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Great Lakes Environmental Infrastructure Center

Environmental Finance Center for EPA Region 5

Wellhead Protection: Concepts and Practices

Tuesday, July 8, 2025

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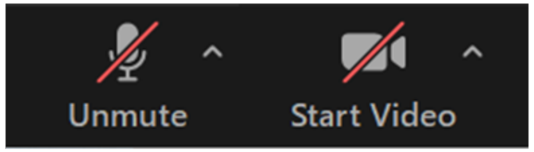

Asking a Question

Type questions into the chat box any time throughout the session

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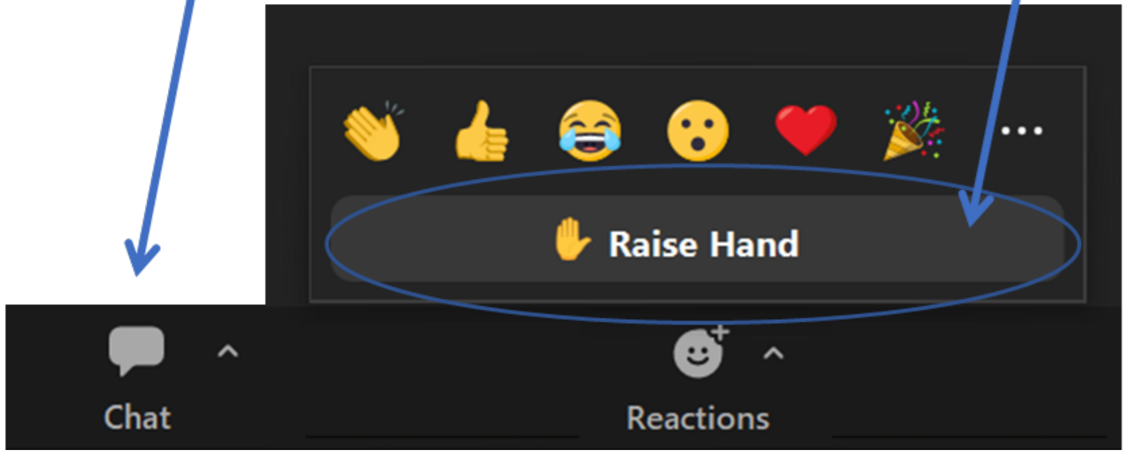

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Certificate of Completion

This session has **NOT** been submitted for pre-approval of Continuing Education Credits, but eligible attendees will receive a certificate of attendance for their personal record.

To receive a certificate:

- 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

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

EFCN
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About Us

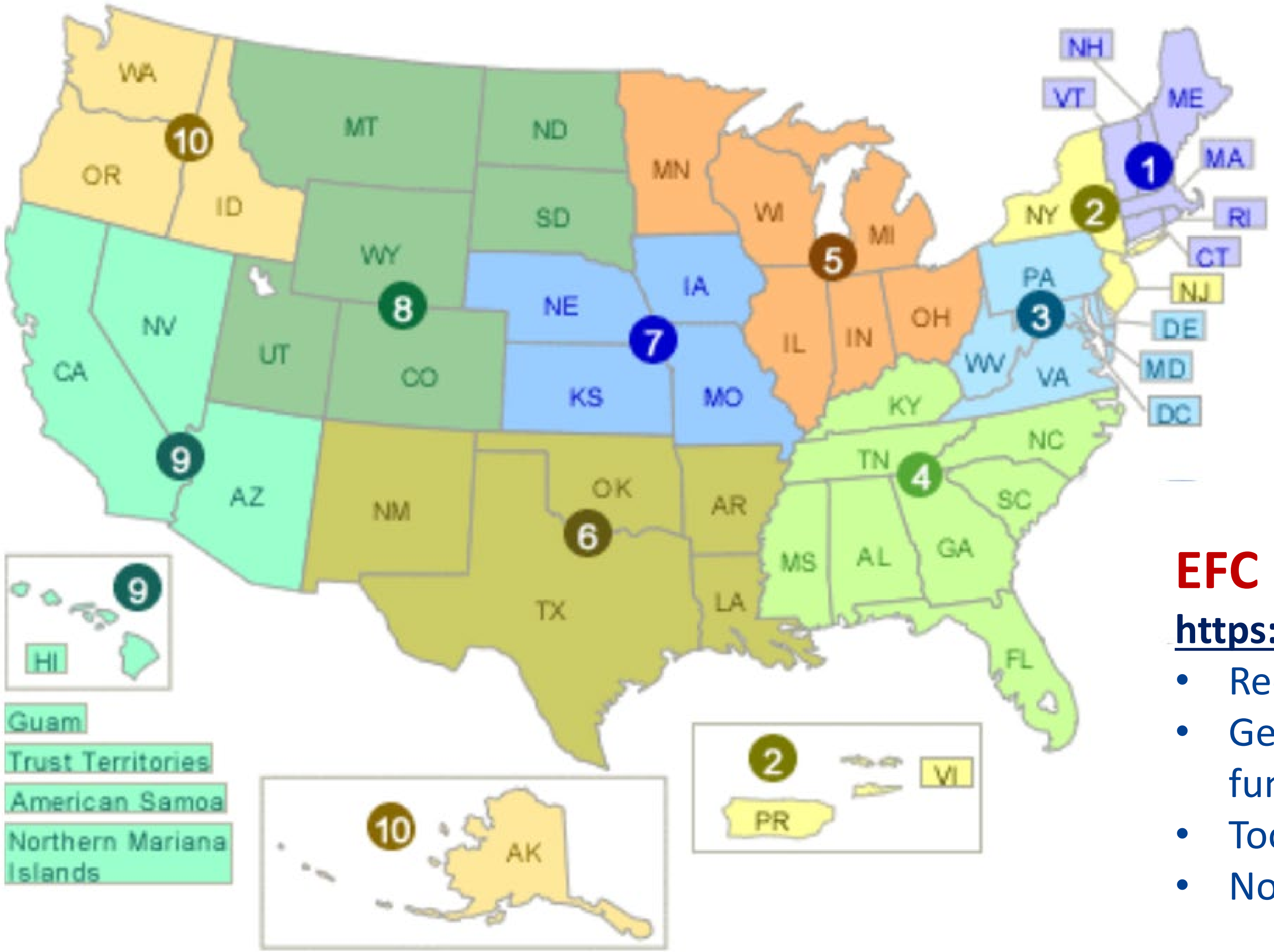
The **Environmental Finance Center Network (EFCN)** is a university- and non-profit-based organization creating innovative solutions to the difficult how-to-pay issues of environmental protection and water infrastructure.

The EFCN works collectively and as individual centers to address these issues across the entire U.S, including the 5 territories and the Navajo Nation. The EFCN aims to assist public and private sectors through training, direct professional assistance, production of durable resources, and innovative policy ideas.

EFCN environmental finance center network

Nationwide reach of EFC Network

USEPA Environmental Finance Centers
https://www.epa.gov/waterfinancecenter/efcn



EFC Network

https://efcnetwork.org/

- Request technical assistance
- Get help with infrastructure funding
- Tools, resources
- No cost

EFCN
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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: Indiana, Illinois, Michigan, Minnesota, Ohio, Wisconsin, and 35 federally recognized American Indian governments.

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

Greg Pearson, MBA Water & Wastewater Systems Trainer

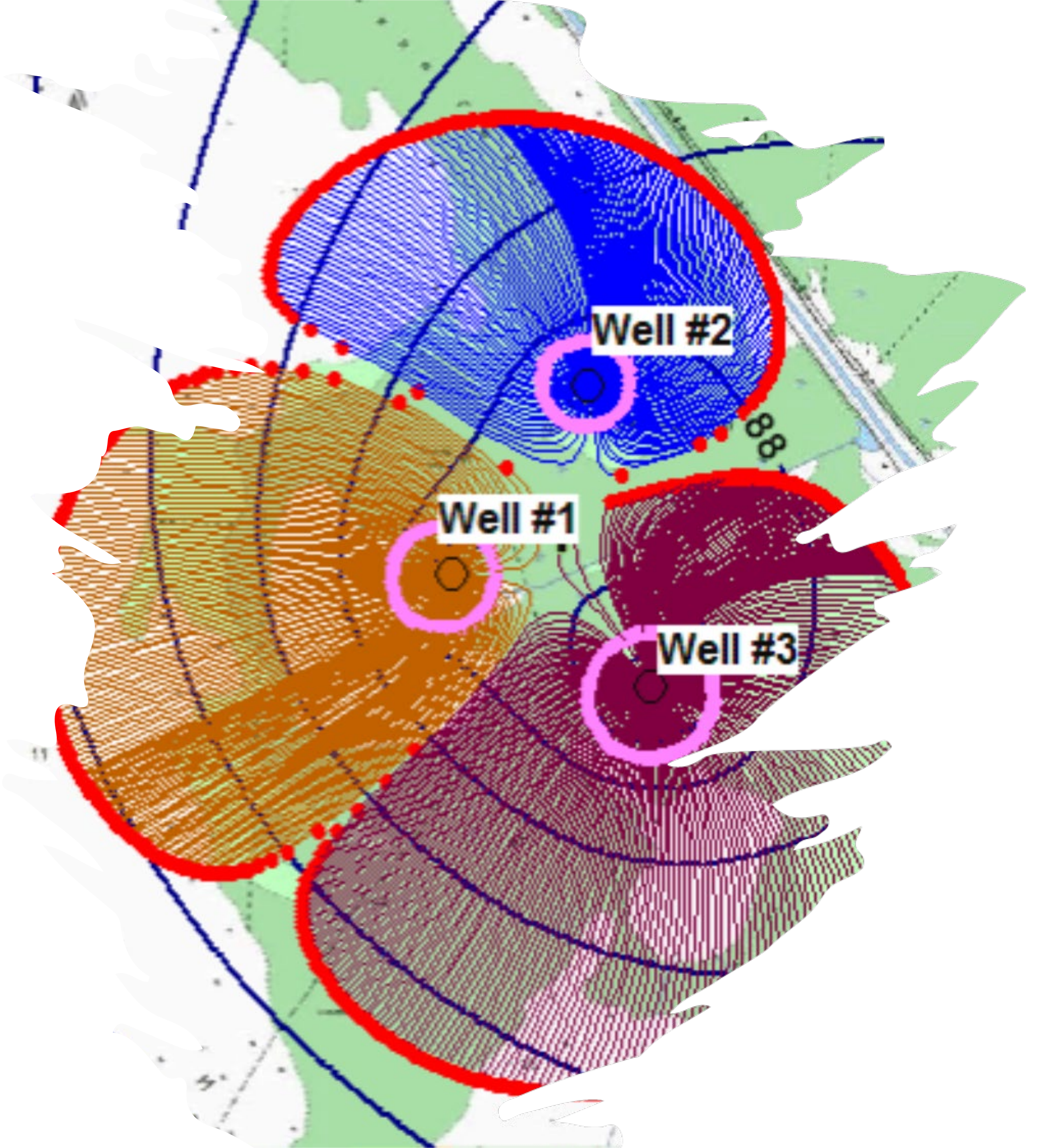
What we will cover today

1. Source water protection concepts
2. Wellhead protection planning steps
3. Hydrogeology concepts (basic)
4. Well construction
5. Where to begin and next steps

- Please share your expertise, ask questions and network with other attendees in the chat

Resources

- Links to guidance documents, templates, and studies
- Access to the nation-wide EFC network



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Wellhead protection basic 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.

Pathogens, pollutants

Source Protection

Treatment

Disinfection

WQ testing

Sanitary Surveys

Backflow Prevention

- **Multiple barrier approach** – creating multiple protective barriers to contamination of drinking water.
- **Wellhead protection** – determining and analyzing threats to groundwater, developing ordinances, sanitary construction and maintenance practice.

Source water protection concepts

Consumer Drinking Water

EPA Source Water Protection

(1) **Delineate**: Define and map the area to be protected

(2) **Inventory**: Identify sources of contamination within the protected zone.

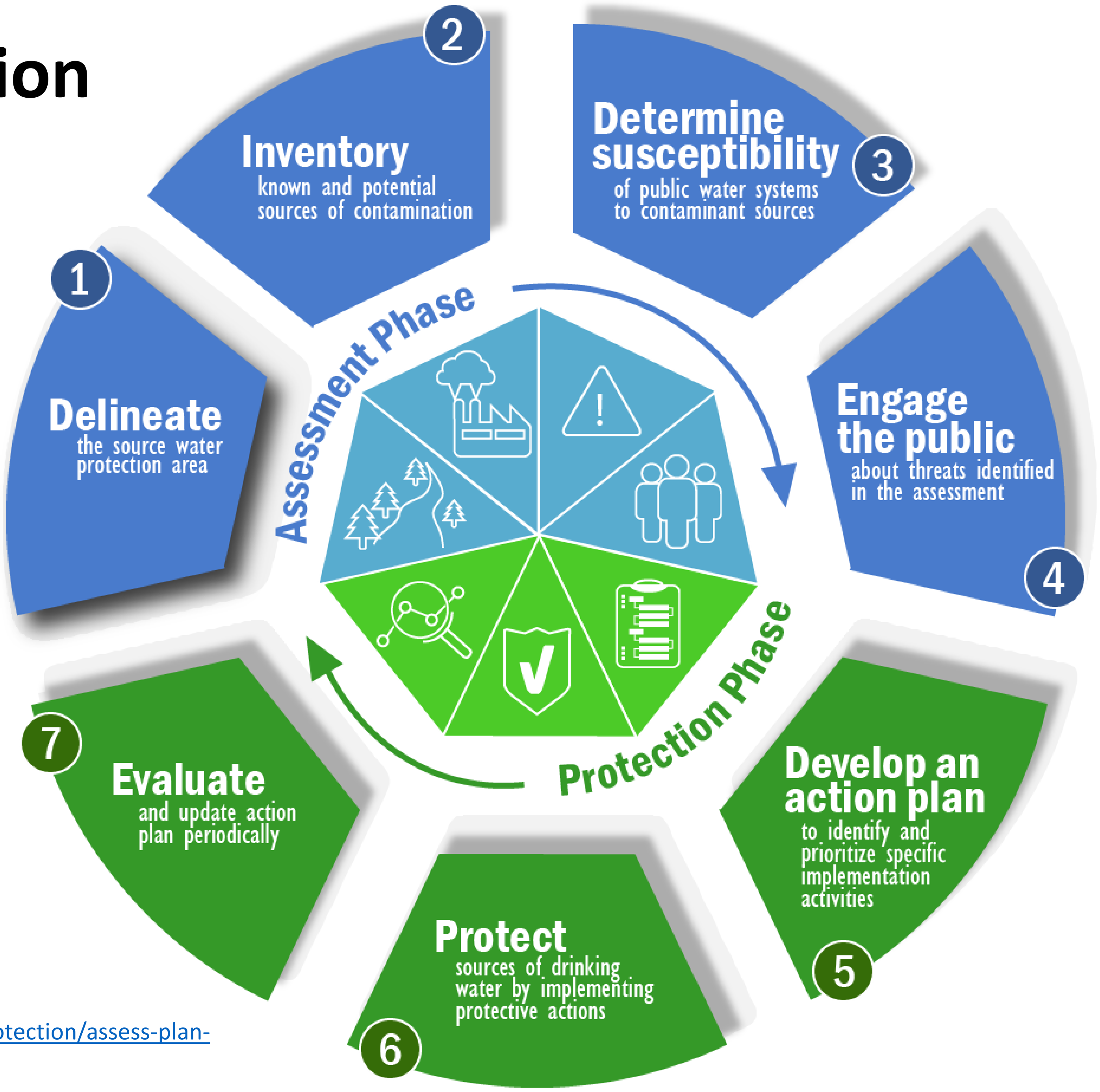
(3) **Determine susceptibility**: Analyze the risk of each contaminant source.

(4) **Engage the public**: Public education and communication about threats

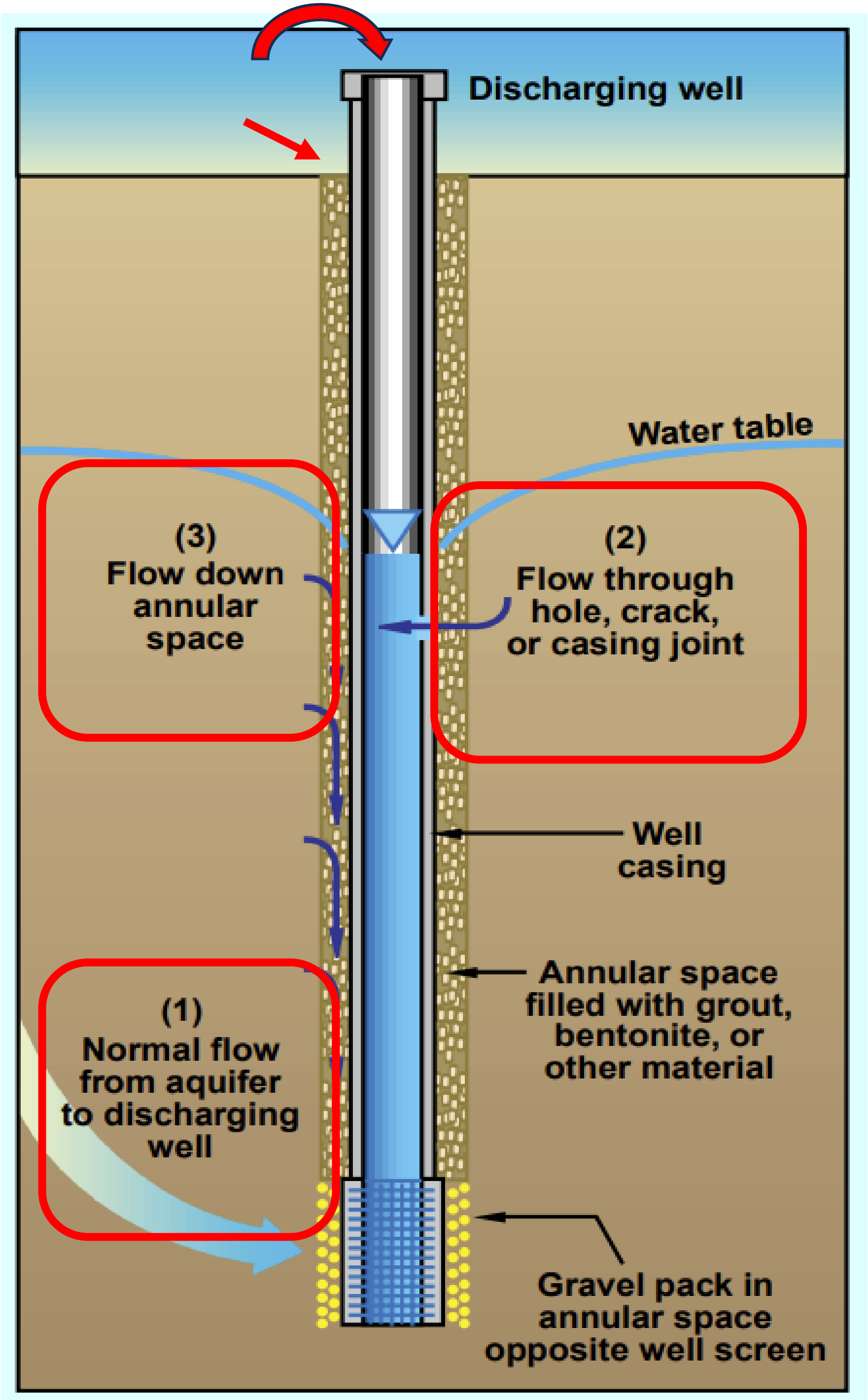
(5) **Action Plan**: Plan to mitigate and recover from prioritized risks.

(6) **Protect**: Implement protective actions

(7) **Evaluate**: Periodic updates and evaluation of Wellhead Protection Plan.

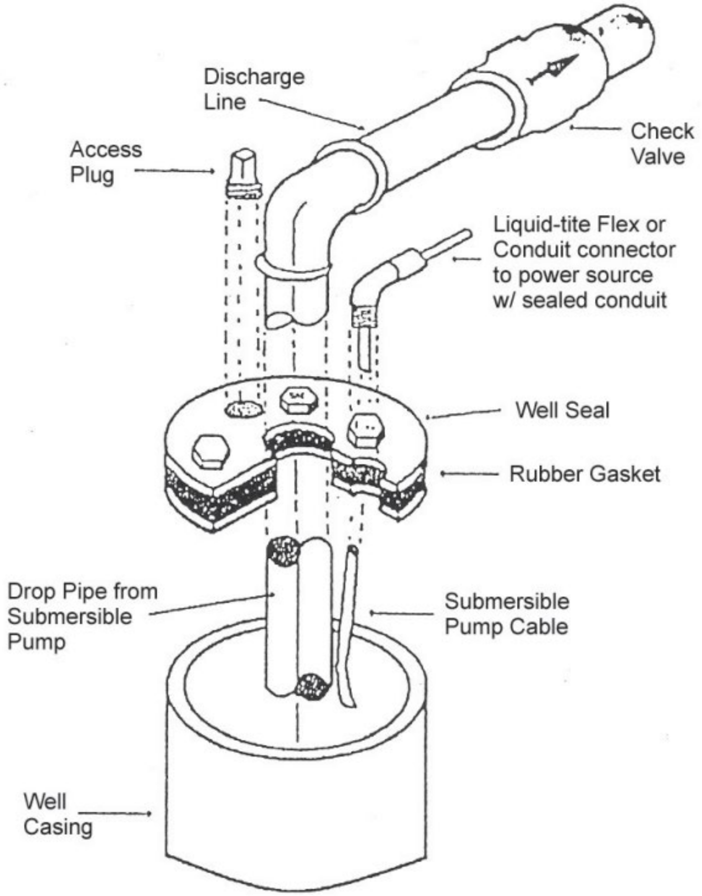


https://www.epa.gov/sourcewaterprotection/assess-plan-and-protect-source-water



Contamination entry points

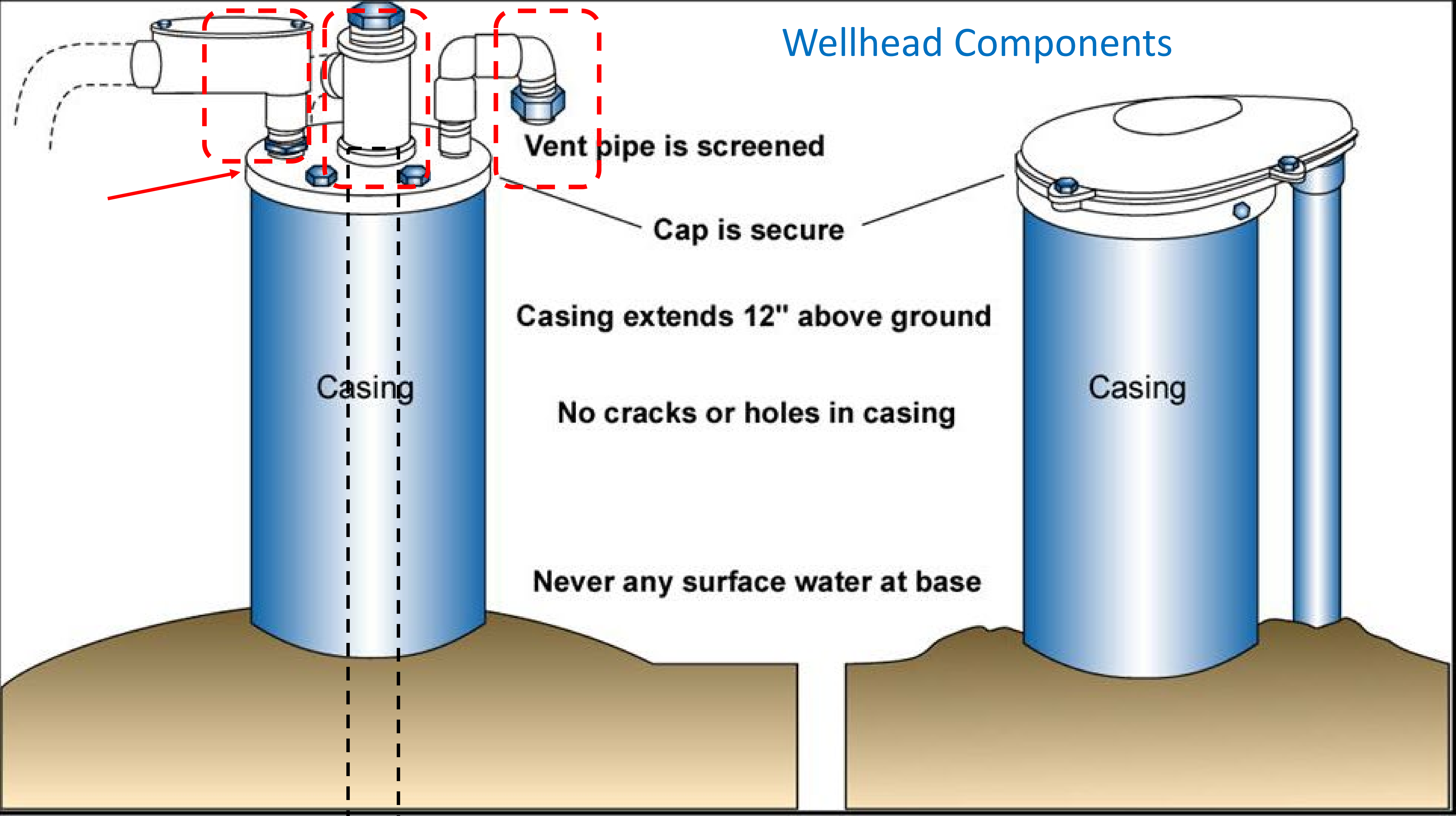
1. Normal flow from aquifer
2. Flow through casing crack or joint
3. Flow down through unsealed annular space



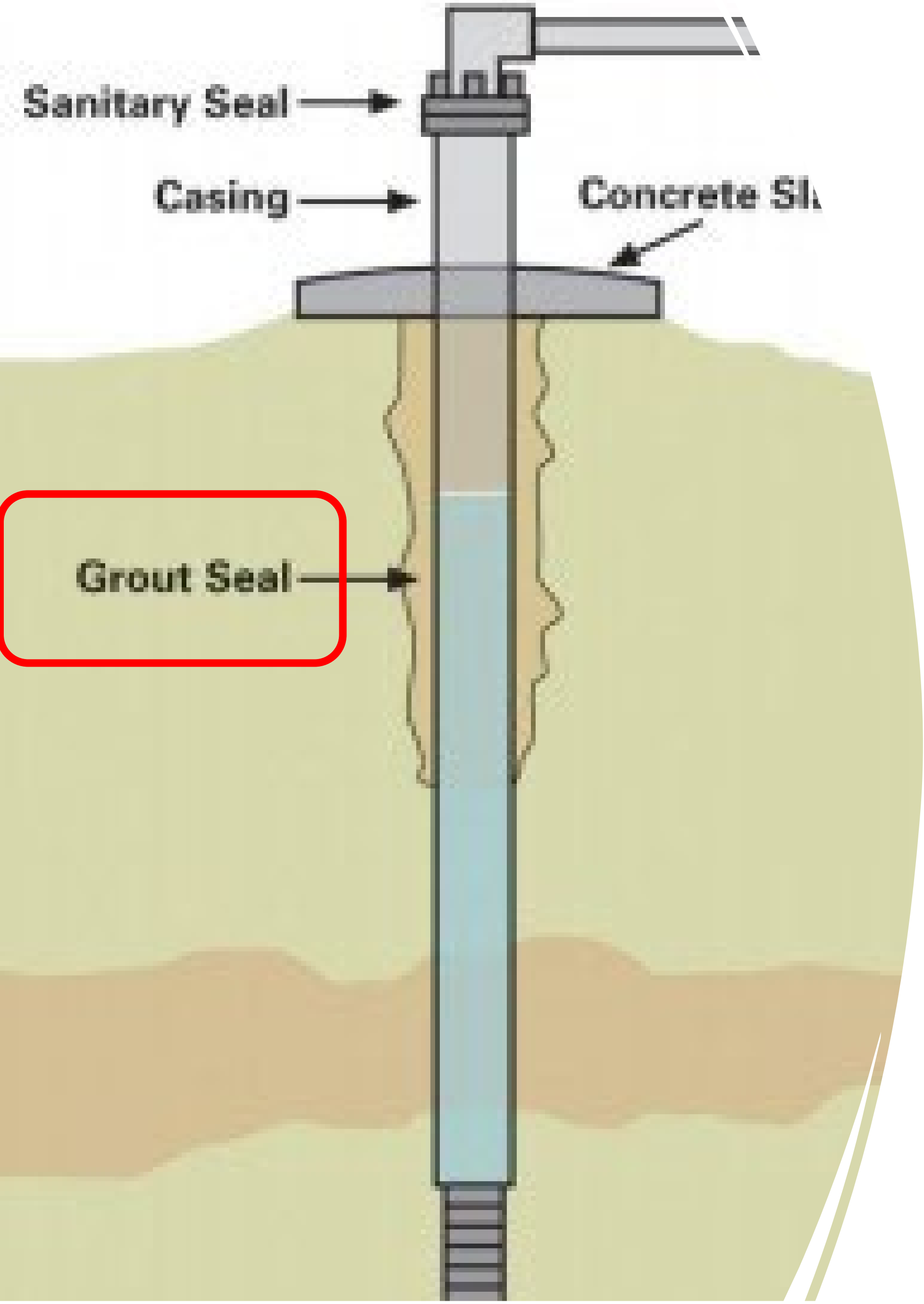
Well Sanitary Seal

- Provides an air-tight seal that prevents the entrance of contaminants directly into the casing

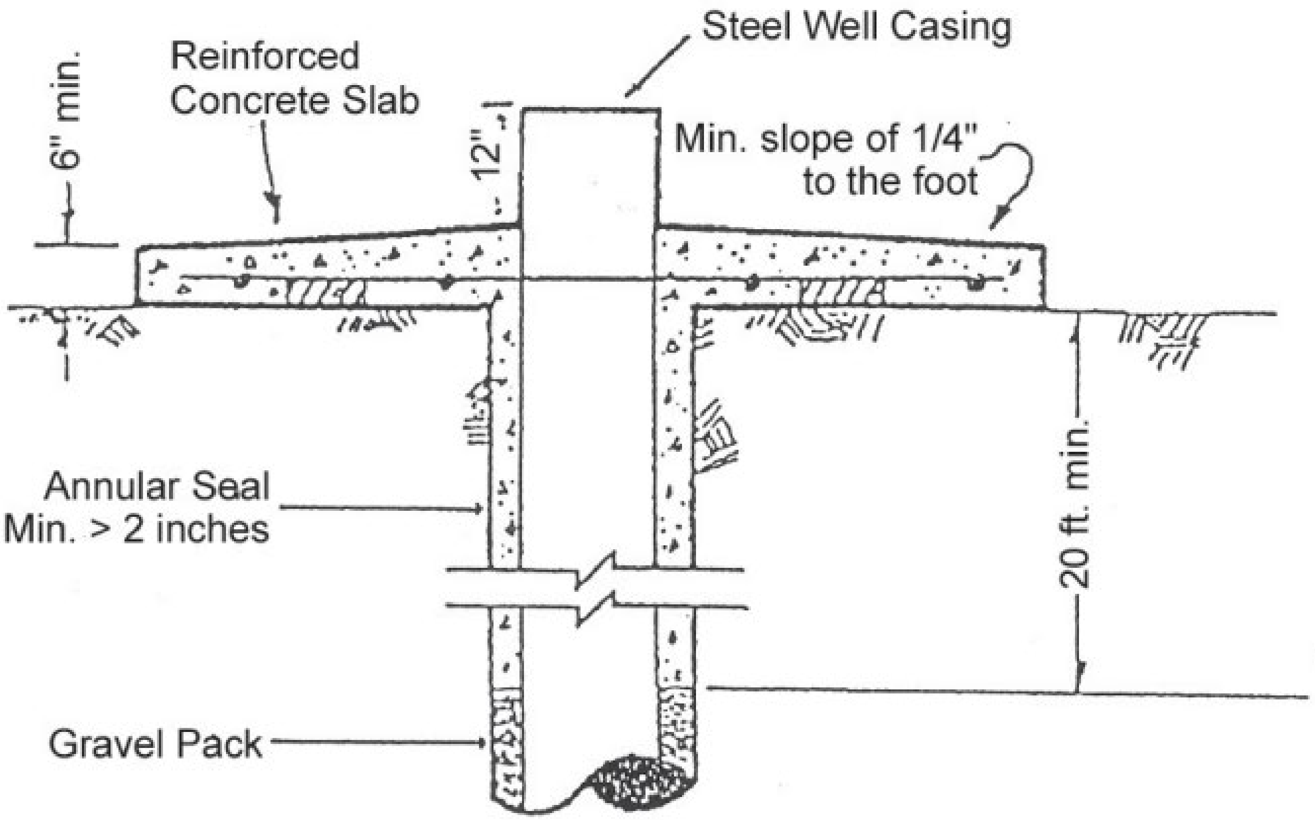
Wellhead Components



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.



Poll 1

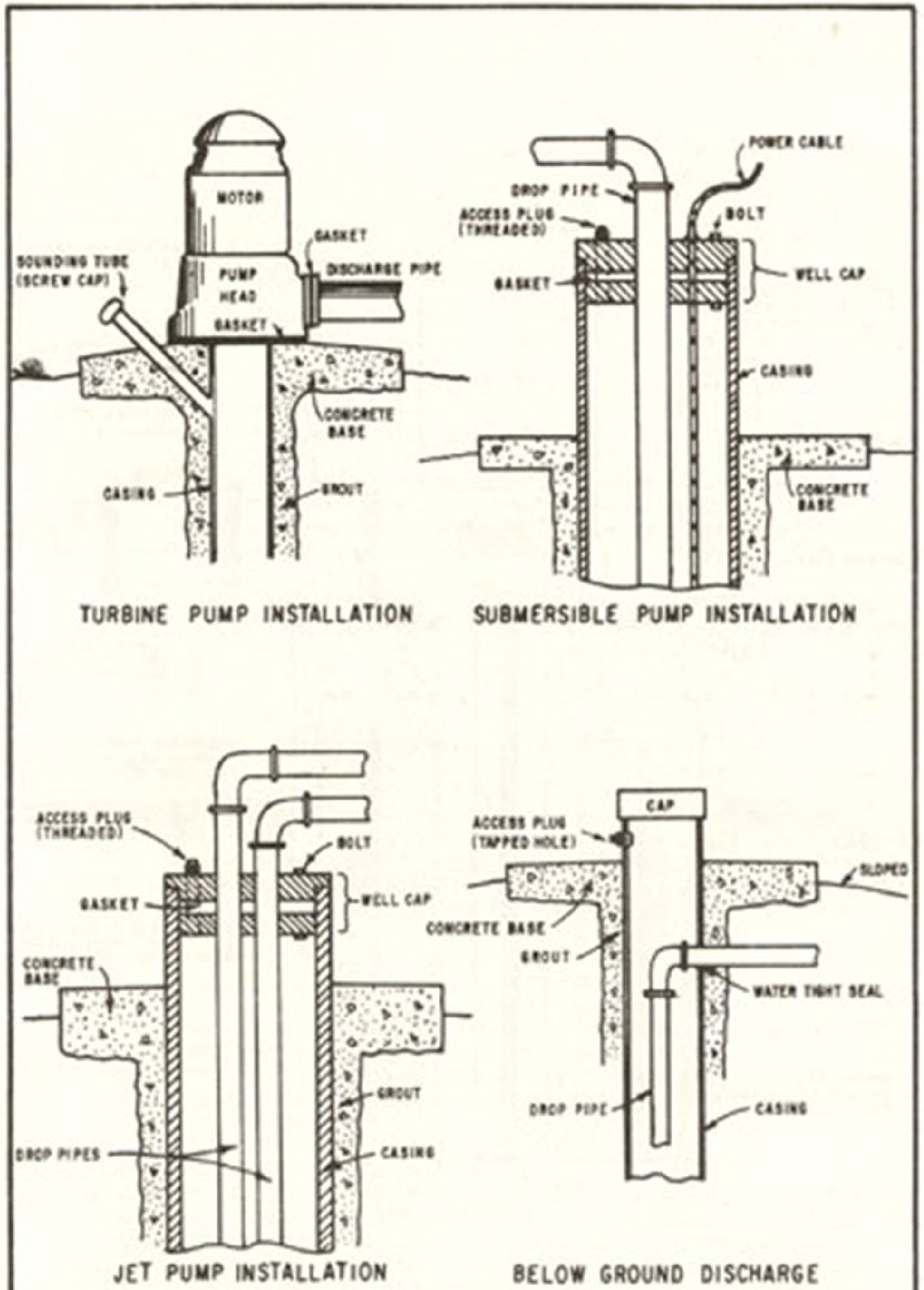
Which of the following wellhead construction elements could help prevent contamination during a flood?

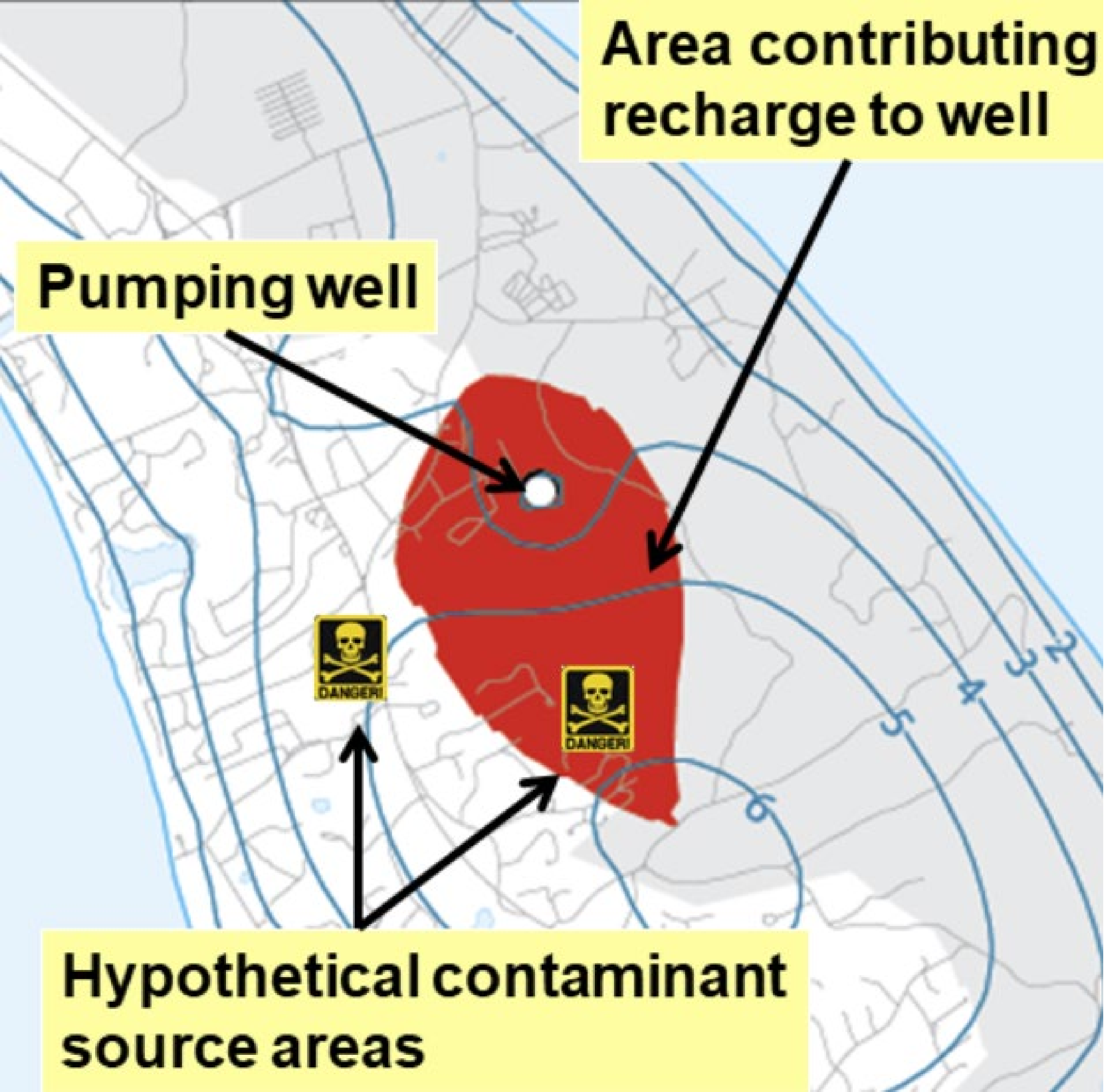
a) Well casing extends above ground a specified distance

b) Annular space sealed with grout

c) Sanitary seal at top of casing

d) All of the above

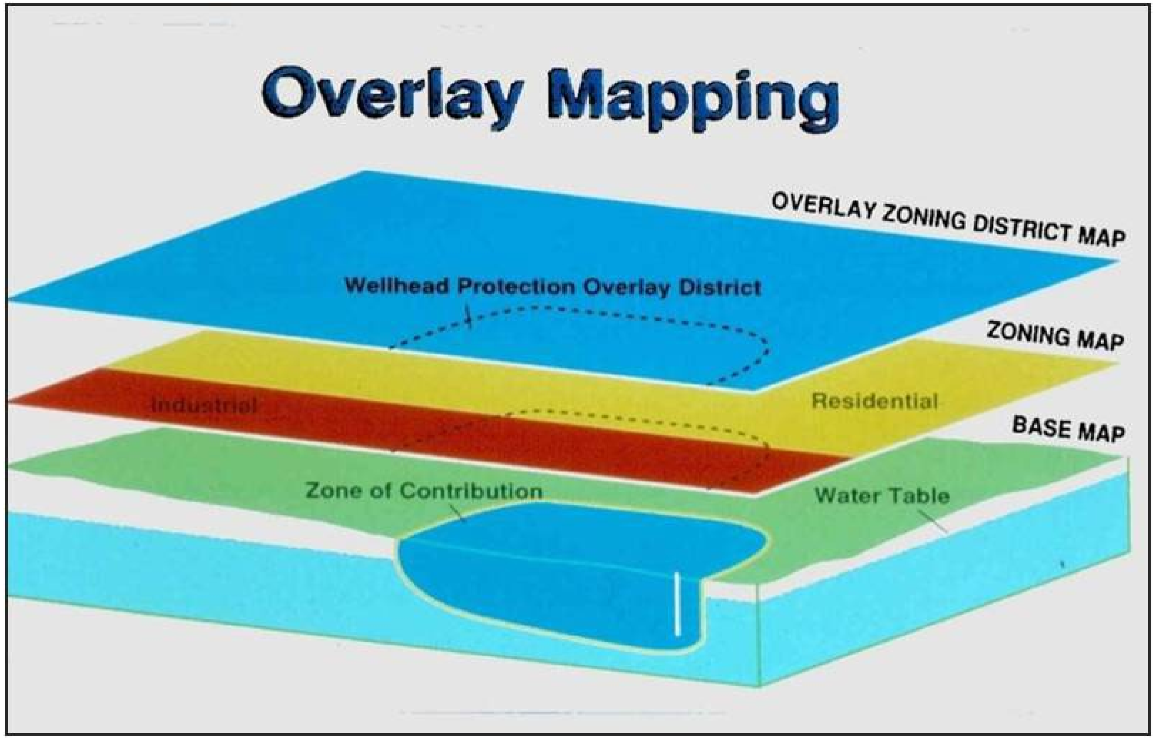




Area of well recharge

Delineation Means Defining the Areas of Recharge for the aquifer that contribute to the well within a time of travel

- Allows analysis of interaction with potential contamination sites
- Maps layers : sewer systems, pipelines, industrial facilities, land usage, roads, etc.

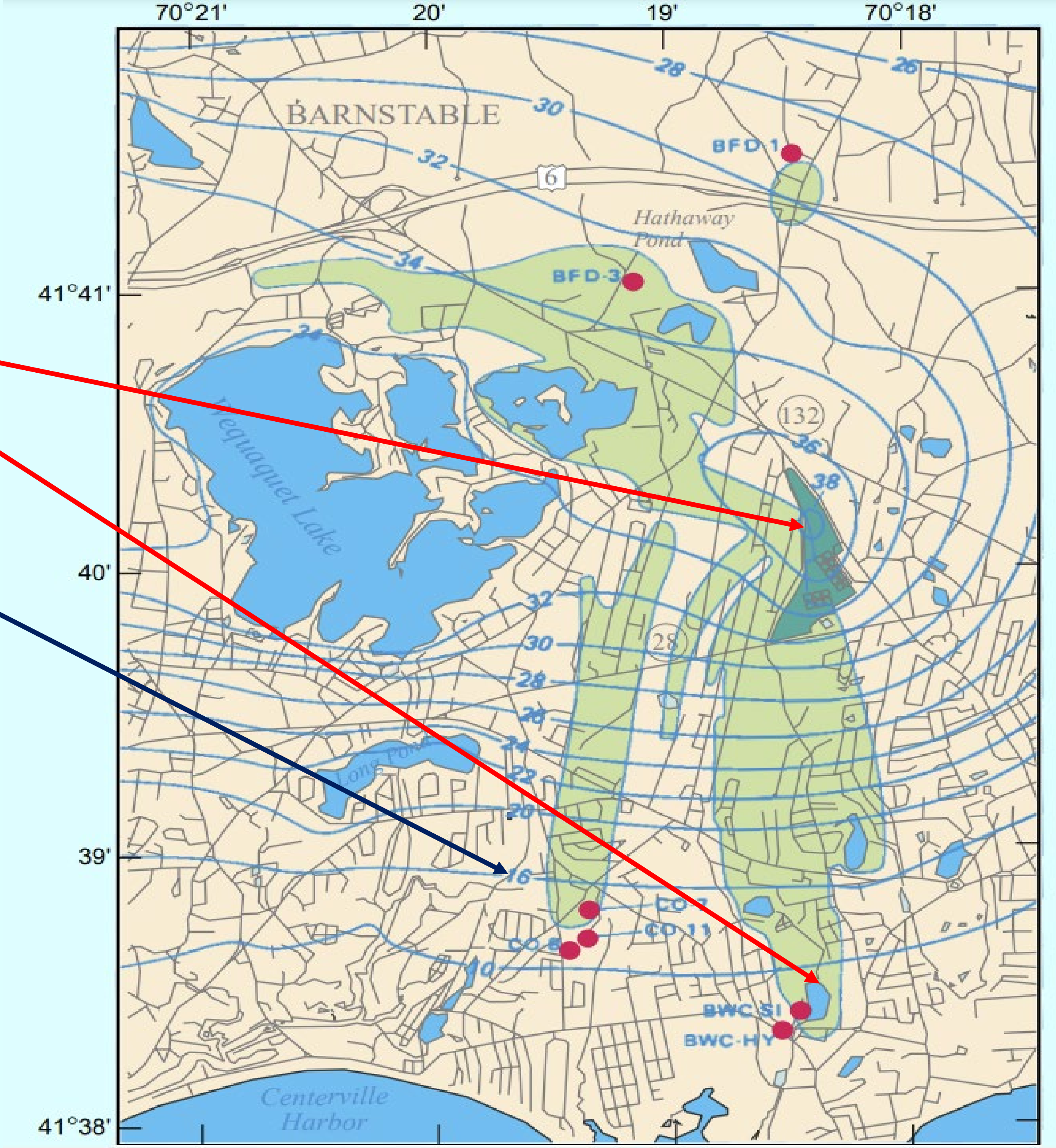


Overlay mapping

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 intersect wastewater infiltration beds and lakes
- Blue lines show elevation height of water table



EXPLANATION

Wastewater-treatment-facility infitration beds

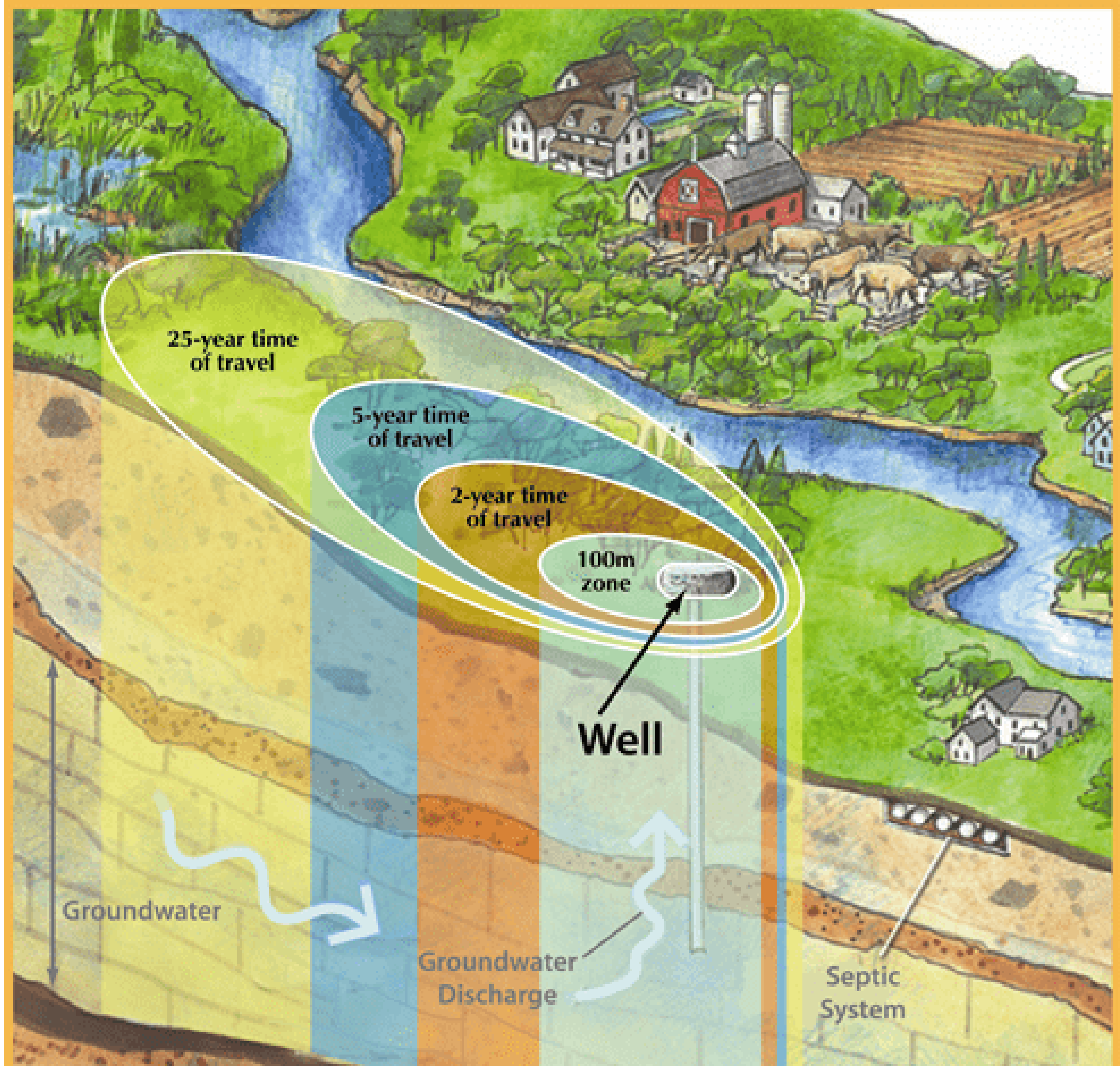
Areas contributing recharge to public-supply wells

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

Delineating the Wellhead Protection Area

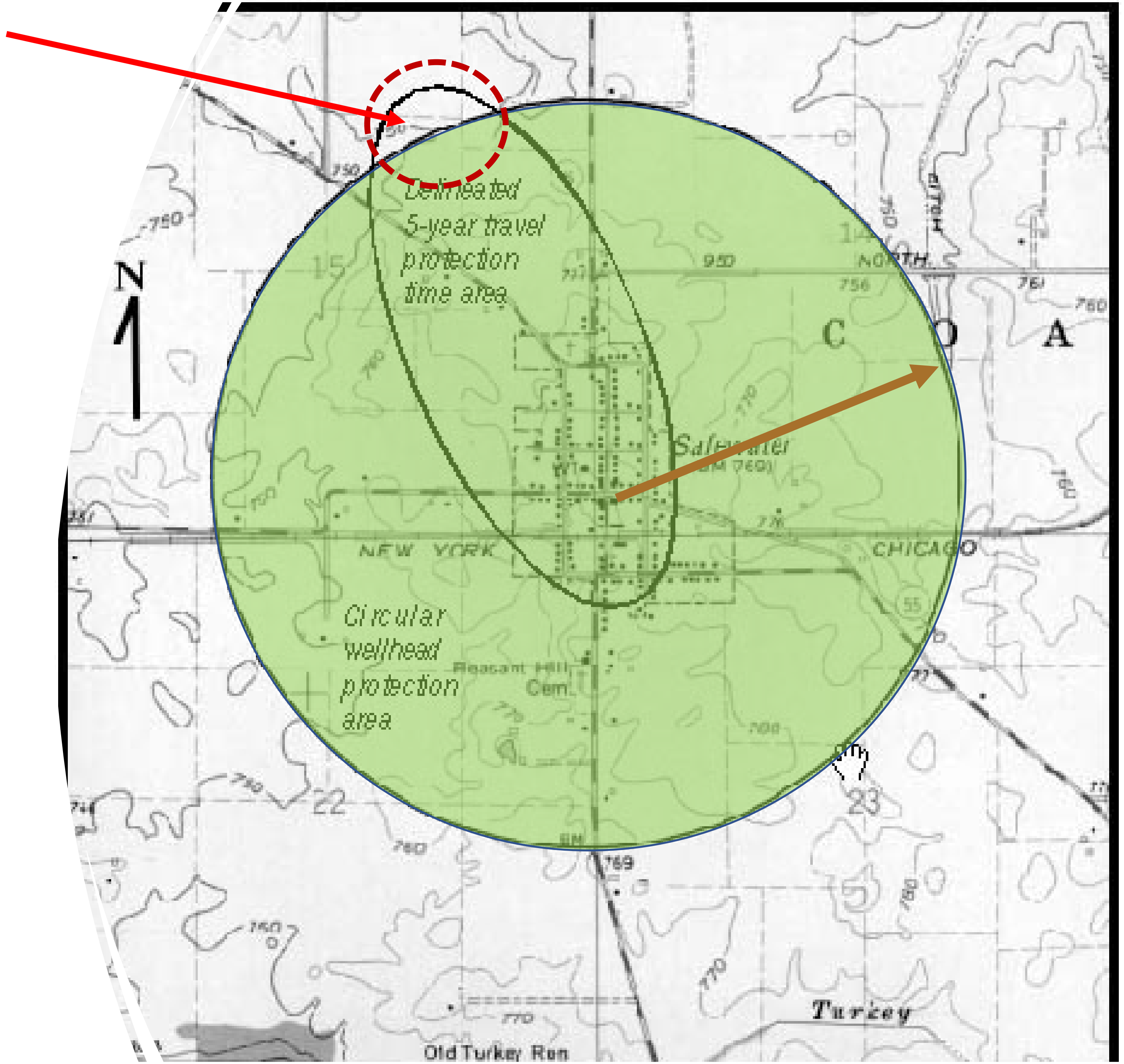
- What delineation involves
- Fixed Radius
- Calculated Radius
- Hydrogeologic Studies



Simple WHPA Delineation

- Primacy agency standards may provide a minimum or suggested pre-prescribed radius (e.g. a 1,200 feet radius).

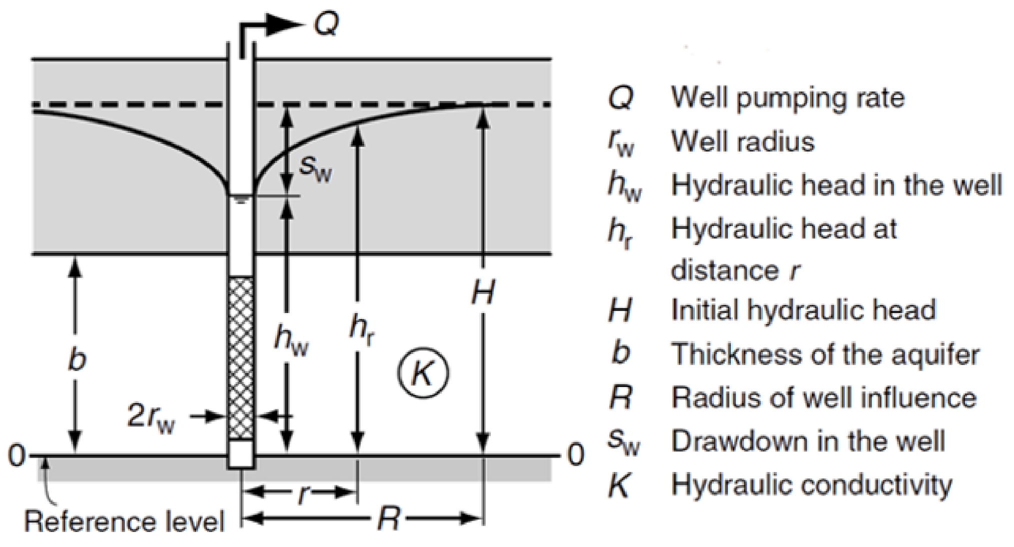
- Ideally the WHPA should delineate the recharge area that contributes water within a five-year time of travel (at a minimum.)

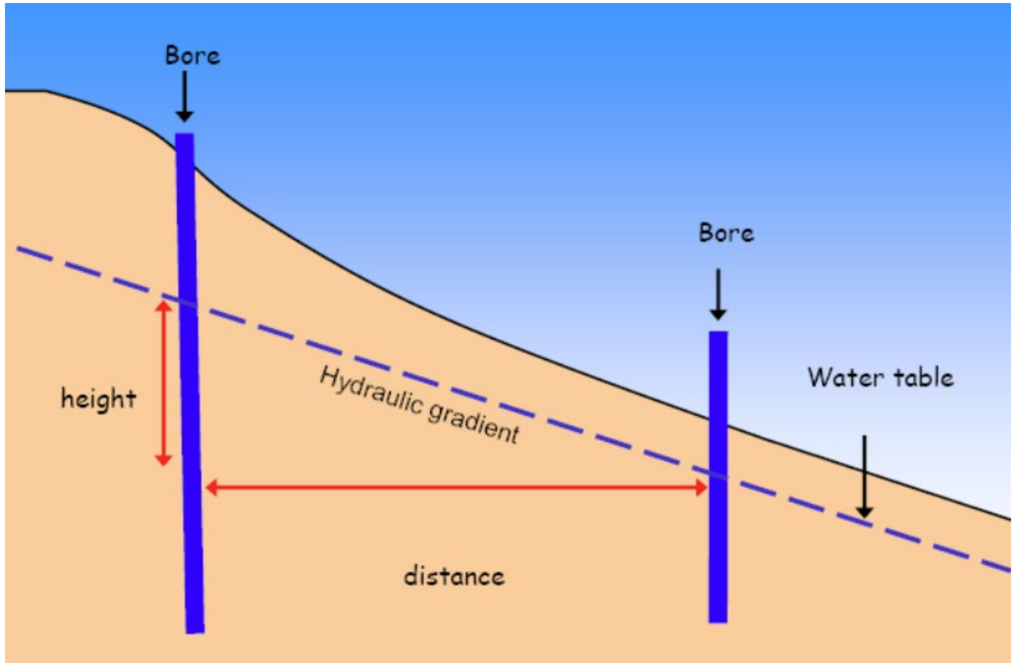


Hydrogeologic studies

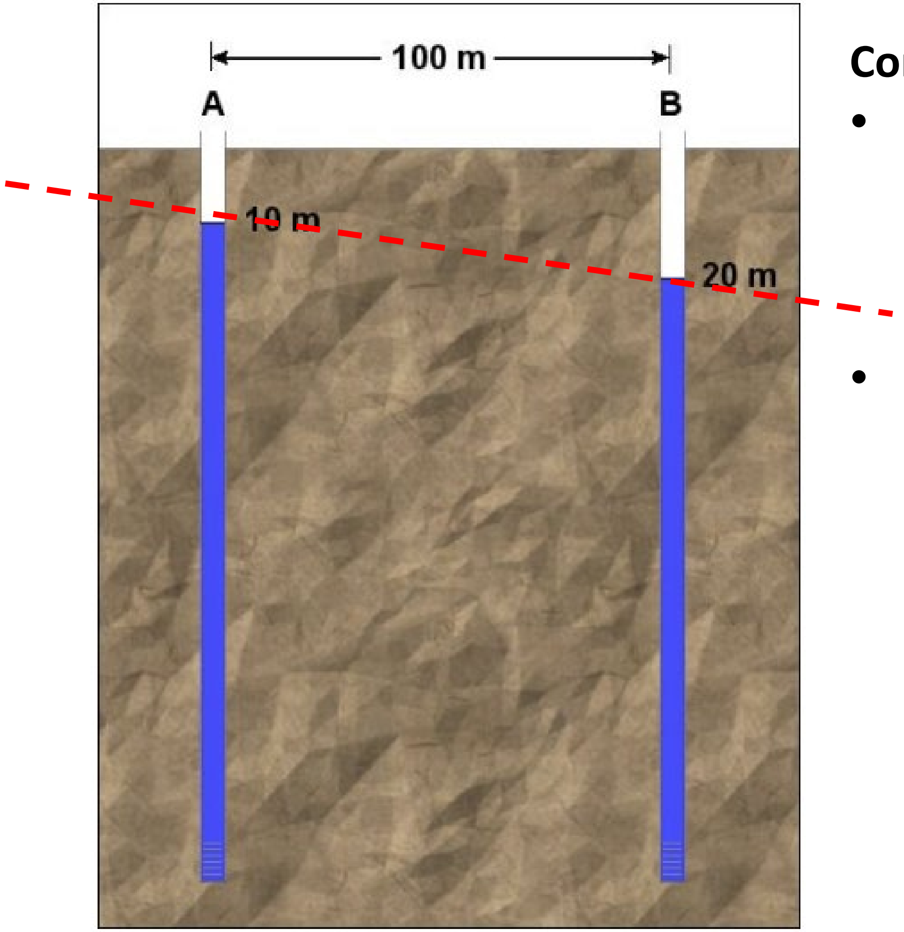
Wells are pumped continuously for a long period of time – from 24 hours to several weeks at a constant rate to assess drawdown of the aquifer and recovery.

Nearby wells and monitoring wells are used to check for changes in the static water level to get an accurate estimate of the hydraulic gradient, hydraulic conductivity, and yield





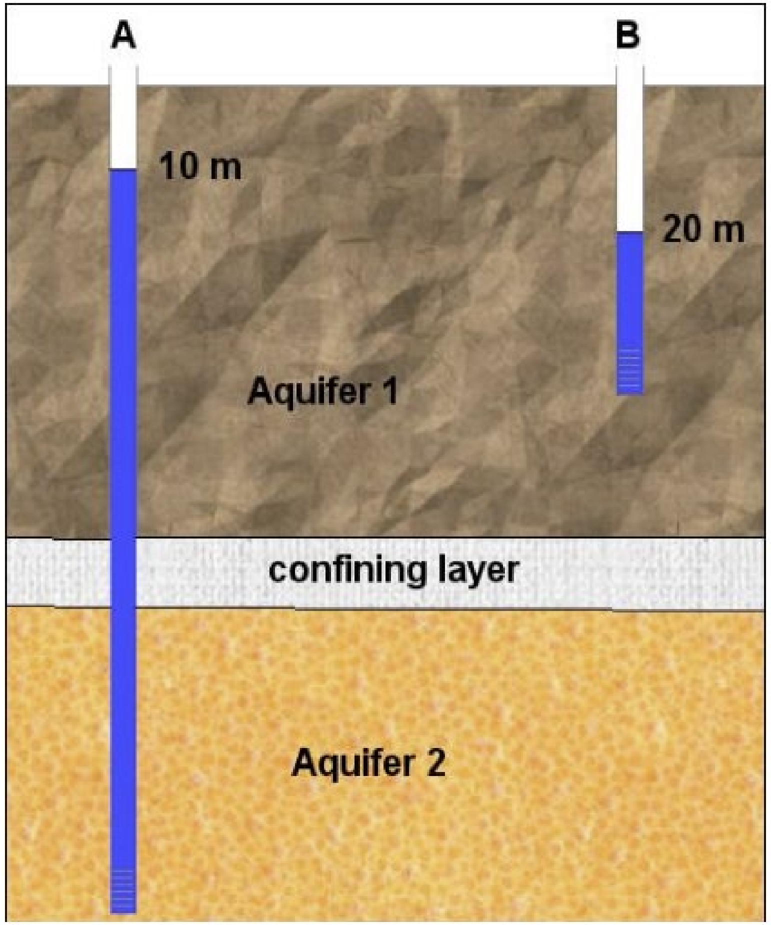
Simple Hydraulic Gradient Calculation (2-dimensional)



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

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.



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

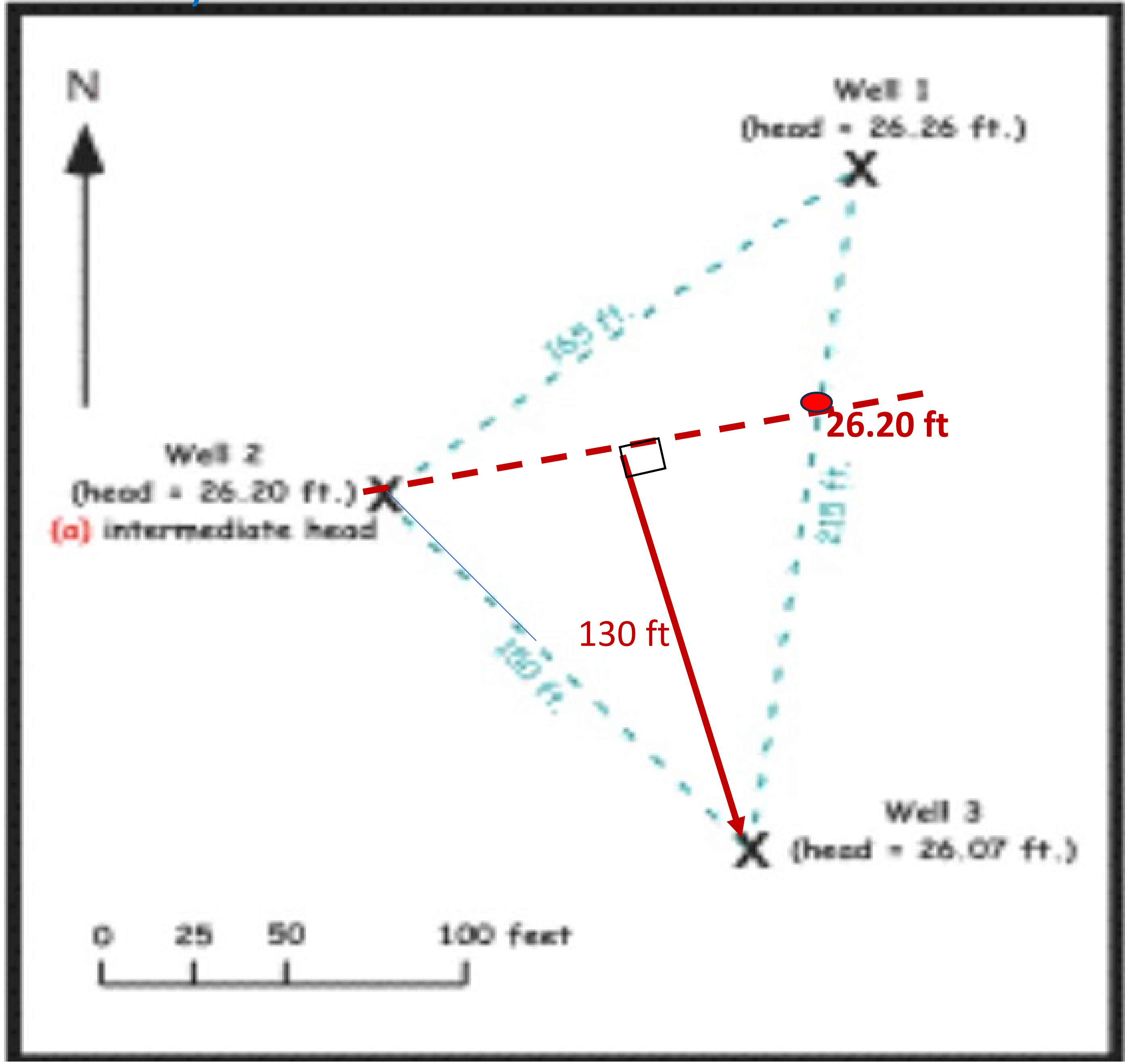
Hydraulic Gradient Calculation (3-dimensional)

a) Identify the well that has the intermediate water level. **Well 2: 26.20 ft**

(b) Calculate where the elevation of the well with the intermediate head would fall between the high and low

(d) Draw a line perpendicular between the water-level contour line just plotted and the well with the lowest head. This line is the line that parallels ground water direction.

(e) Calculate the difference between the head of the well and the contour by the distance between the well and the contour to reveal the hydraulic gradient.



Hydraulic gradient

$$\frac{26.20\text{ft} - 26.07\text{ft}}{130\text{ feet}} = \mathbf{0.001\ ft/ft}$$

In a S-SE direction

Specific capacity

Flow in GPM of a pumping well at equilibrium divided by feet of drawdown.

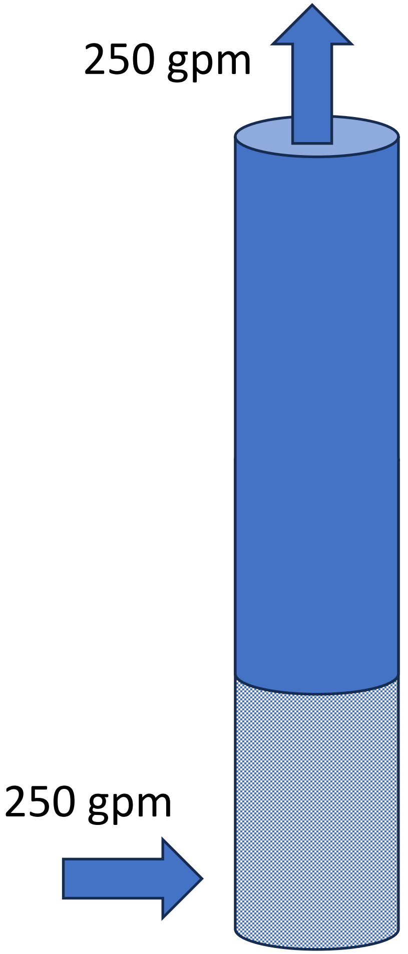
$$\text{Specific capacity} = \frac{\text{Flow (GPM)}}{\text{Ft drawdown}}$$

Example: **A well produces 250 gpm with a drawdown of 30 feet.**

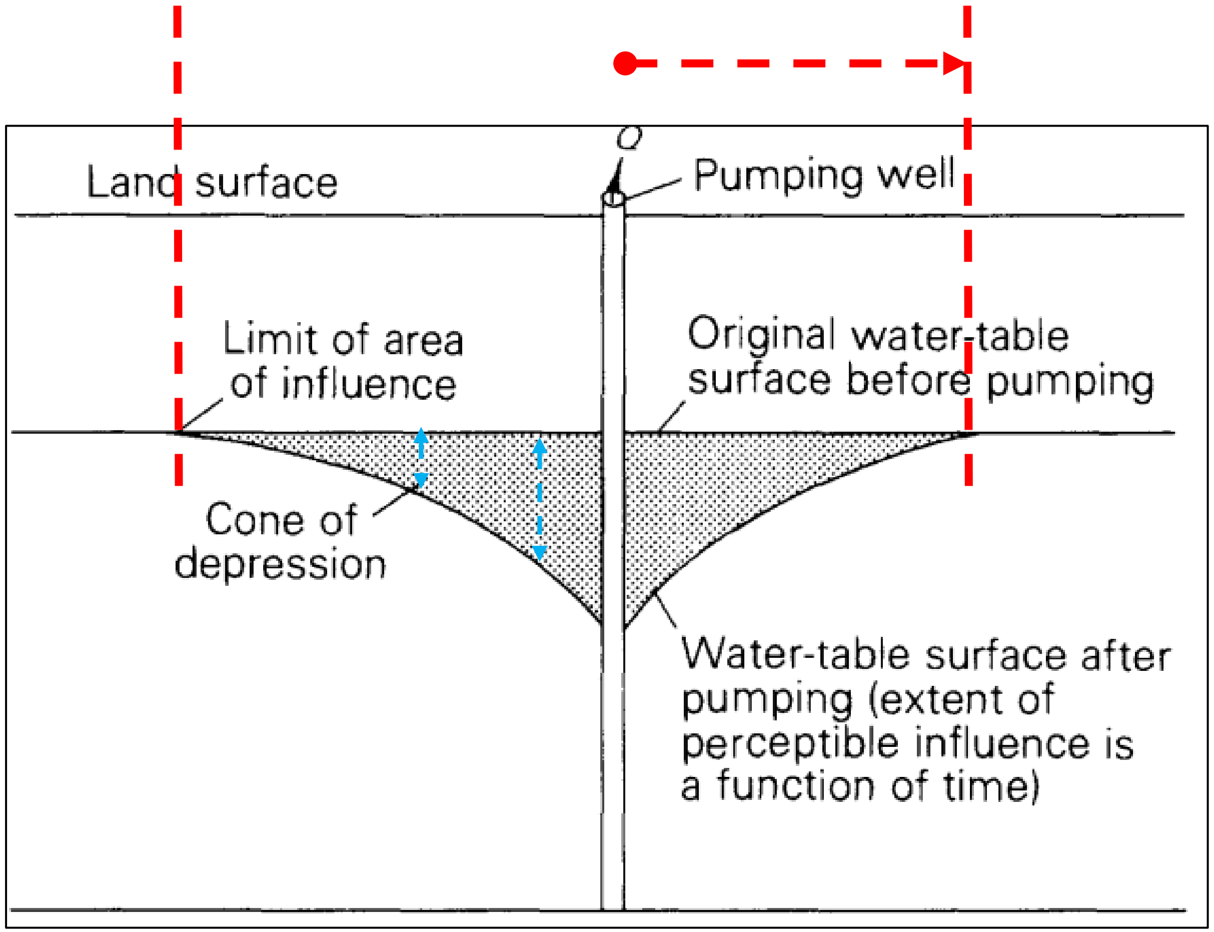
$$\text{Specific Capacity} = \frac{250\text{ gpm}}{30\text{ ft}} = 8.3\text{ gpm/ft}$$

Also if we know that there is available drawdown of say 50 ft we can estimate the max pumping rate with specific capacity.

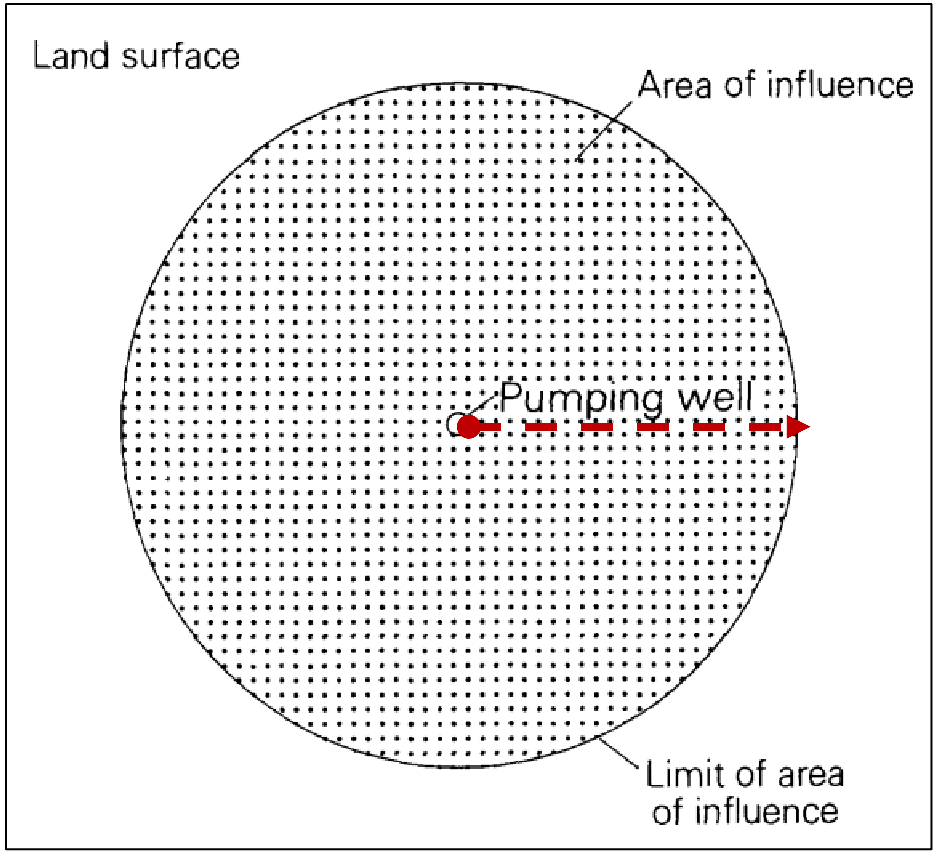
8.3 gpm/ft x 50 ft = 415 gpm



Area of influence

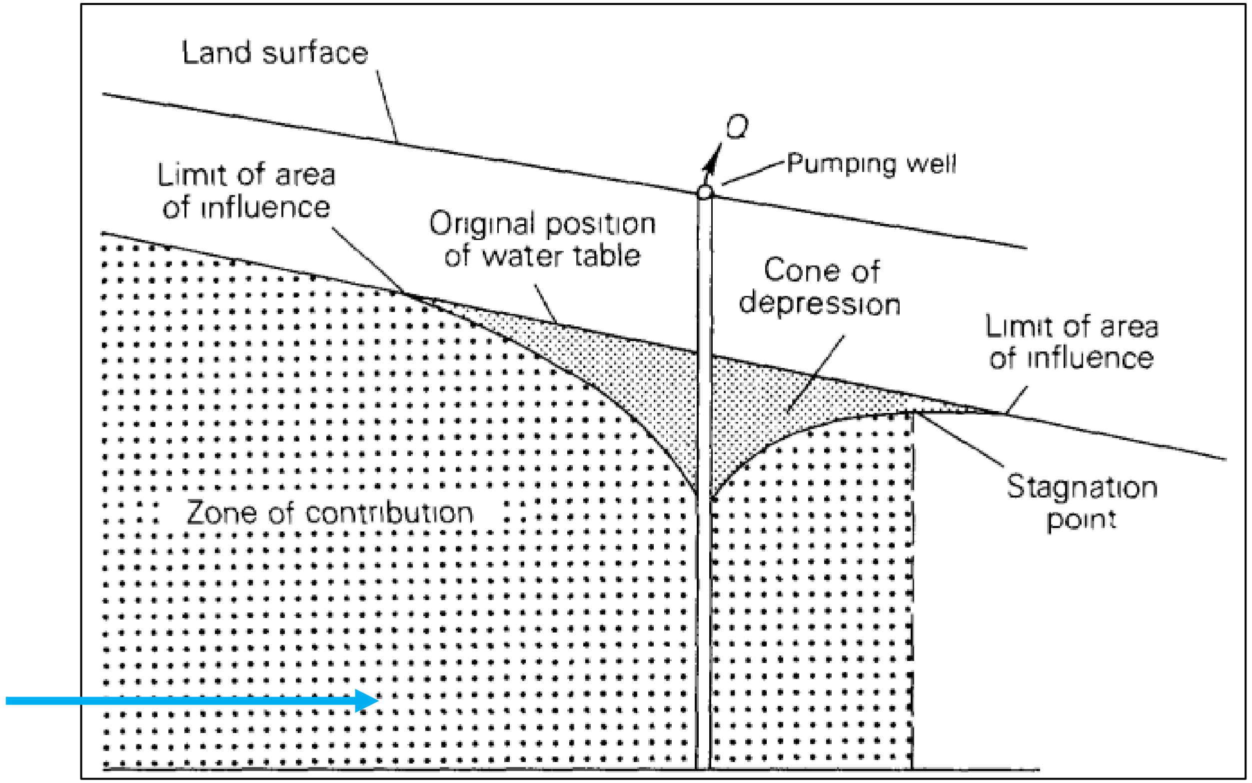


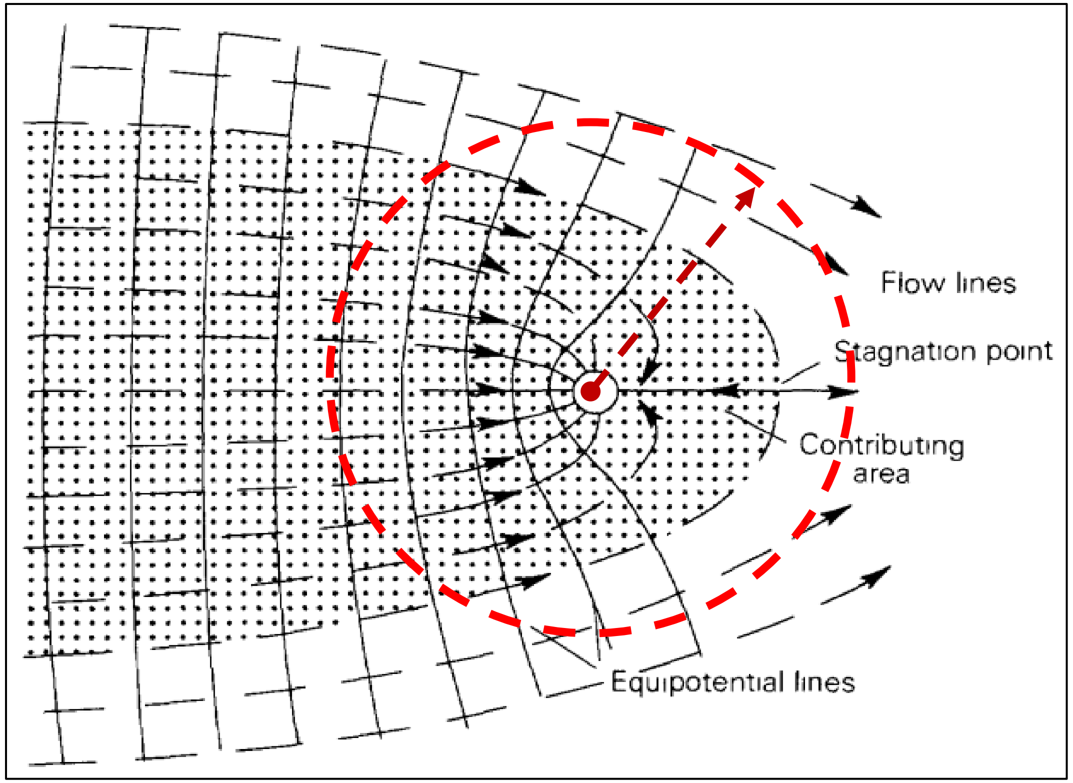
Cross sectional view



Plan view

Intersection of groundwater flow and area of influence





The recharge area is determined by a combination of the well's area of influence plus the velocity and direction of groundwater flow.

Poll 2

A ground water well has a pumping rate of 200 gpm with a drawdown of 10 ft. Estimate the max pumping rate given available drawdown of 40 feet.

a) 400 gpm
b) 600 gpm
c) 800 gpm
d) 1,000 gpm

Poll 2 Solution

A ground water well has a pumping rate of 200 gpm with a drawdown of 10 ft. Estimate the max pumping rate given available drawdown of 40 feet.

Specific capacity = $\frac{200 \text{ gpm}}{10 \text{ ft}}$ = 20gpm/ft

At 40 ft drawdown → 40 ft x 20 gpm = 800 gpm

Porosity & Permeability

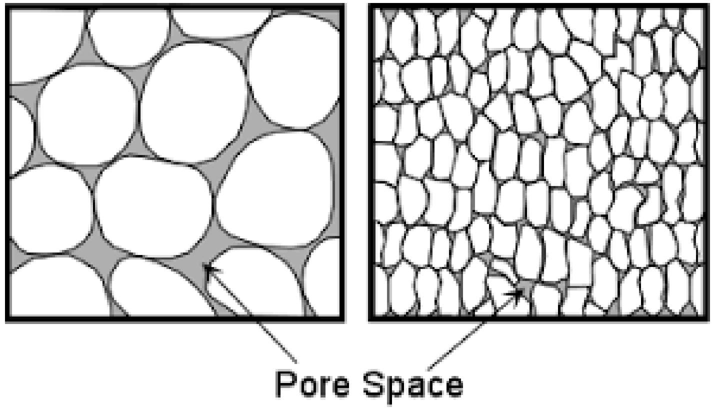
Porosity is a measure of an aquifer material's ability to store water. It is a percent measure of the available space between grains.

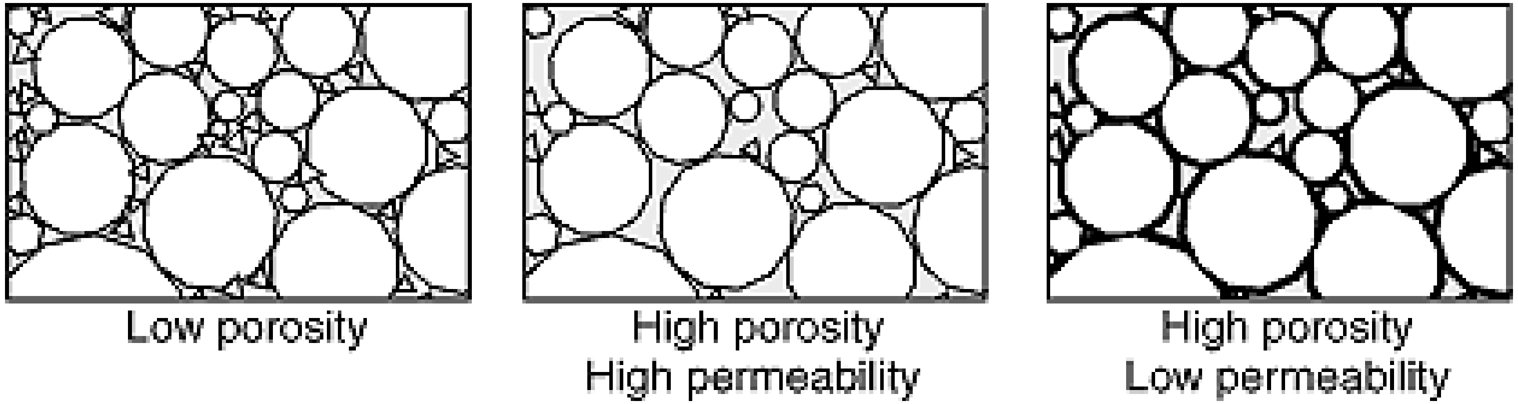
Permeability expresses how well water is able to flow through the aquifer material.

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

- Units (K, ft/sec or m/sec)
- Describes the ease with which water moves through an aquifer material
- Corrects for balance between porosity, specific yield, and specific retention.

SELECTED VALUES OF POROSITY, SPECIFIC YIELD(%) & RETENTION(%)				
Grain Size	Material	Porosity (%)	Specific Yield	Specific Retention
Fine ↕ Coarse	Clay	50	2	48
	Sand	25	22	3
	Gravel	20	19	1

i. Hydraulic conductivity varies greatly among different materials; for instance, sand has a high hydraulic conductivity while clay has a low hydraulic conductivity.

ii. The hydraulic gradient influences the actual flow rate of groundwater, in conjunction with hydraulic conductivity.

iii. Contaminants in groundwater can be transported at rates influenced by the hydraulic conductivity of aquifer materials

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.*
- *Expressed as distance/time or rate: (meters per second or feet per day).*

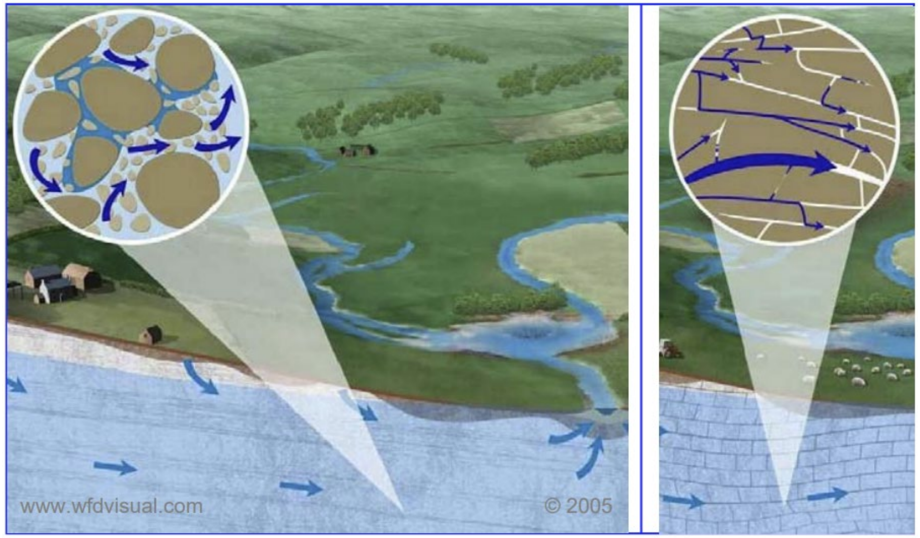


Figure 2-1 Intergranular groundwater flow (left) and fissure flow (right) (Sniffer (2005) www.wfdvisual.com)

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}

Course sand 0.006 meters per second
518.4 meters in a day (max given hydraulic gradient)
(About 1700 feet or 1/3 of a mile in a day)

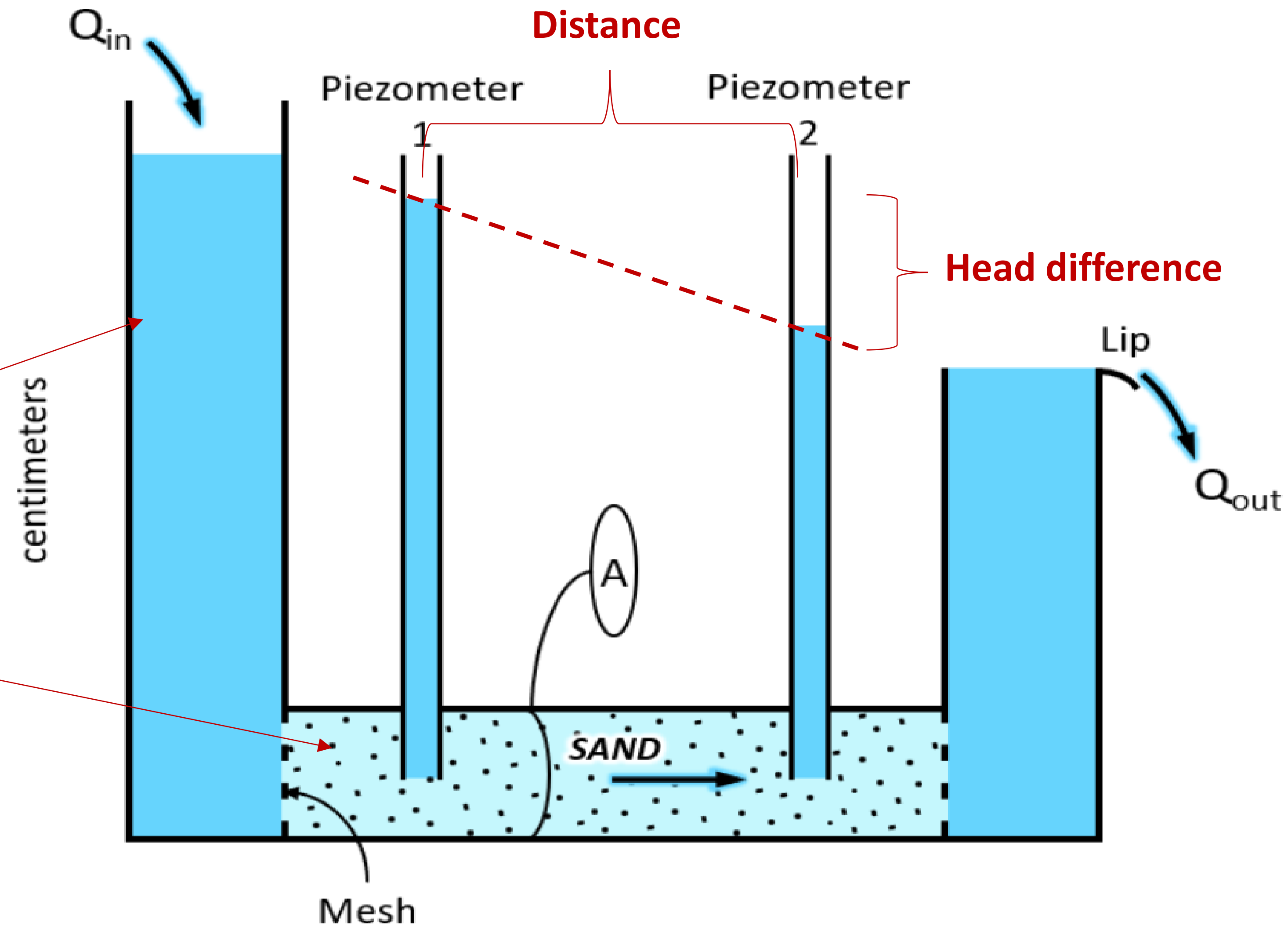
Clay 0.0000000047 meters per second
0.00041 meters in a day (about 1/64 of an inch in a day)

Hydraulic conductivity

Darcy's Law

The flow velocity of groundwater (V) is directly proportional to the hydraulic conductivity (K) and the hydraulic gradient (*i*) .

Velocity =K × *I*



Experimental apparatus simulates a flowing aquifer

Hydraulic conductivity is a characteristic of the aquifer material.

The Ground Water Project, Cohen, J. & Cherry, J. 2020. **Conceptual and Visual Understanding of Hydraulic Head and Groundwater Flow**. https://books.gw-project.org/conceptual-and-visual-understanding-of-hydraulic-head-and-groundwater-flow/

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)

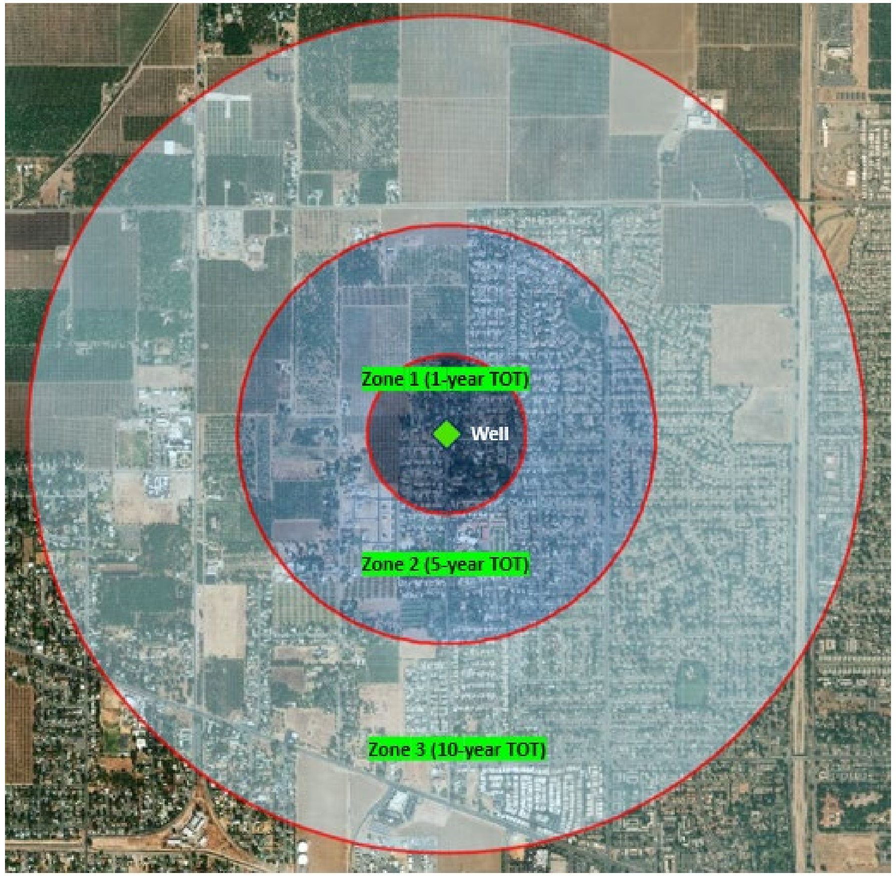
∏ = 3.1416

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.



Calculated Radius example

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

A wellhead has the following information, calculate the WHPA radius

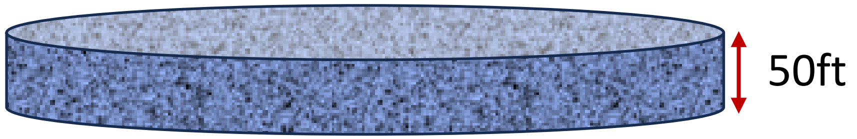
Q = 20,500,000 gallons per year
T = time of travel = 2 years
n = porosity = 20%
H = Length of well screen = 50 feet
∏ = 3.1416
7.48 gal per cubic foot

$$\sqrt{\frac{20{,}500{,}000 \text{ gal/year} \times 2 \text{ years}}{7.48 \text{ gal/cf } (0.2)(50\text{ft})(3.1416)}}$$

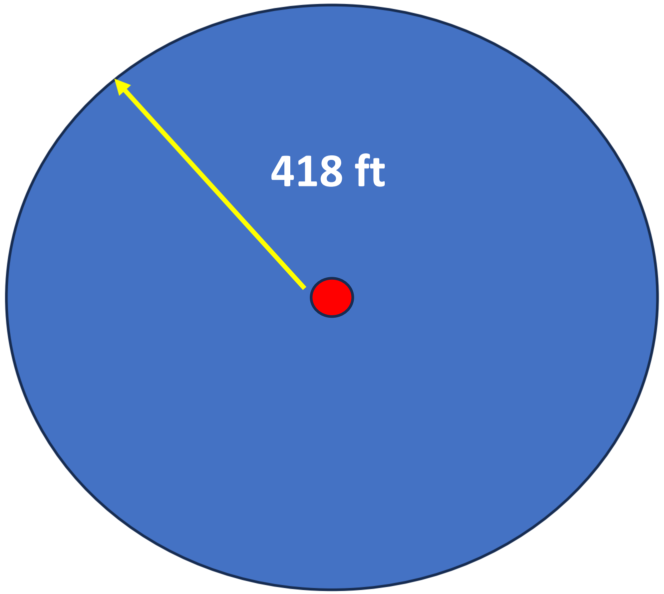
$$= \sqrt{174{,}474.3 \text{ ft}^2}$$

= **417.7 ft.**

Adding a safety factor [1.5 x 417.7ft ➔ 626.6 ft



Total volume of the aquifer disk is approx. 205,000,000 gal but it only holds 41,000,000 gallons of water because of the 0.2 porosity.
V = $\pi r^2 H \times 7.48$ gal/cf



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.

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

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.

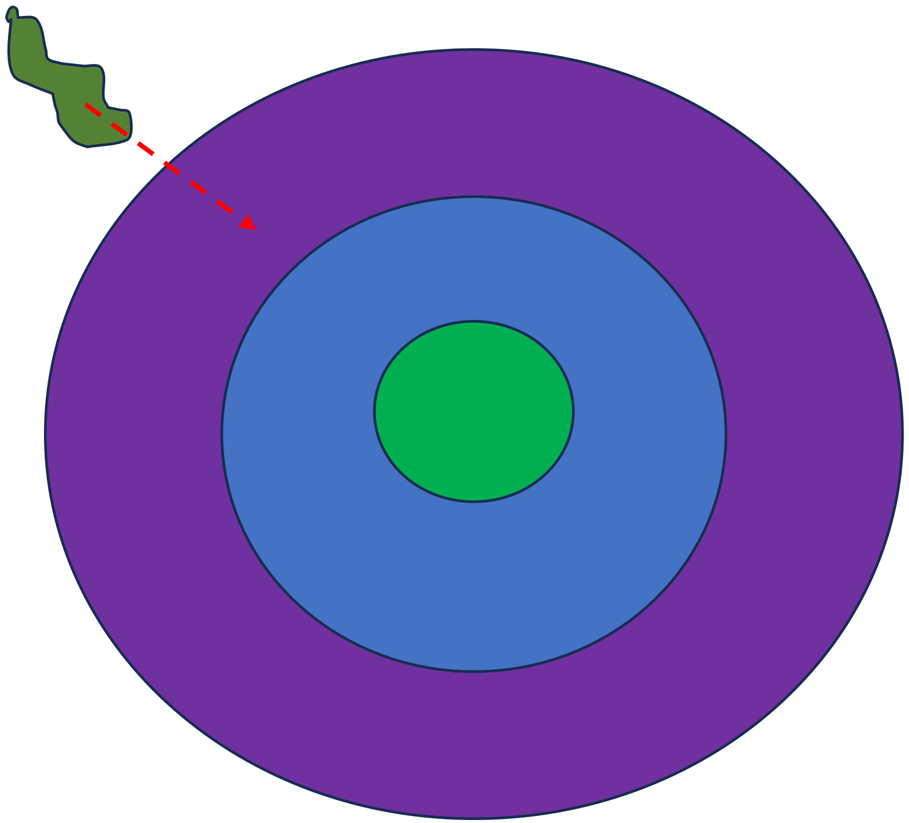
https://www.epa.gov/sites/default/files/2015-06/documents/nbsect5.pdf

Poll 3: Calculating movement of a contamination plume

Velocity $= \frac{K \times i}{n}$

An aquifer has a hydraulic conductivity (K) of 4 ft per day, a hydraulic gradient (*i*) of 0.1 ft/ft, and an effective porosity (n) of 0.2. Estimate how many feet a plume could move in one year?

a) 146 feet
b) 292 feet
c) 730 feet
d) 1460 feet



Calculating movement of a contamination plume

Velocity = $\frac{K \times i}{n}$

An aquifer has a hydraulic conductivity (K) of 4 ft per day, a hydraulic gradient (*i*) of 0.1 ft/ft, and an effective porosity (n) of 0.2. Estimate how many feet a plume could move in one year?

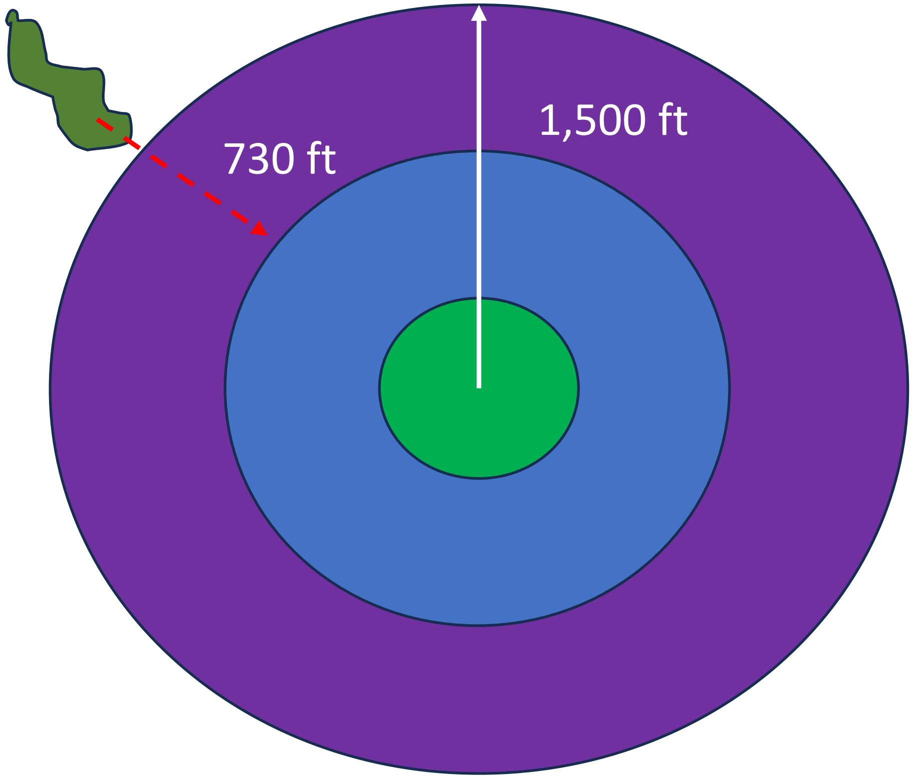
Solution:

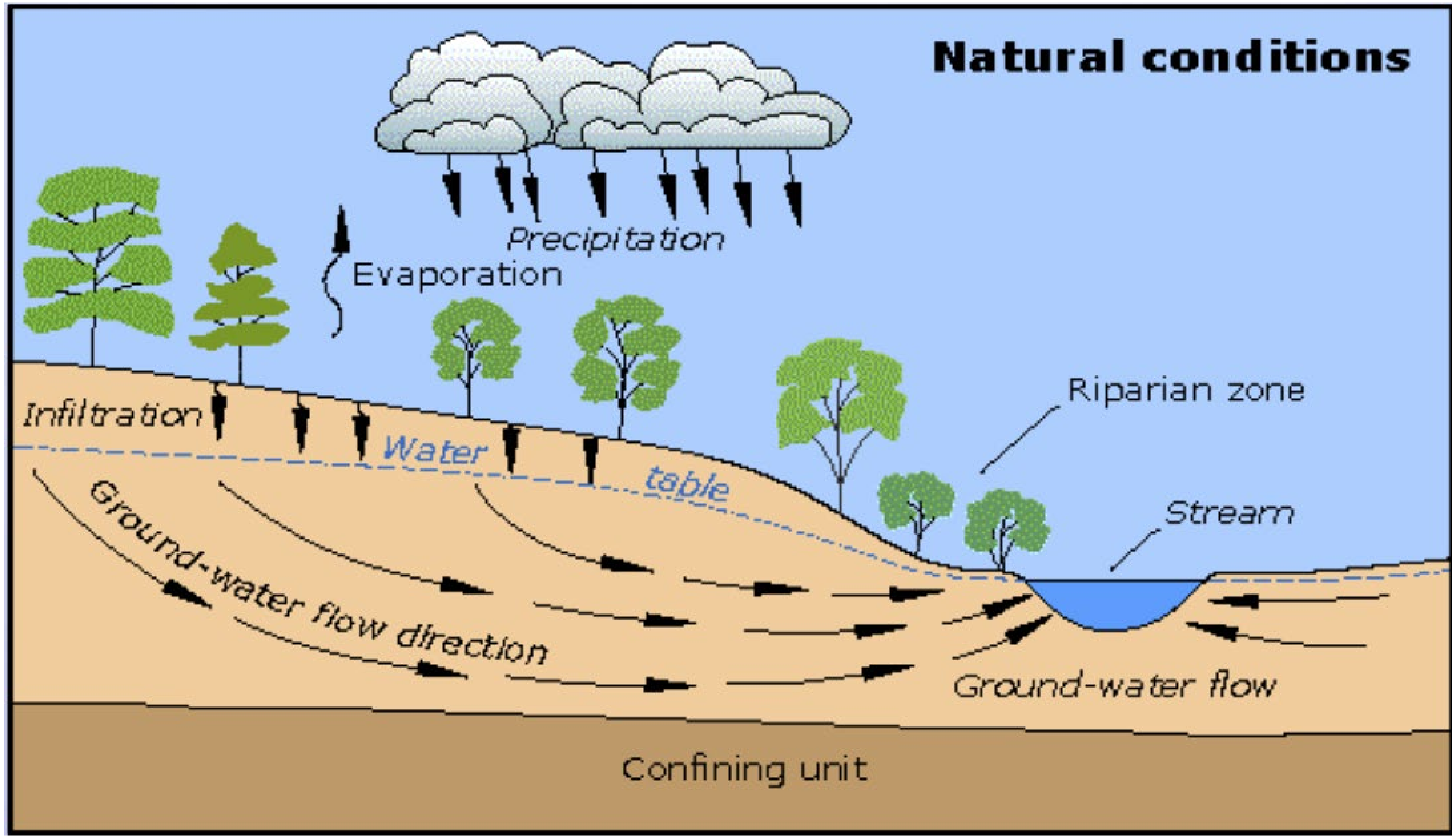
Step 1: Determine how many feet in in 1 day

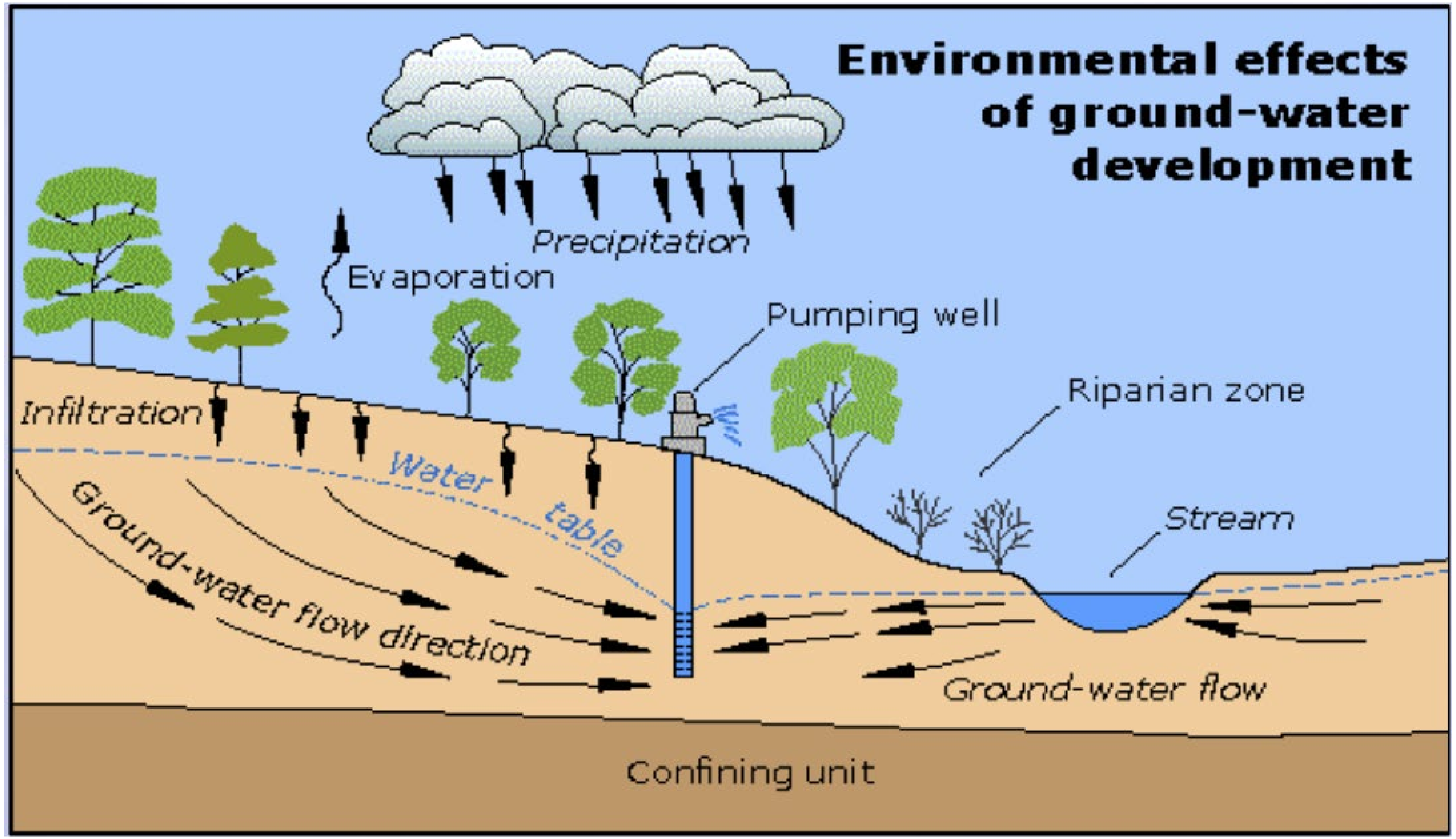
$\frac{4 \text{ ft/day} \times 0.1 \text{ ft/ft}}{0.2}$ = **2 ft/day**

Step 2: Multiply by 365 days/year

2 ft/day x 365 day/year = **730 ft/year**




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


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

Impacts of Well Pumping on Groundwater Flow

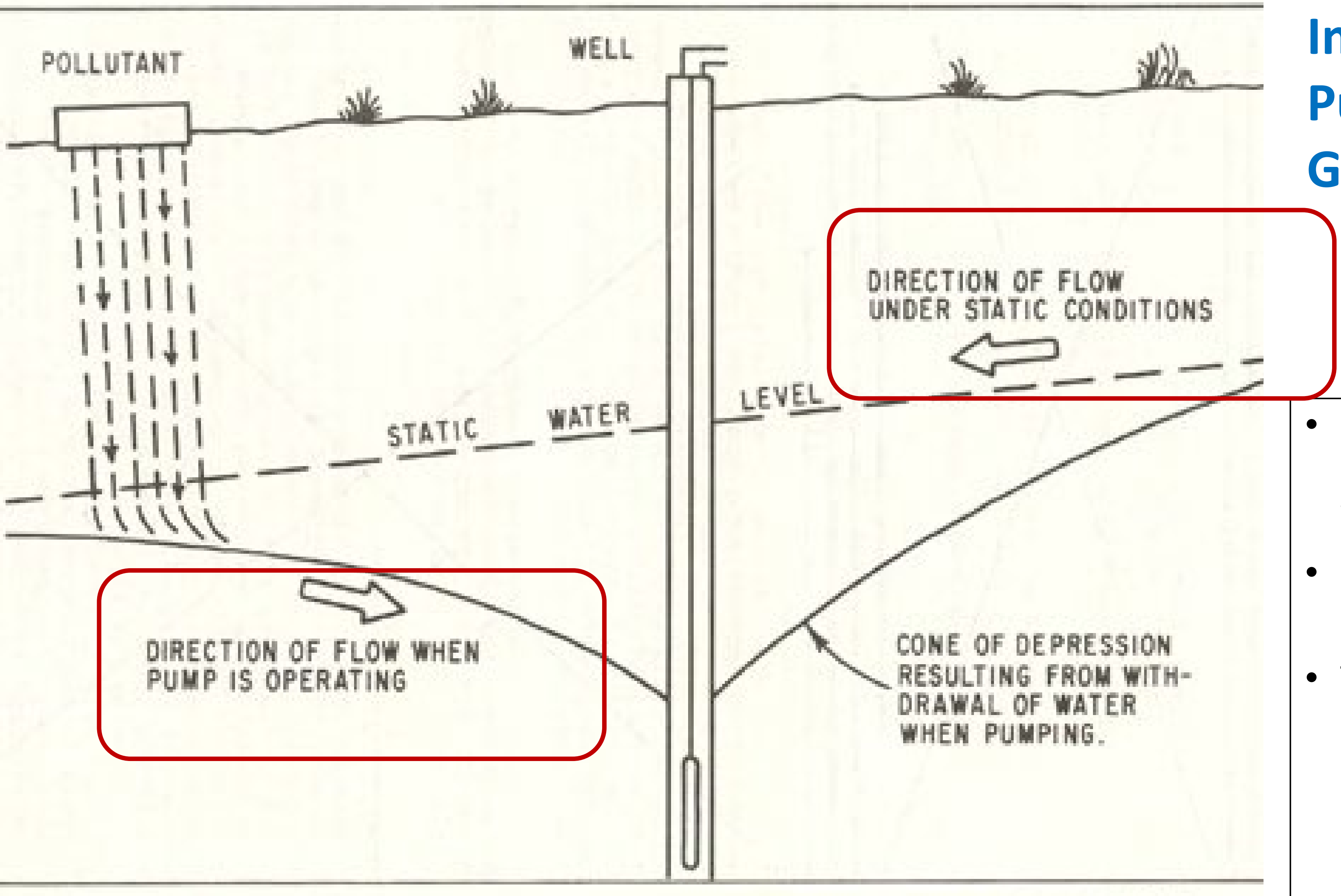
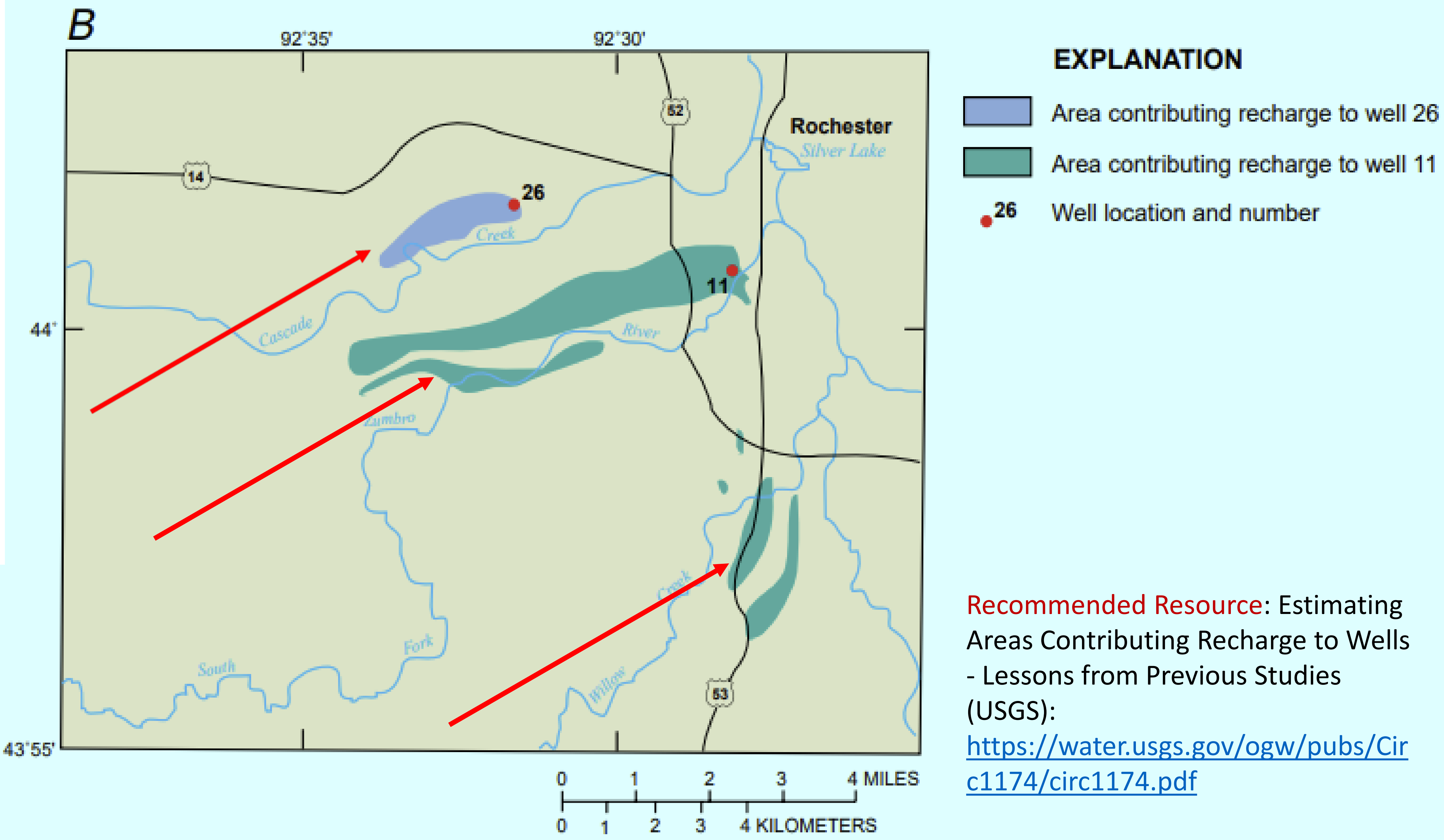
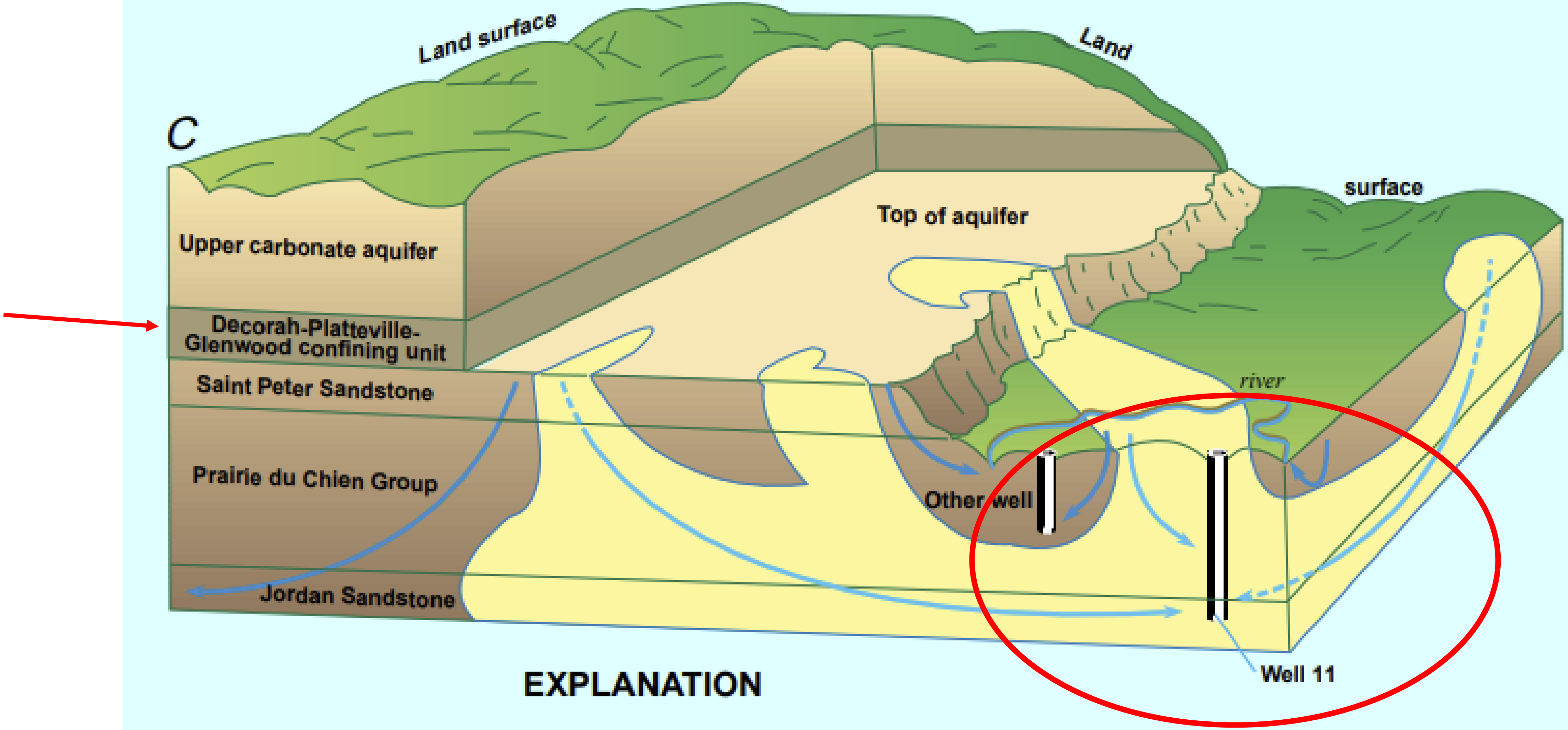


Figure 3. EFFECT OF REVERSAL OF GROUND WATER GRADIENT

- 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.



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



EXPLANATION

Model computed areas contributing recharge and subsurface volumes containing flowpaths that discharge to well 11

Ground-water flowpaths that discharge to well 11, dashed where flow is not along face of block diagram

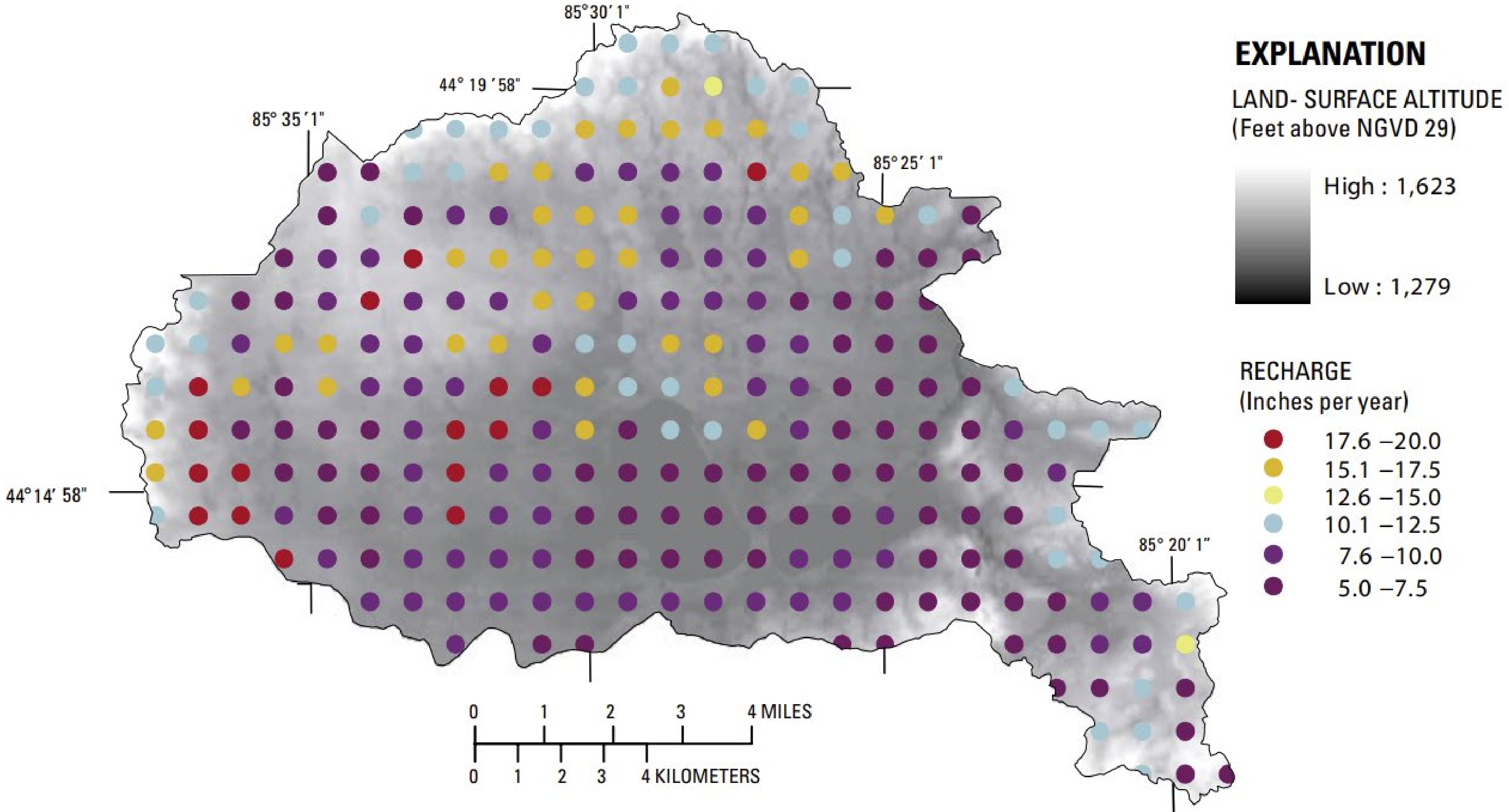
Other ground-water flowpaths

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

1. Record in a database or spreadsheet
2. Indicate on map
3. Analyze risk
4. Determine preventative mitigations

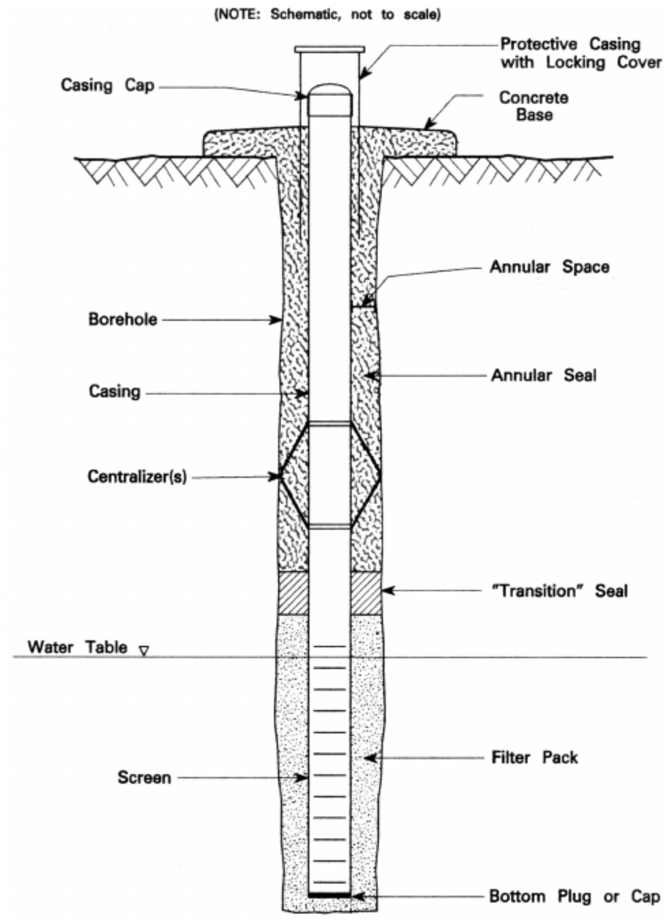
Poorly stored drums are a groundwater pollution risk

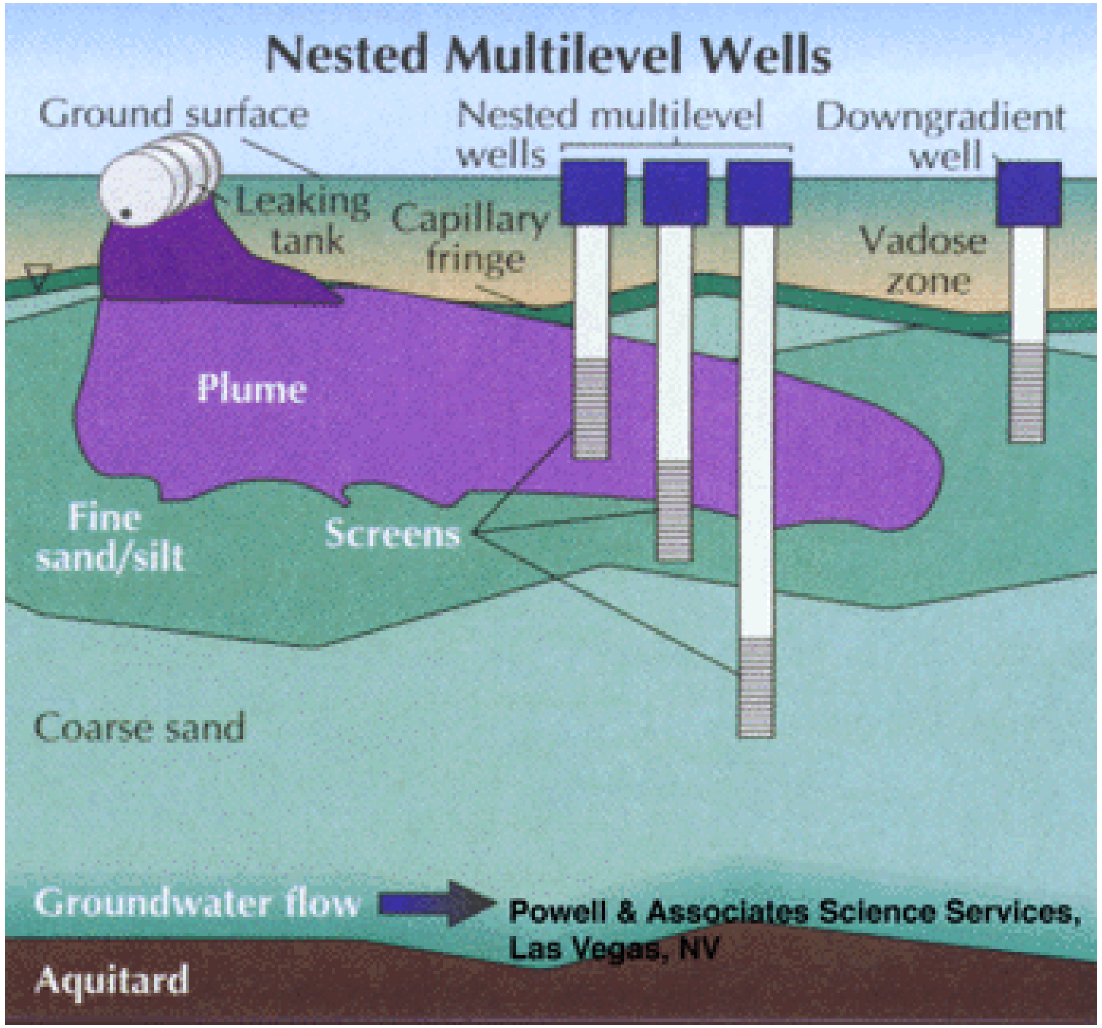
Recharge area map



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

Monitoring wells





Susceptibility Analysis

- **The likelihood that contaminants will be released from a source** and contaminate the source water
- **The vulnerability of the public water system** and probability that it would be impacted by source water contamination
- **The potential consequences of source water contamination** experienced by the public water system and customers

Poll 4

A meat processing plant is near a municipal well that is at a lower elevation than the plant. Which of the following is a vulnerability?

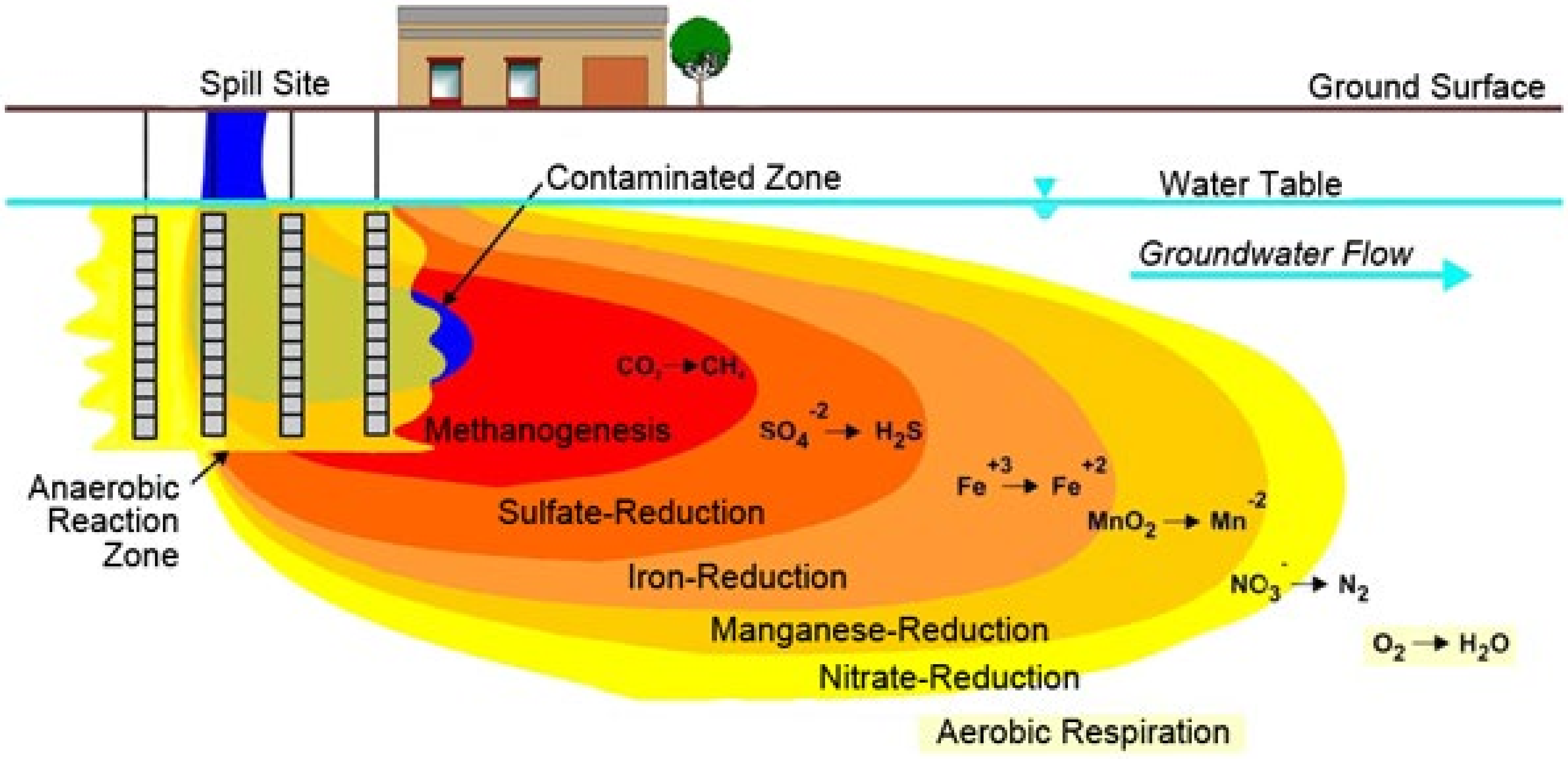
a) Potential illness of customers
b) Likelihood of contamination from the plant
c) The low elevation of the well
d) All of the above

Managing the WHPA

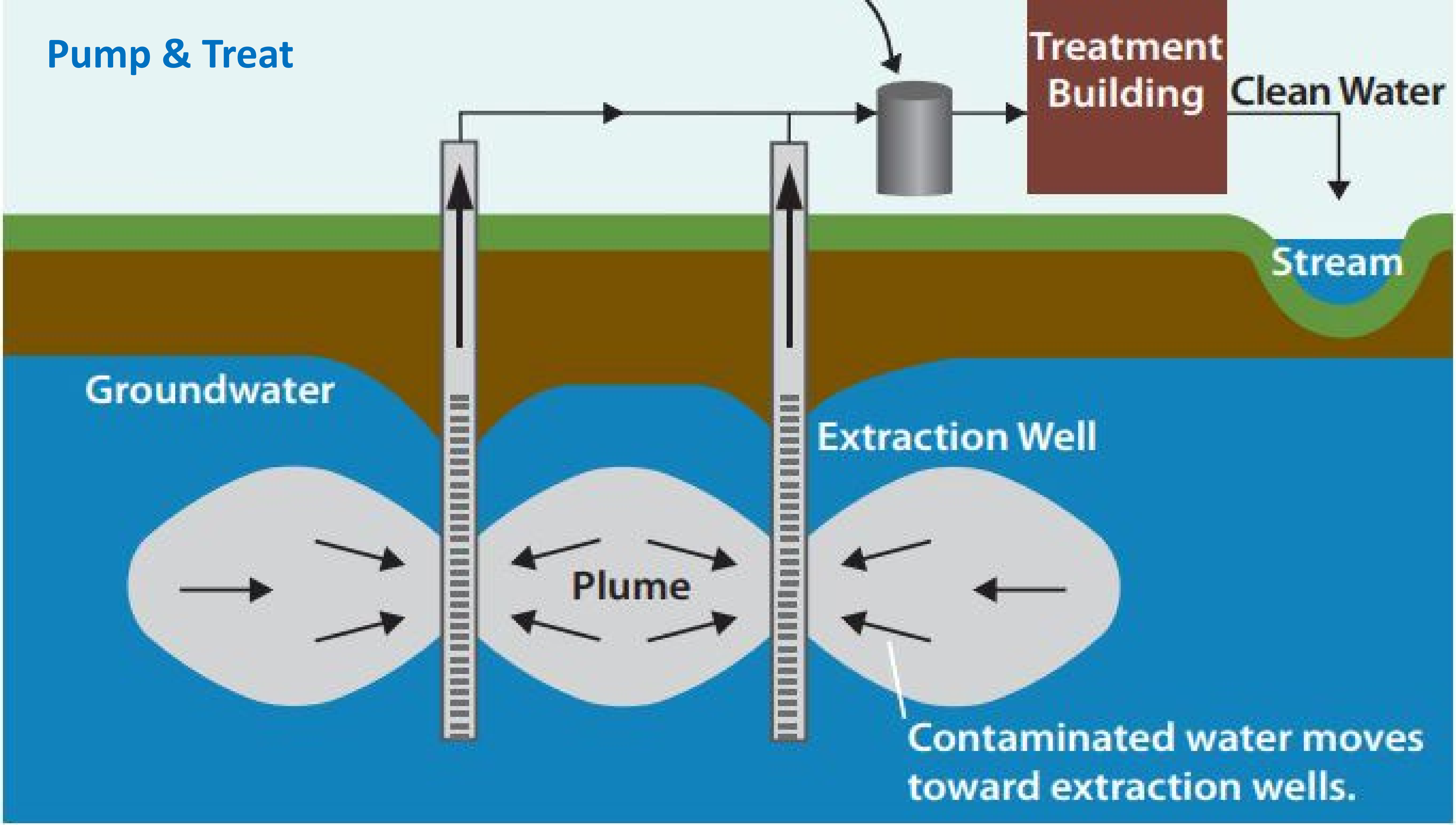
- adoption of zoning restrictions or ordinances,
- development of contamination contingency plans
- working with facilities within the WHPA to minimize potential pollution problems
- purchasing property around wells and
- conducting a public educational program.

Bioremediation

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



Pump & Treat

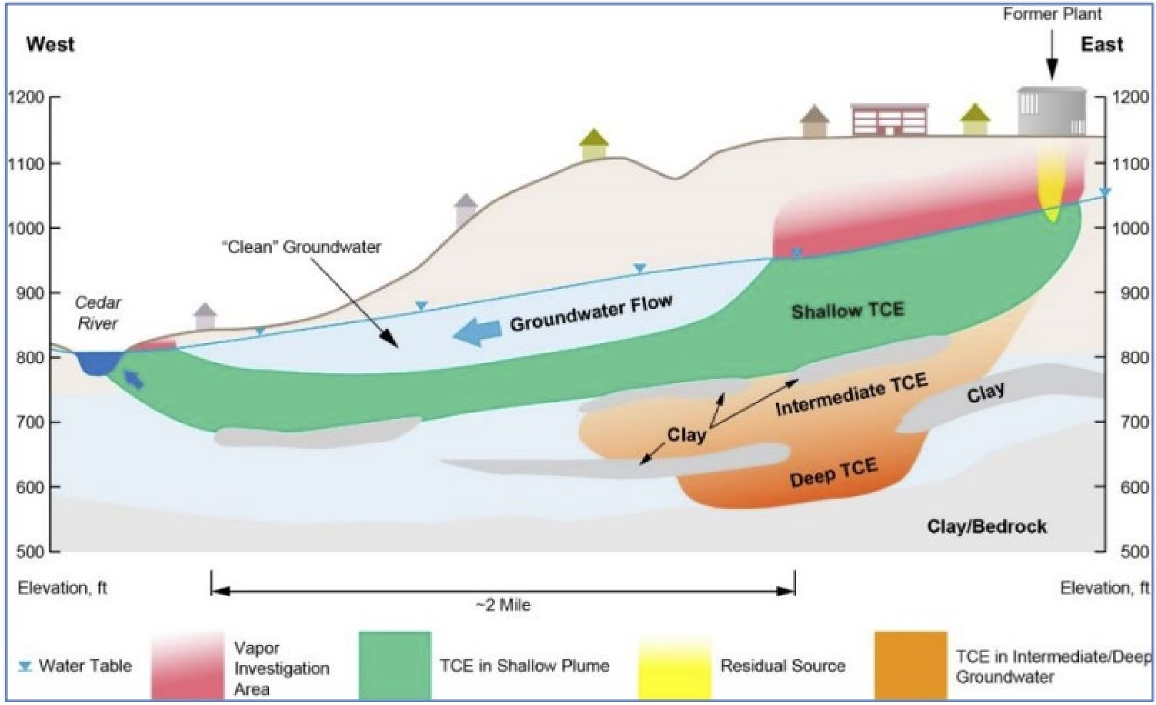


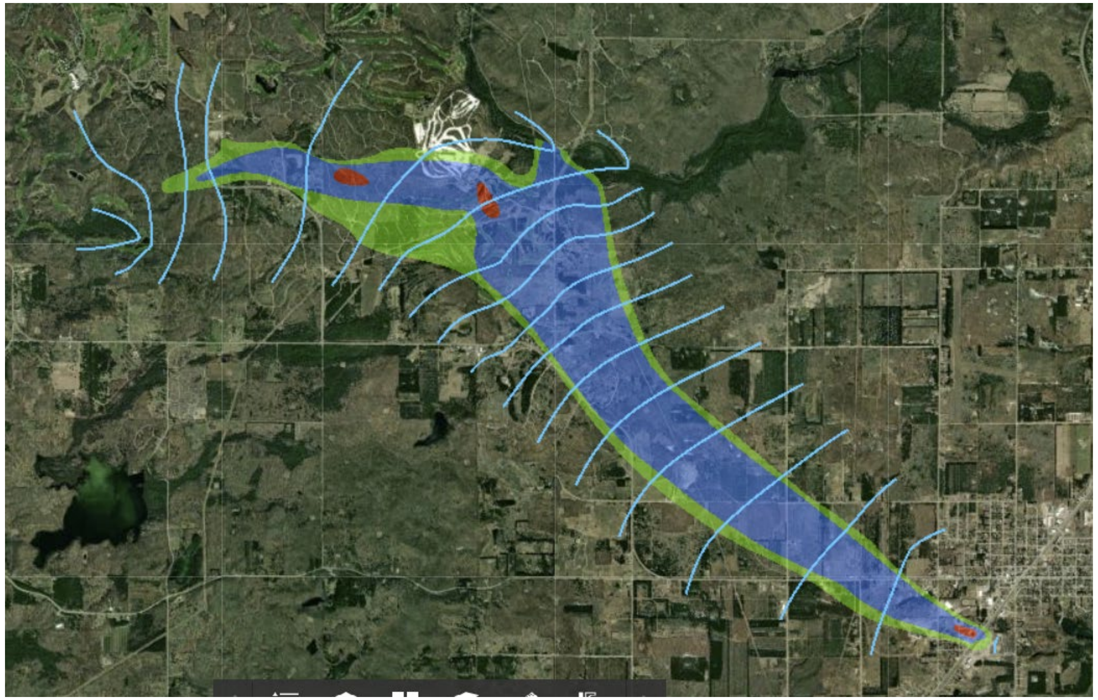
Treatment Building
Clean Water
Stream
Groundwater
Extraction Well
Plume
Contaminated water moves toward extraction wells.

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 #5 screen.

- Operators ignored loss of chlorine residual and falsified records.

- 7 people died and over 2,000 people sick


THE TORONTO STAR

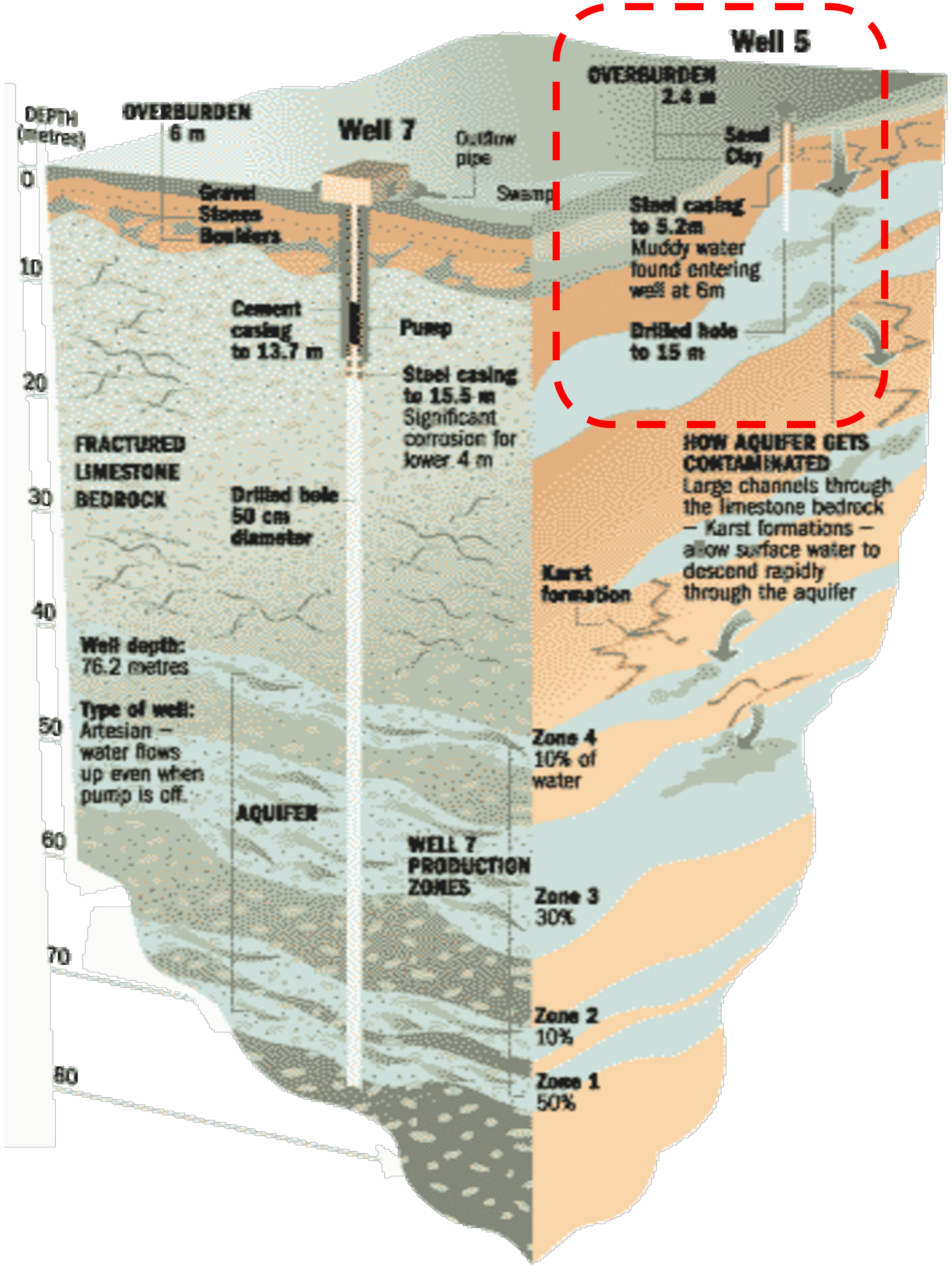
Jackie Chan rides again

Air force showdown

Here's a first aid primer

Police probe E. coli crisis

'Preventable' tragedy claims fifth victim

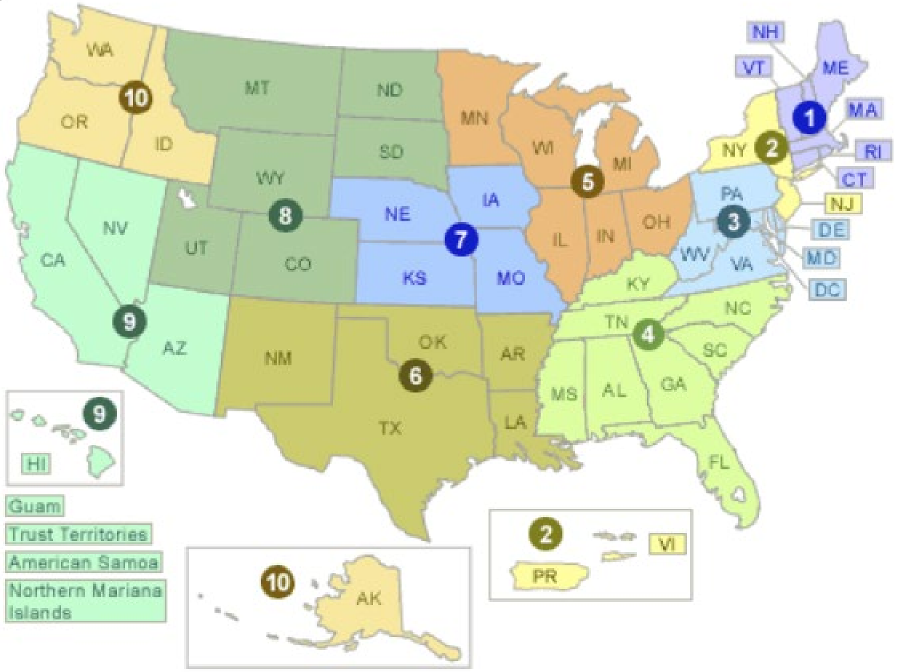


Which methods of public outreach/communication do you think will be most effective in your community?

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 and analyze risks of contaminant sources** within the WHPA
6. **Establish ordinances** and best practices
7. **Inform and educate** stakeholders and public

Source Water Contacts in EPA's Regional Offices



Start with resources provided by your local primacy agency and USEPA

https://www.epa.gov/sourcewaterprotection/source-water-contacts-epas-regional-offices

We're now open for questions

Environmental Finance Center Network
www.efcnetwork.org

Great Lakes Environmental Infrastructure Center
www.gleic.org

Share 1 thing you enjoyed learning about today in the chat

Greg Pearson
gpearson@mtu.edu

EFCN environmental finance center network