GROUNDWATER BASICS FOR PROTECTING UNDERGROUND SOURCES OF DRINKING WATER IN WESTERN IOWA

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Contaminated Sites Section

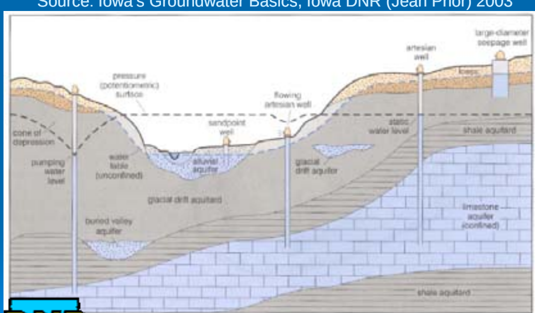
DNR

AQUIFERS and AQUITARDS

- Aquifer: a saturated geologic formation that yields water in sufficient quantity to be economically useful capable of yielding. Water moves relatively easily through an aquifer.
- Aquitard: a saturated geologic formation that does not yields water a significant quantity to be economically useful. An aquitard *retards* groundwater flow.

Wells and Aquifers in Iowa

Source: Iowa's Groundwater Basics, Iowa DNR (Jean Prior) 2003



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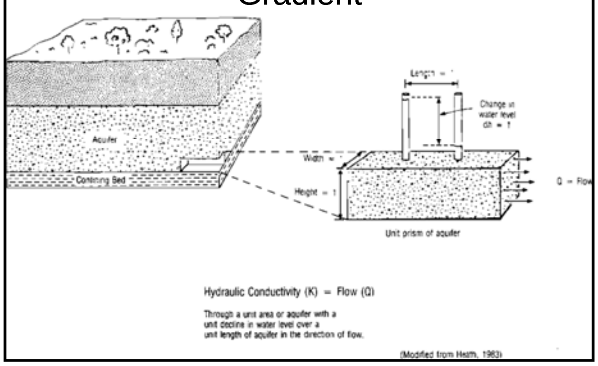
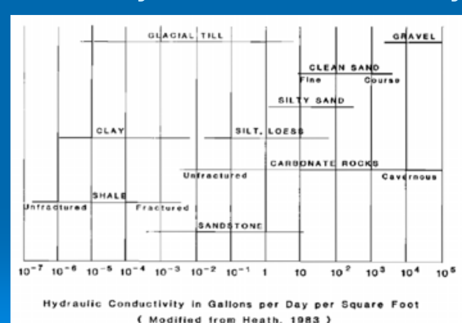
WHAT MAKES A GOOD AQUIFER?

1. Yield
2. Storage
3. Recharge
4. Water Quality
5. Cost

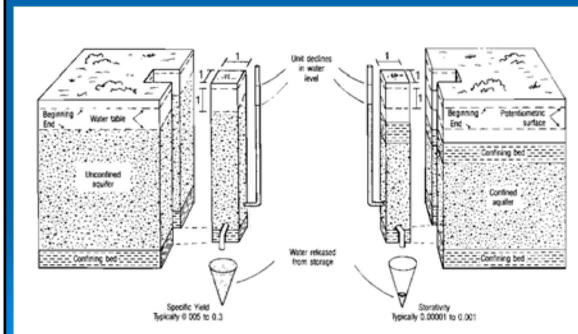
Hydraulic Conductivity and Gradient



YIELD: Hydraulic Conductivity



Storage

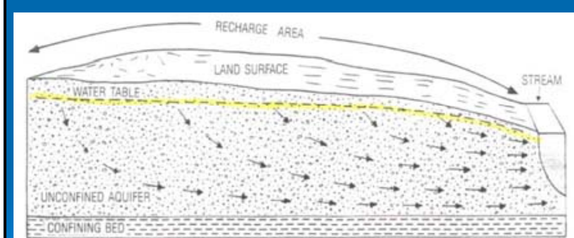


RECHARGE
Water Entering an Aquifer

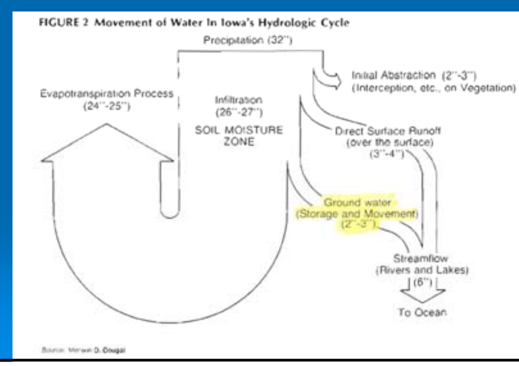
Three forms of recharge:

1. Infiltration of precipitation
2. Discharge of underlying or overlying formations (often minor)
3. Surface water

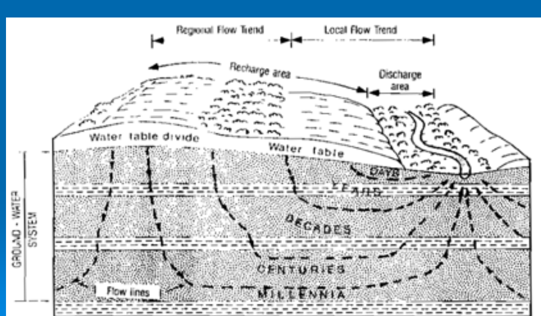
Natural Condition, No Pumping



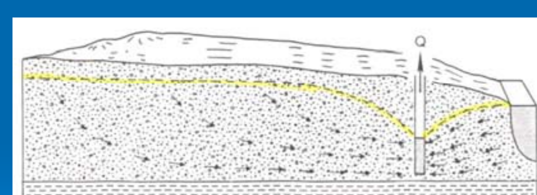
Water Budget



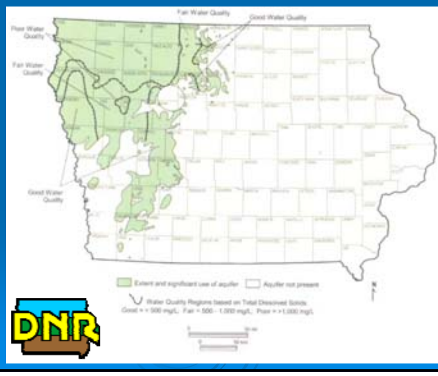
Regional Groundwater Flow

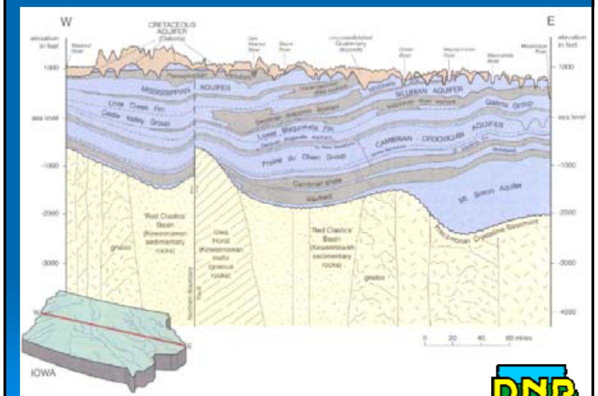


Induced Surface Water Recharge



Water Quality in the Dakota Aquifer

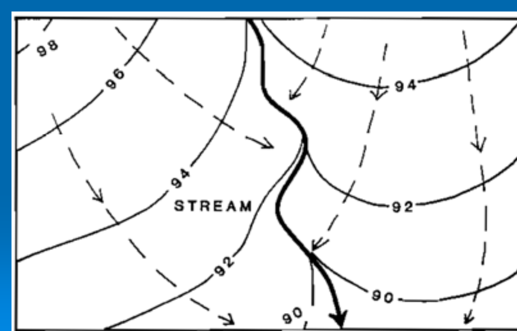




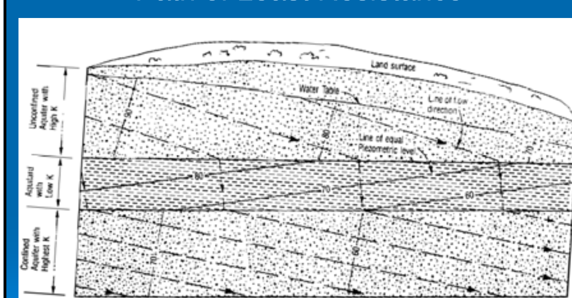
Groundwater Movement

- Groundwater flow is a function of
  - hydraulic conductivity
  - head gradient
- Groundwater moves from high head (water level in a well) to low head
- Groundwater takes the path of least resistance

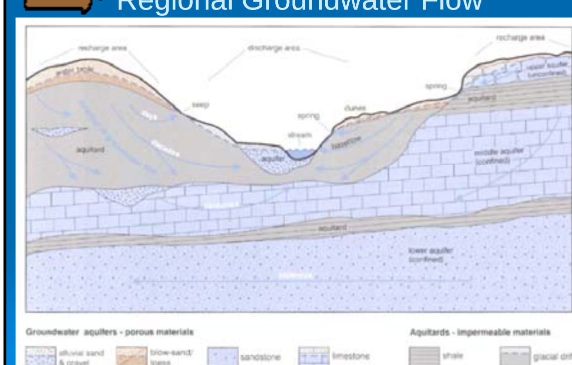
Groundwater Movement
High Head to Low Head



Path of Least Resistance



Regional Groundwater Flow

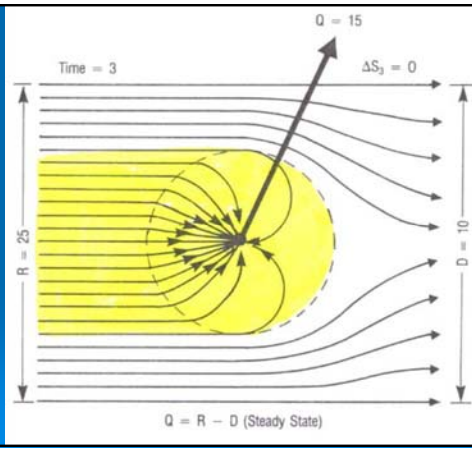


Measuring Vertical Component of Groundwater Movement

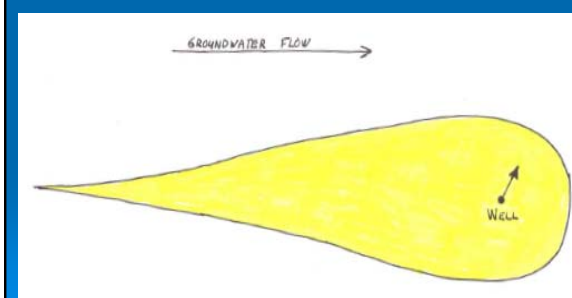
Source Water Protection: Where Does My Water Come From?

1. Recharge in the zone of influence of wells (a.k.a. source water protection zone)
   - Infiltration of precipitation within SW zone
   - Discharge from under/overlying formations
   - Surface water, natural or induced
2. Change in aquifer storage

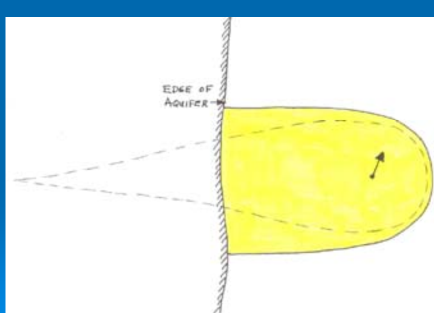
   (equals zero under stable conditions)



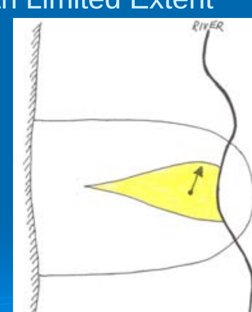
Source Water Zone of an Infinite Homogeneous Aquifer



Source Water Zone of an Aquifer with Limited Extent



Source Water Zone of an Aquifer with Limited Extent



Source Water Protection Area:
Sioux Center, Iowa

Where Does My Water Come From? Sioux Center Example

Q = R @ stable conditions = I + U + S

Where:

- Q = Annual pumpage from the well field = 213 mgal
- I = Infiltration of precipitation (assume 3 inches/year x 2.0 square miles = 104 mgal)
- U = Discharge from underlying formations (minor, assume 10% of I = 10 mgal)
- S = Induced recharge from the stream = Q - I - U = 99 mgal = 46% of Q

Induced Recharge Considerations

- Most prominent with alluvial aquifers, although may even be a factor with shallow bedrock
- Affected by nature of streambed
- Greater influence with closer proximity of well to stream
- Greater influence with larger pumping rates
- Potentially much reduced source water area compared to time-of-travel predictions
- Potential de-nitrification through streambed

The Good News

The more induced surface water recharge the smaller the groundwater recharge source water area

The Bad News

Induced surface water recharge brings the entire upstream surface water drainage into the source water area

Protected vs. Susceptible Aquifers

- Susceptible aquifers tend to be shallow, without an overlying aquitard, and with most recharge coming nearby
- Protected aquifers typically receive recharge from great distances and are threatened most by conduits (e.g.,wells) through overlying aquitards

Groundwater Quality
Contaminant Sources

- Naturally occurring
  - TDS (e.g. sulfate, chloride, hardness, iron, arsenic)
  - Radionuclides (e.g., radon)
  - Nutrients (e.g. nitrate)
- Man-caused
  - Nutrients (e.g., nitrate)
  - Pesticides (e.g., atrazine)
  - Fuels (e.g., benzene, toluene, xylene)
  - Chlorinated solvents (e.g., TCE)
  - Metals (e.g., arsenic)

Groundwater Quality
Localized vs Regional Contaminant Sources

- Regional Sources: widespread contamination not attributed solely to a localized activity
  - agricultural chemical applications
  - urban lawn & garden chemical applications
  - fallout from air

Groundwater Quality
Localized vs Regional Contaminant Sources

- Localized sources: contamination resulting from localized activities
  - Land disposal (on or under)
  - Leaky underground storage tanks
  - Accidental spills
  - Businesses handling bulk quantities of chemicals

Contaminant Movement
Natural Attenuation

- Sorption
- Volatilization
- Chemical/biological breakdown
- Dilution
  - en route to a well
  - from other water being drawn into the well

"Where's the Benzene?" — Examining California Ground-Water Quality Surveys

by Paul W. Hadley and Richard Armstrong

Abstract

Introduction

"While many processes influence the environmental fate of organic contaminants in groundwater, the most likely explanation for the nonoccurence of benzene is that it is destroyed near its source by biodegradation"

Contaminant Movement
Natural Attenuation

Contaminant	Sorption	Breakdown	Migration Potential
Nitrate	Low	Low (aerobic) High (anaerobic)	**High (aerobic)** Low (anaerobic)
Pesticides	High	Varies	Low
Gasoline	Low	High (aerobic) Low (anaerobic)	Low (aerobic) High (anaerobic)
Chlorinated Solvents	Low	Low (aerobic) High (anaerobic)	**High (aerobic)** Low (anaerobic)
Metals	High	None	Low

Contaminant Movement
Localized vs Regional Man-Caused Contaminants

Contaminant	Localized Sources?	Regional Sources?
Nitrate	**YES**	**YES**
Pesticides	**YES**	YES
Gasoline	**YES**	NO
Chlorinated Solvents	**YES**	NO
Metals	**YES**	NO

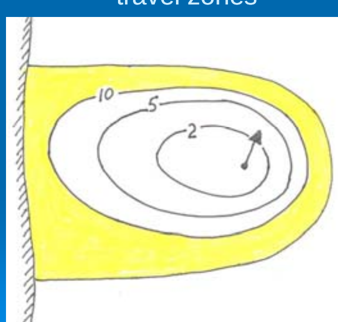
Contaminant Movement
Localized Sources of Nitrate

- Accidental spills
- Incidental leaks and spills from day-to-day handling of fertilizer (1 lb. N >13,000 gal. $H_2$0)
- Feedlots
- Over-application of manure or fertilizer

Significance of Localized vs Regional Contamination

- Localized easier to identify source
- Localized more likely to achieve cleanup in the near term
  - Fewer parties involved
  - Most focused effort
  - Legal authority to require cleanup
- Difficult to accurately define source water area as distance from well increases

Don't Forget: There still may be source water area outside the estimated time-of-travel zones



Conclusions

- Defining the source water area is extremely difficult
- Surface water recharge can be a major component of source water
- Source water areas estimated with time-of-travel models are based on multiple assumptions
- Accuracy of estimated source water zones decreases with distance from the wells
- Confidence in the success of source water protection measures decreases with increased distance from wells
- Greatest contaminant threats tend to be close to well

Conclusions (cont.)

- Natural attenuation of contaminants complicates matters, some contaminants are more problematic than others (e.g., NO_3, TCE)
- Effective source water protection measures require:
  - accurate definition of the source water area for regional contaminant sources
  - Identification of existing, localized contaminant sources

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