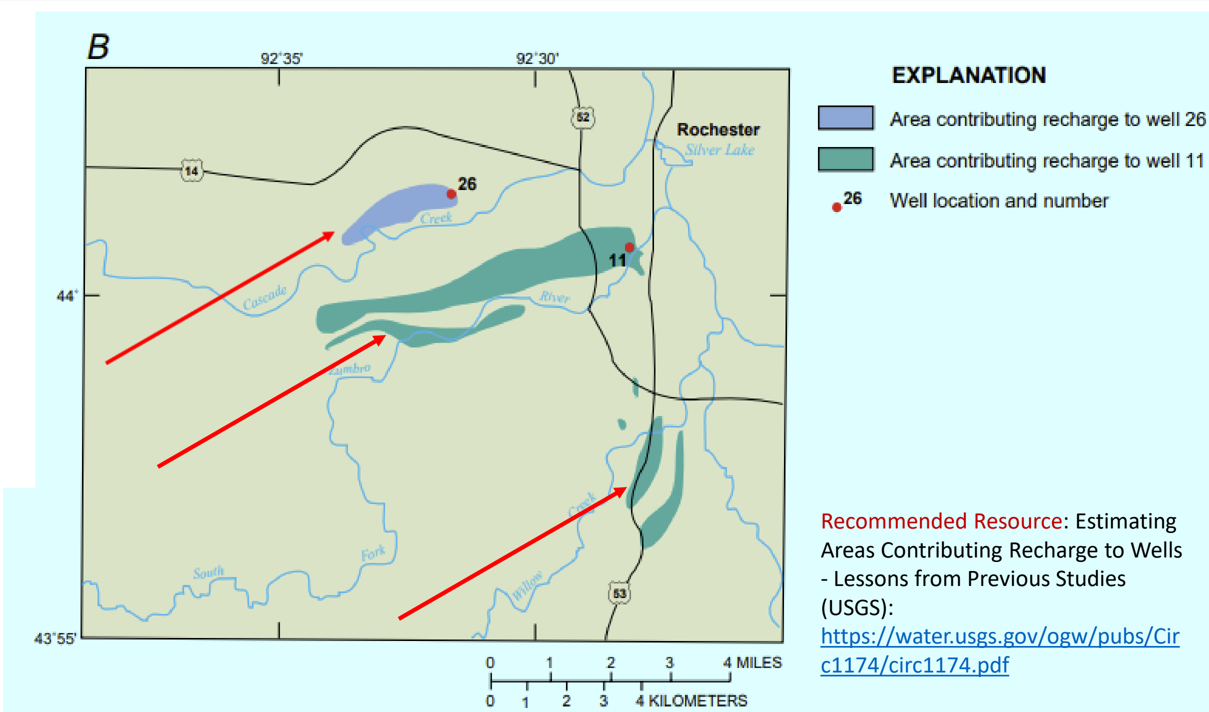
BFD-1 Public-supply well and local well number



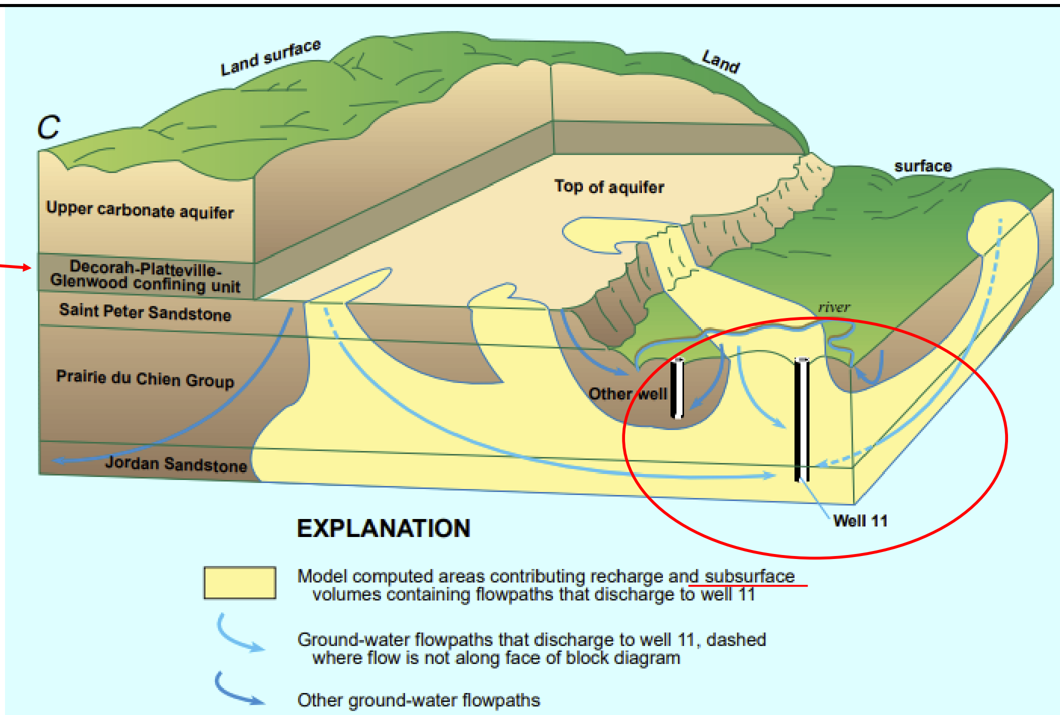
Recharge area affected by confining layers

Investigation of aquifer material may reveal that confining layers are present that prevent or limit recharge in some areas

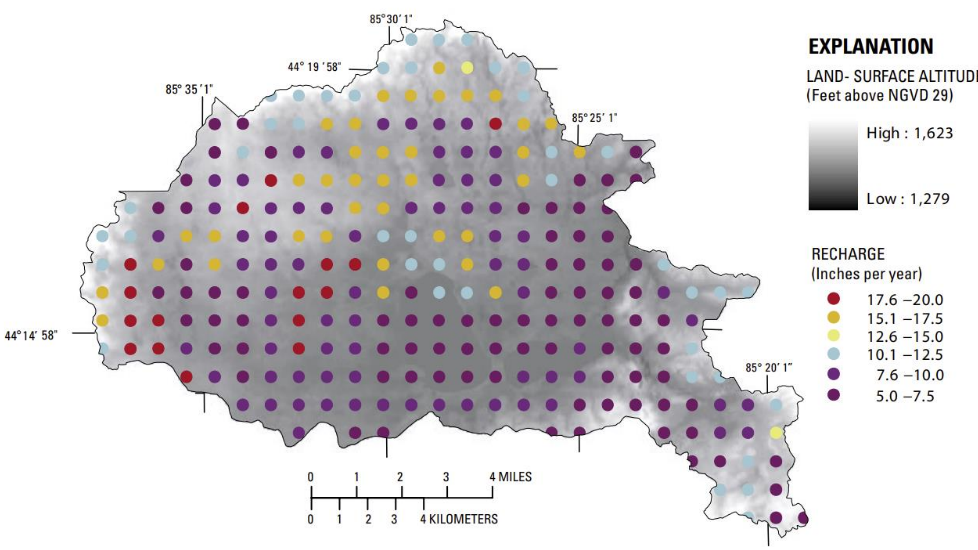




Recommended Resource: Estimating Areas Contributing Recharge to Wells - Lessons from Previous Studies (USGS): https://water.usgs.gov/ogw/pubs/Circ1174/circ1174.pdf



Recharge area map



Simulation of Ground-Water Flow and Areas Contributing Ground Water to Production Wells, Cadillac, Michigan (USGS 2005)

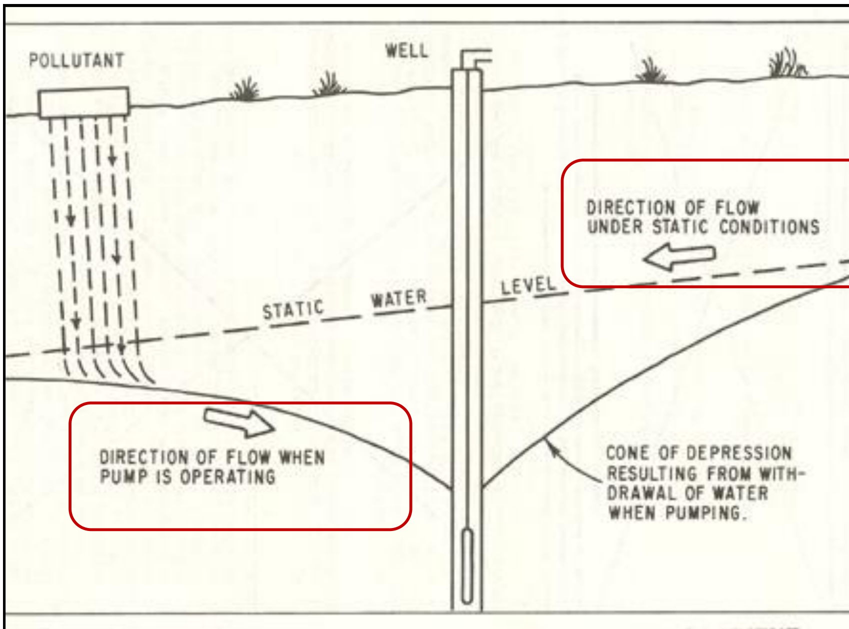
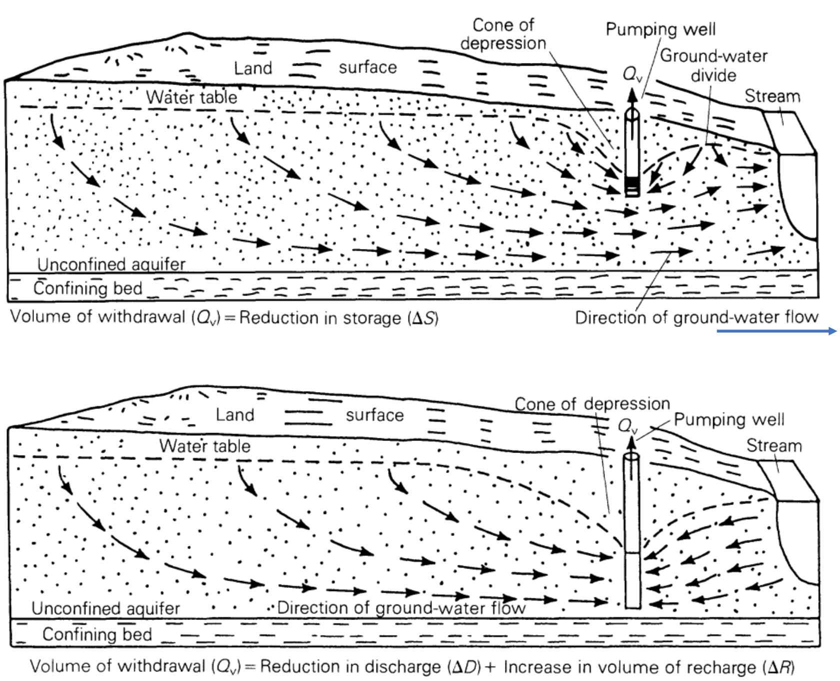


Figure 3. EFFECT OF REVERSAL OF GROUND WATER GRADIENT

Impacts of Well Pumping on Groundwater Flow

- Pumping of a groundwater well can affect natural ground water flow.
- In this diagram, the natural groundwater flow is reversed.
- This has implications about the location of the recharge area and how contaminant plums interact with the recharge area.

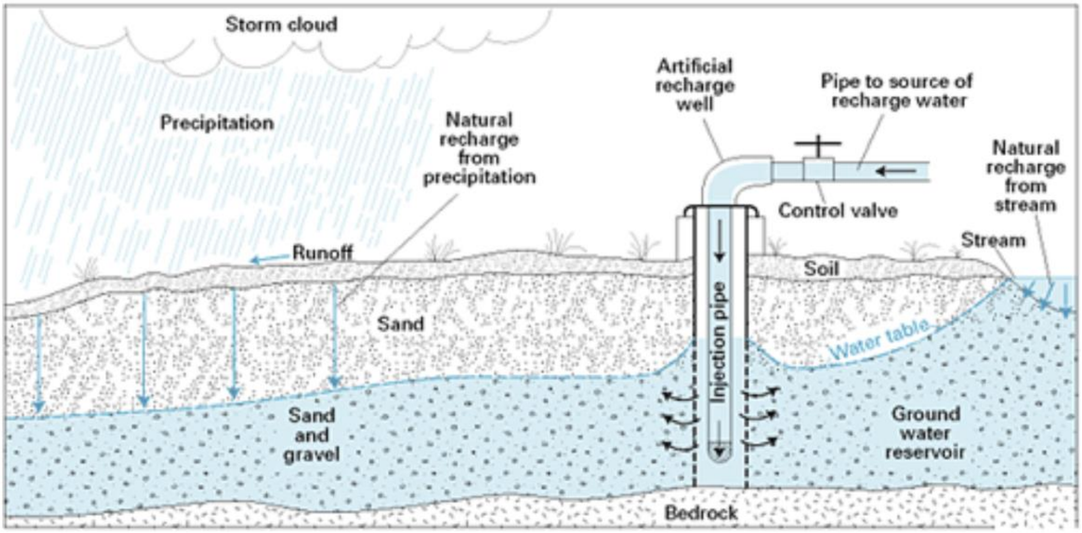


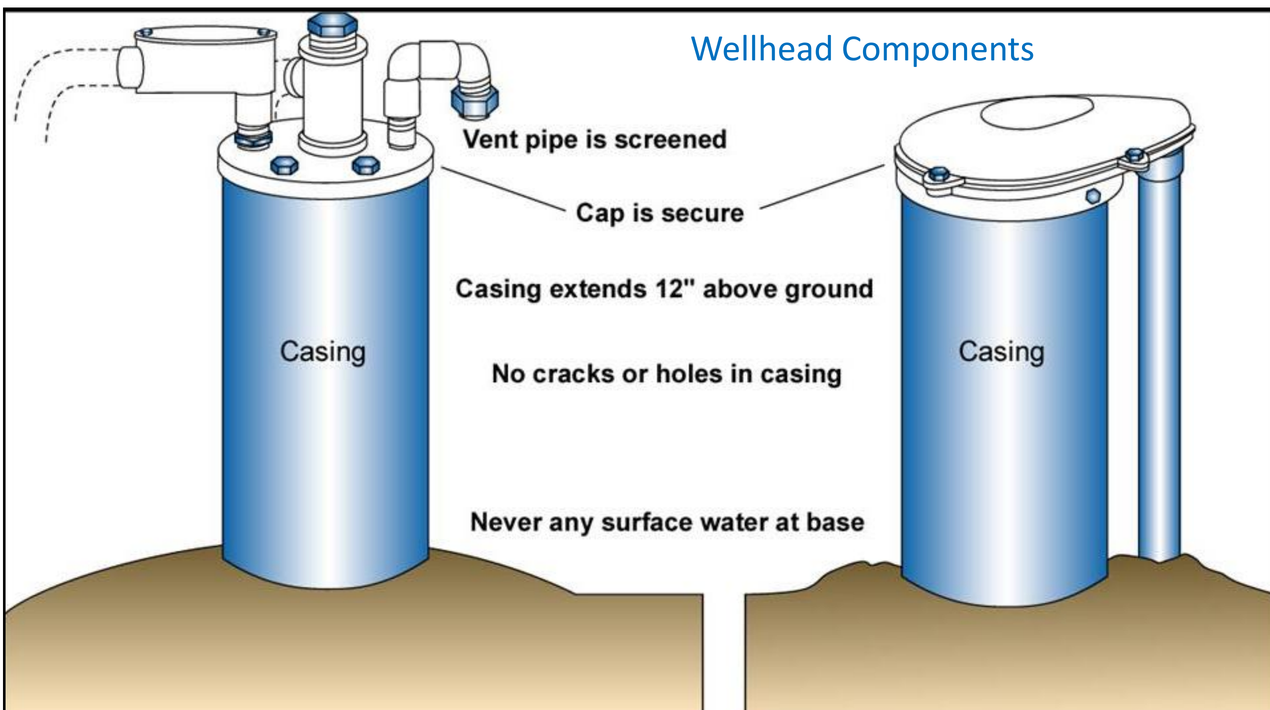
Effects of increased pumping rate

Safe well yield
Groundwater flow naturally discharges to a stream. Pumping rate #1 reduces this discharge but does not reverse it.

Increased pumping rate
Pumping rate #2 reverses natural discharge to stream and causes leads to groundwater under the direct influence of surface water (GWUDI).

Ways that groundwater recharge can occur





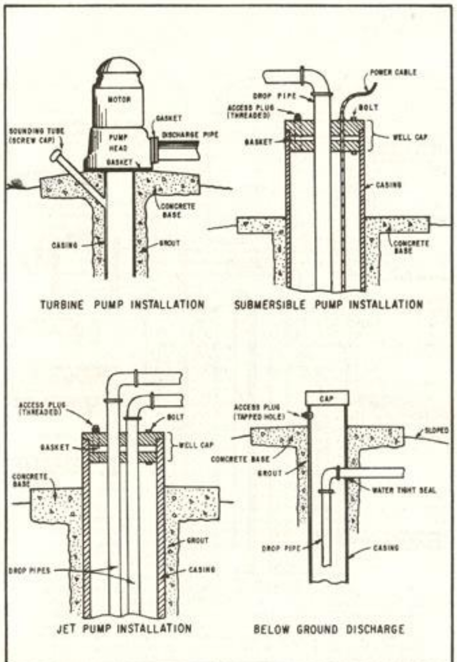
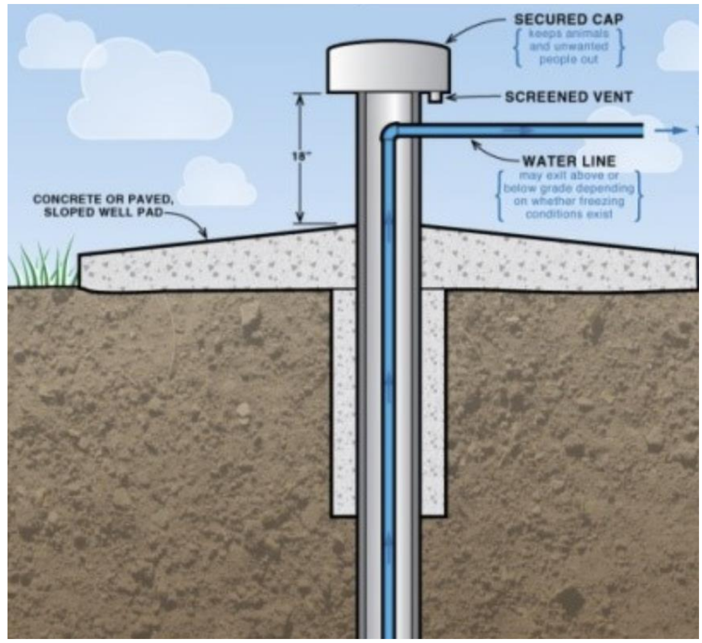
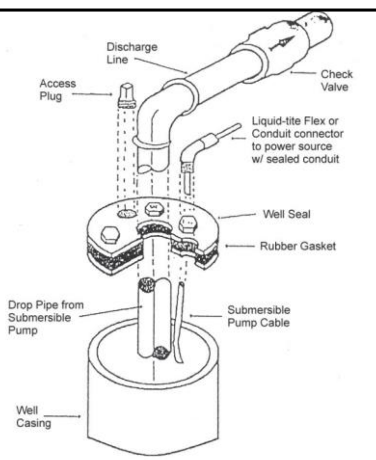
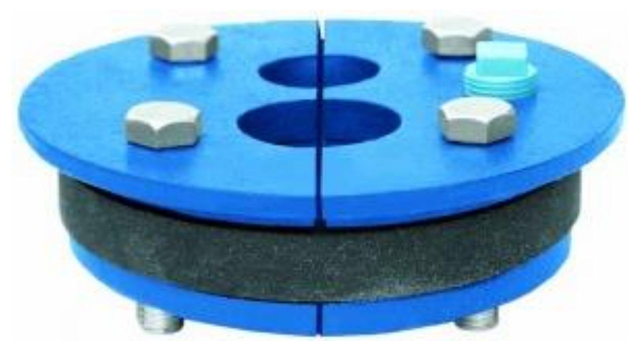


Figure 6. TYPICAL SURFACE CONSTRUCTION FEATURES

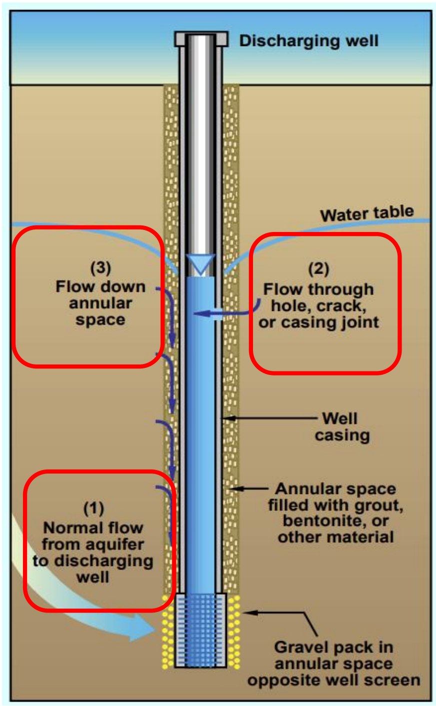






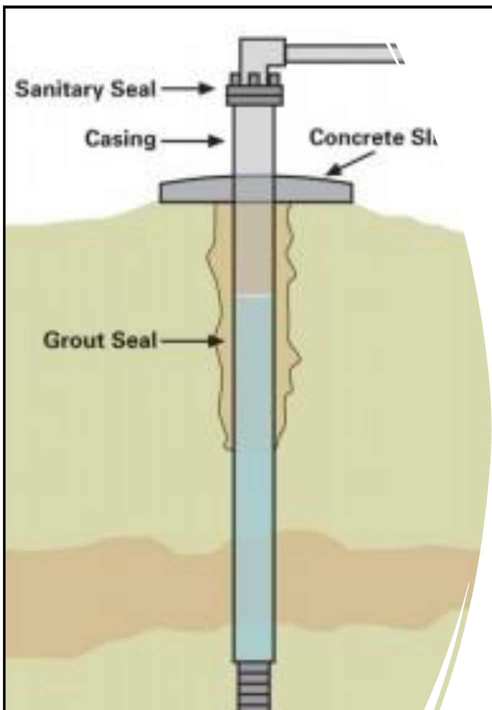
Well Sanitary Seal

- Provides an air-tight seal that prevents the entrance of contaminants.



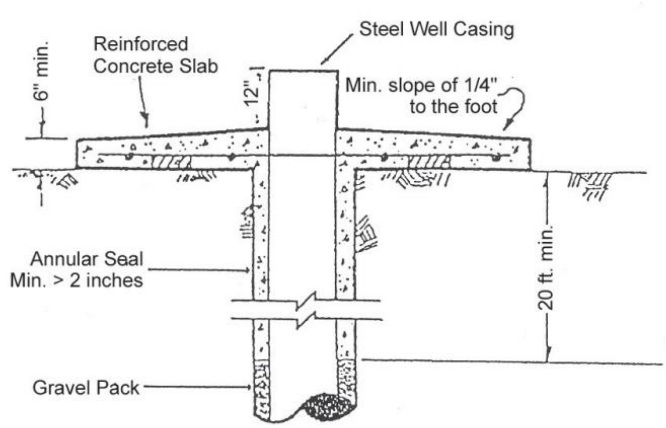
Contamination entry points

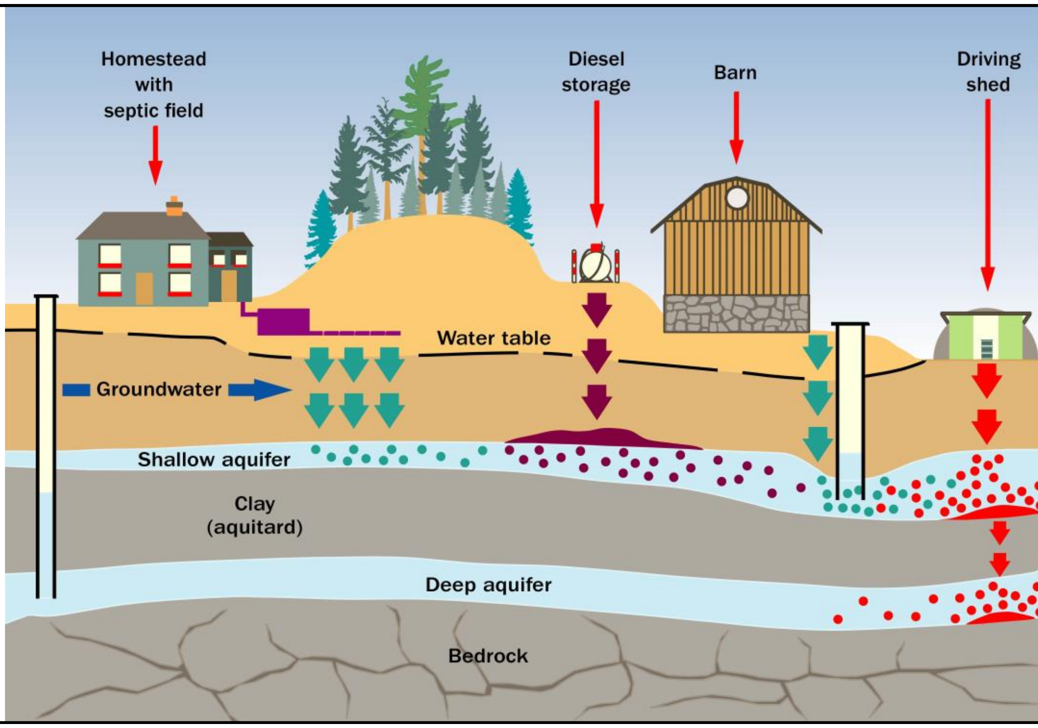
1. Normal flow from aquifer
2. Flow through casing crack or joint
3. Flow down through unsealed annular space



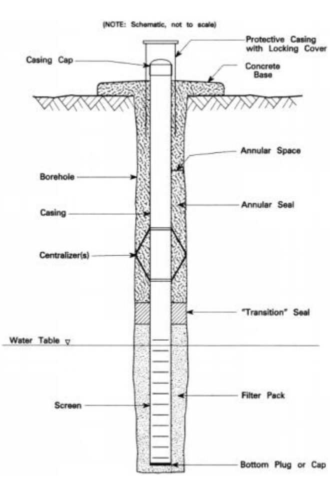
Grout seal

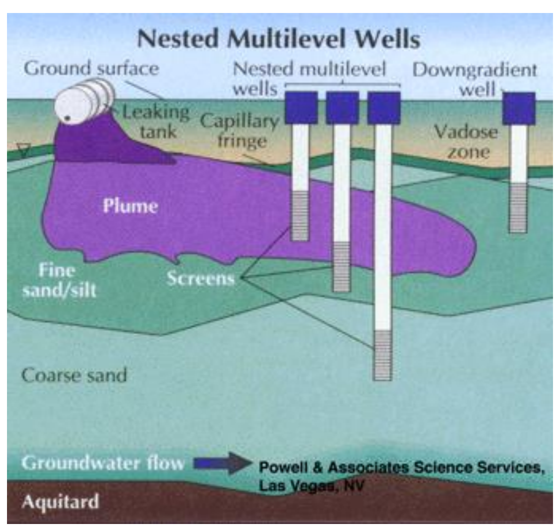
- Seals the annular space between the casing and the bore hole.
- Prevents intrusion of flood waters and lower quality shallow ground water into the casing.



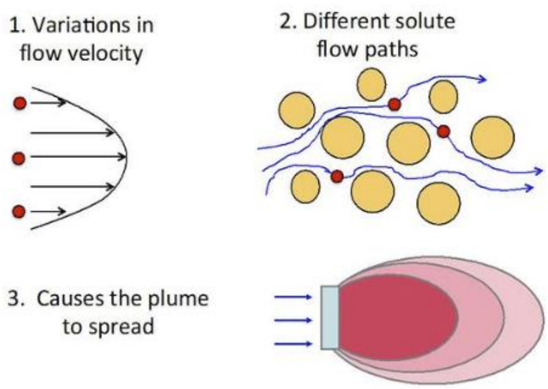


Monitoring wells

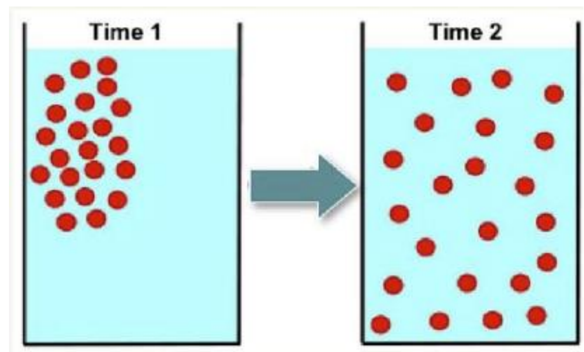




Physical causes of plume spread



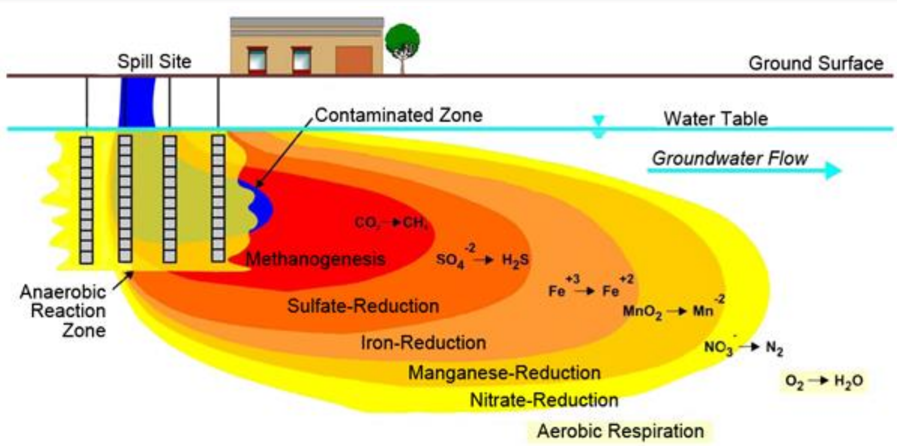
Mechanical Dispersion

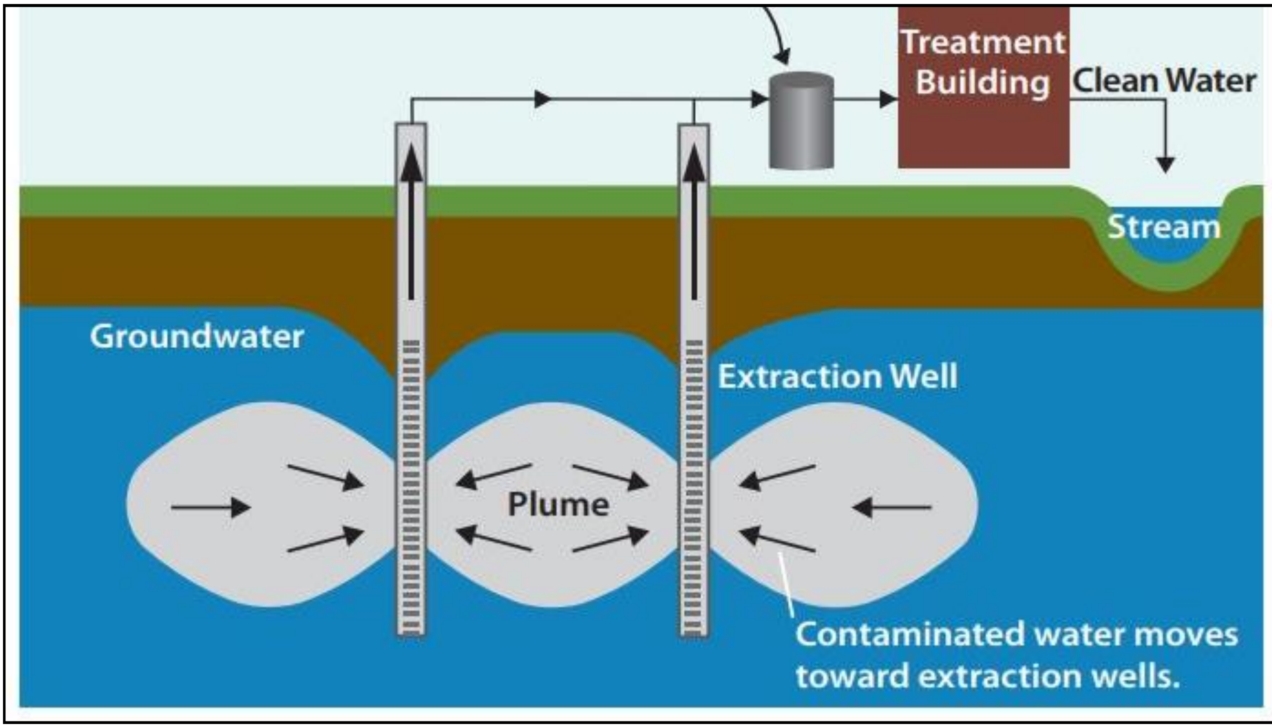


Diffusion of dissolved chemicals

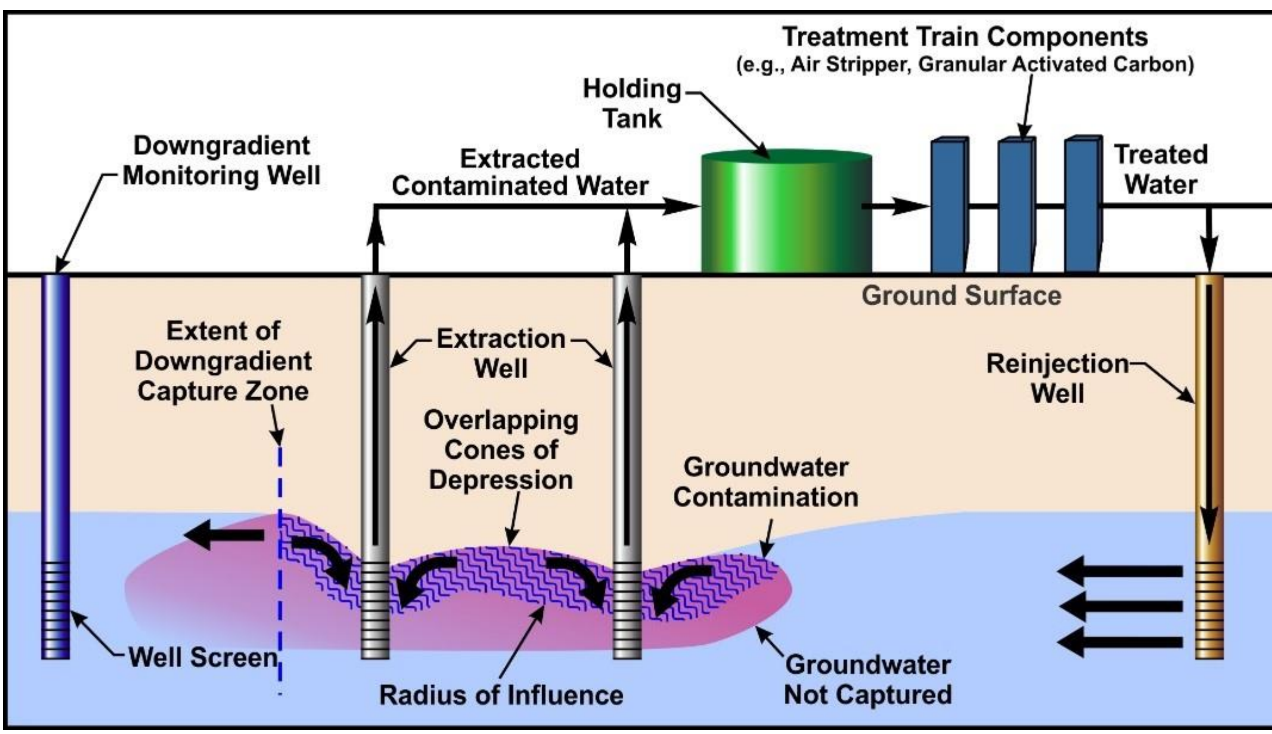
Bioremediation

- Adding oxygen and nutrients to consume midweight hydrocarbon based pollutants such as diesel and jet fuel. Pollutants are consumed by bacteria.





Treatment Building
Clean Water
Stream
Groundwater
Extraction Well
Plume
Contaminated water moves toward extraction wells.



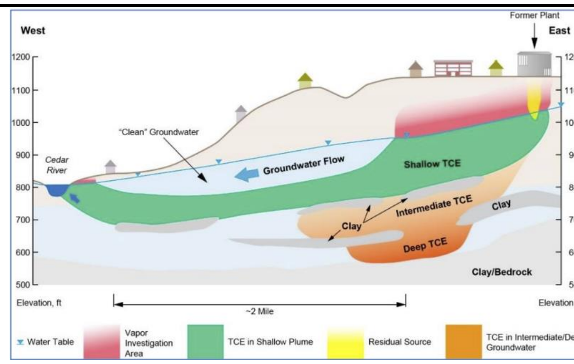
Treatment Train Components
(e.g., Air Stripper, Granular Activated Carbon)
Holding Tank
Downgradient Monitoring Well
Extracted Contaminated Water
Treated Water
Ground Surface
Extent of Downgradient Capture Zone
Extraction Well
Reinjection Well
Overlapping Cones of Depression
Groundwater Contamination
Well Screen
Radius of Influence
Groundwater Not Captured

Kalkaska MI TCE Plume

TCE (trichloroethylene) is a manmade degreasing solvent that was dumped in shallow, sandy pits in Mancelona from 1947-1967 at the site of the Wickes Manufacturing plant.

- Has contaminated 13 trillion gallons of groundwater in Antrim County, MI
- Exposure occurs when: TCE contaminates drinking water supplies, vents to surface water, or vapors enter buildings
- TCE is a known human cancer-causing agent. Long term exposure can adversely affect liver, kidney, immune system and/or central nervous system function
- Travelling at 50 feet to 525 feet per year depending on depth
- 130 monitoring wells installed over the last 20 years to track the plume, however treatment is not being provided

Wickes-Manufacturing-TCE-Plume-Fact-Sheets-January-2012



Walkerton Canada e-coli

Heavy rains caused water contaminated with e-coli bacterial from nearby fields spread with manure to enter a well. The characteristics of the glacial till aquifer allowed contaminated water to enter the well screen.

- Operators ignored loss of chlorine residual and falsified records.

- 7 people died and over 2,000 people sick


THE TORONTO STAR

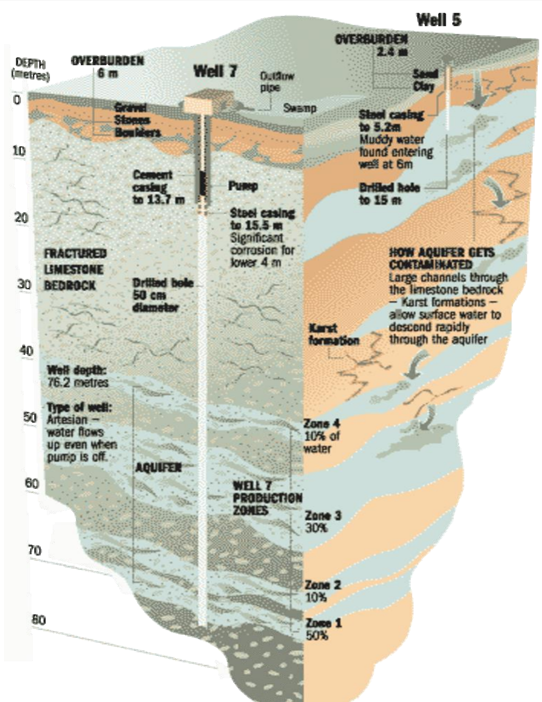
Jackie Chan rides again

Air force showdown

Here's a first aid primer

Police probe E. coli crisis

'Preventable' tragedy claims fifth victim



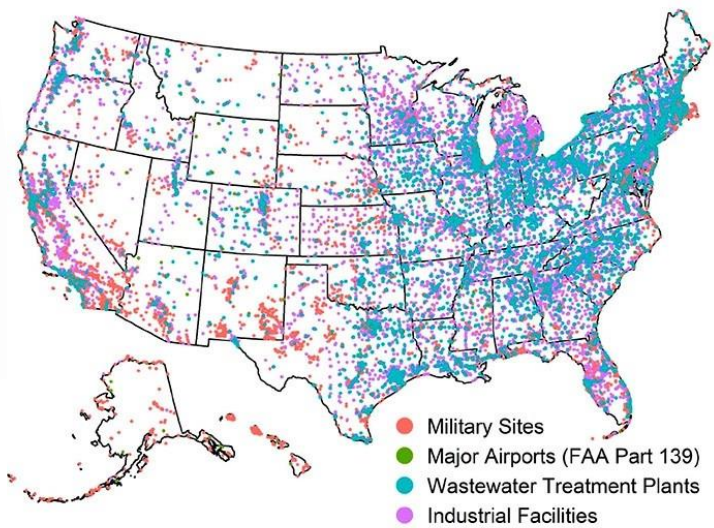
PFAS contamination


NEWS

Toxic chemical foam plume discovered at Camp Grayling airfield

Updated: May 19, 2017, 10:15 p.m. | Published: May 19, 2017, 9:15 p.m.

Presumptive Contamination Sites (n=57,412)

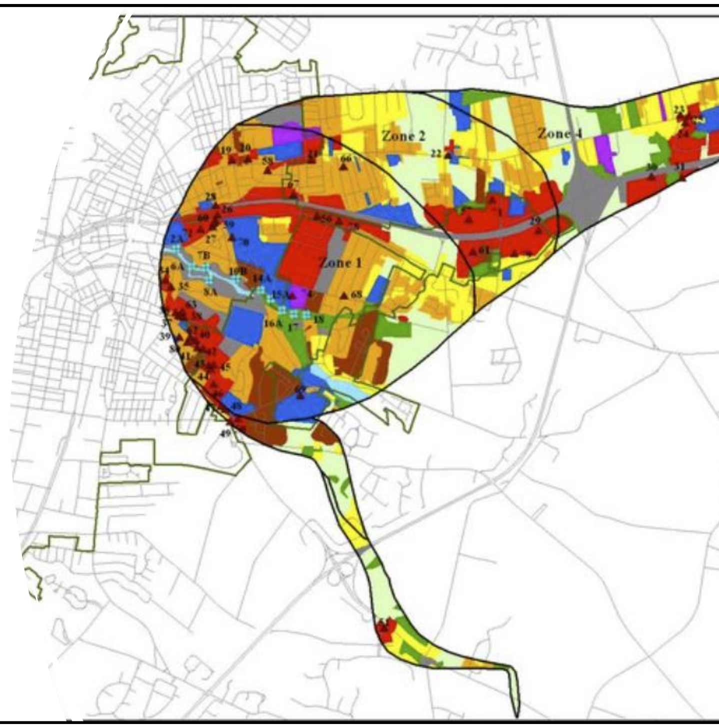


Ordinances

- **Establish minimum distances from wells**
- **Zoning ordinances for activities and businesses**
- Procedures for new wells
- waste disposal guidelines
- Best practices for chemicals
- involve local officials & businesses
- Public outreach

Monitoring

1. Look for trends in entry point sampling
2. Consider installing monitoring wells at key locations
3. Also, gather data from private wells, streams, springs
4. Sampling of raw well water quality
5. Become knowledgeable about contamination sources in the WHPA
   - USTs
   - chemical storage facilities
   - landfills
   - manufacturing activities

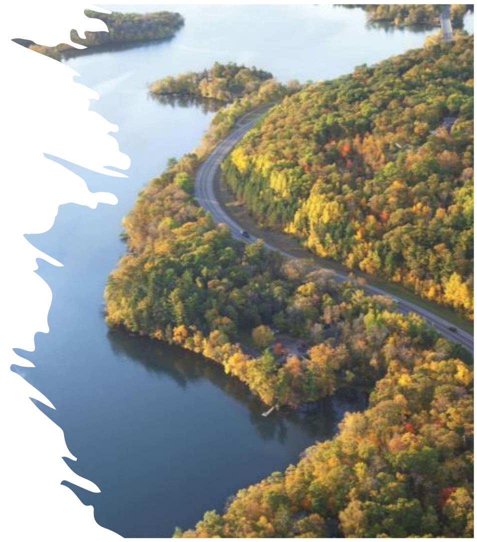


Summary

1. **Form a Wellhead Protection Committee** and determine roles and responsibilities.
2. **Determine what delineation method is best** for your utility (pre-prescribed radius, calculated radius, or hydrogeologic investigation).
3. **Delineate the WHPA**
4. **Create an overlay map of WHPA** (zoning, wastewater system, waterways, roads, etc.)
5. **Inventory contaminant sources** within the WHPA
6. **Establish ordinances** and best practices
7. **Inform and educate** stakeholders and public

Thank you for attending!

Remember to download the slides and reference list. Contact us if you would like to learn more or request one-on-one technical assistance.



Great Lakes Environmental Infrastructure Center

Environmental Finance Center for EPA Region 5

Contact

Environmental Finance Center Network – national collaboration of all EFCs. Find resources, request technical assistance, register for no-cost training events.

https://efcnetwork.org/

Great Lakes Environmental Infrastructure Center – the Region V EFC.

https://gleic.org/

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