

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



by
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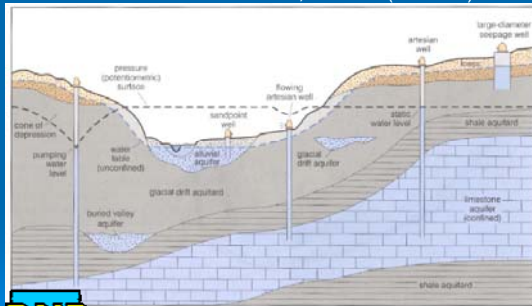


AQUIFERS and AQUITARDS

- **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

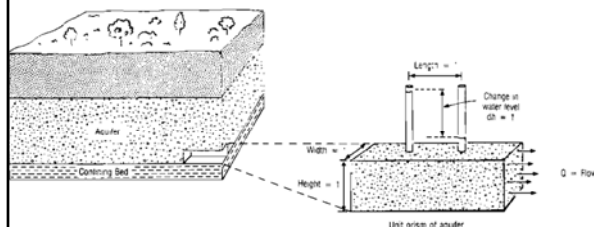


WHAT MAKES A GOOD AQUIFER?

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



Hydraulic Conductivity and Gradient

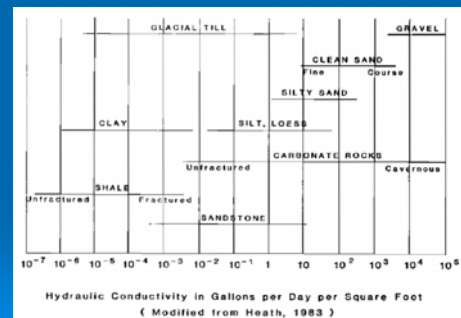


Hydraulic Conductivity (K) = Flow (Q)

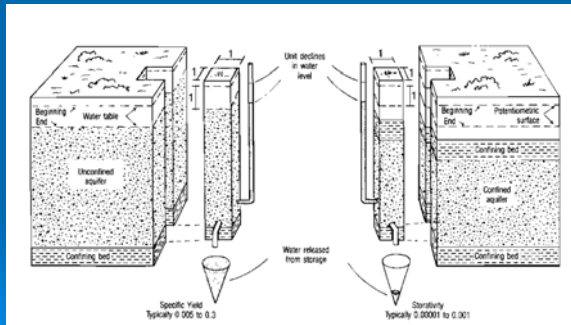
Through a unit area of aquifer with a unit decline in water level over a unit length of aquifer in the direction of flow.

(Modified from Heim, 1983)

YIELD: Hydraulic Conductivity



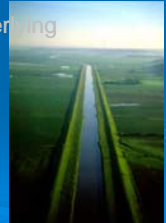
Storage



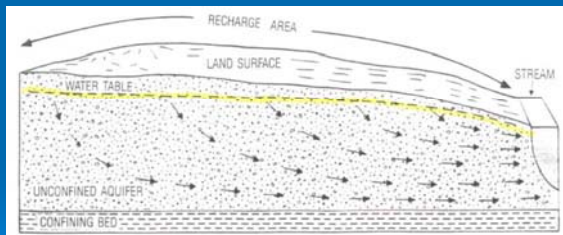
RECHARGE Water Entering an Aquifer

Three forms of recharge:

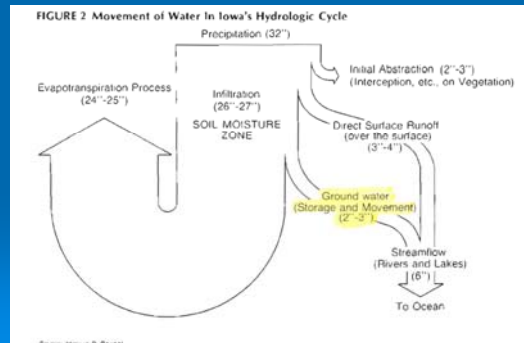
1. Infiltration of precipitation
2. Discharge of underlying or overlying formations (often minor)
3. Surface water



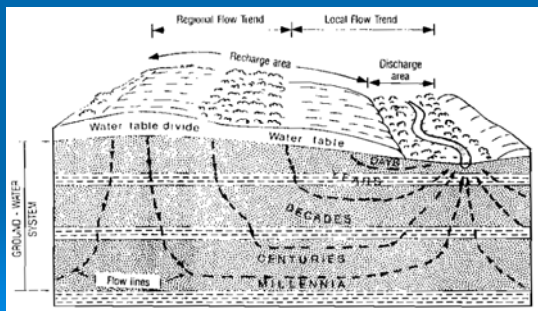
Natural Condition, No Pumping



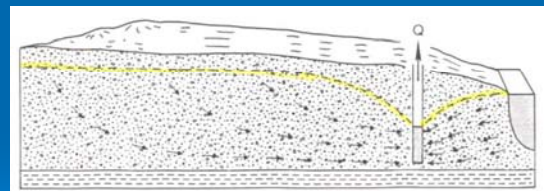
Water Budget



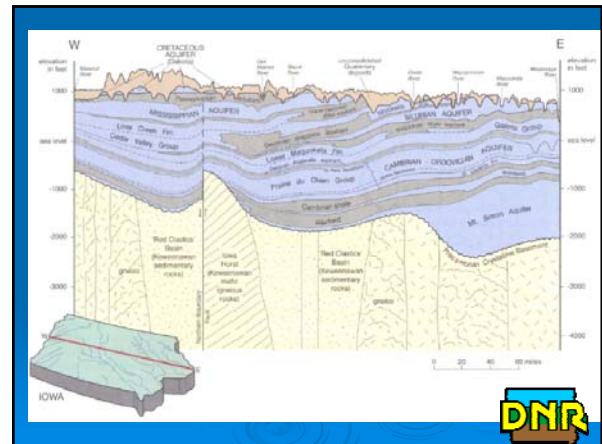
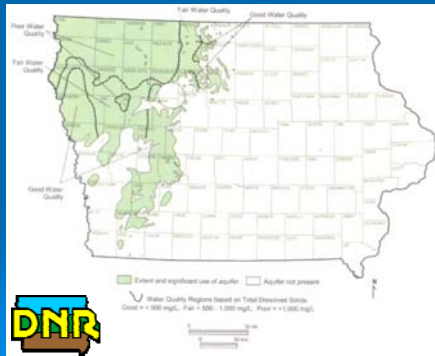
Regional Groundwater Flow



Induced Surface Water Recharge



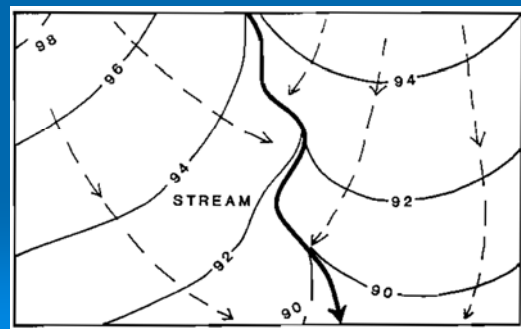
Water Quality in the Dakota Aquifer



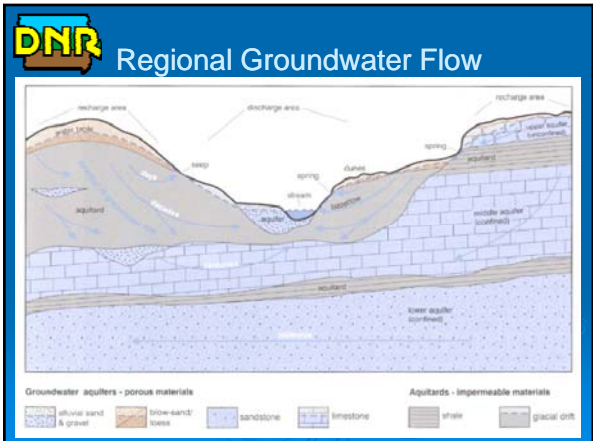
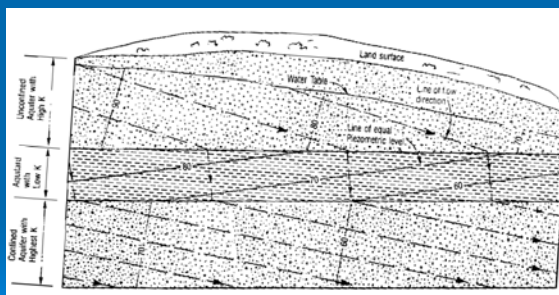
Groundwater Movement

- 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

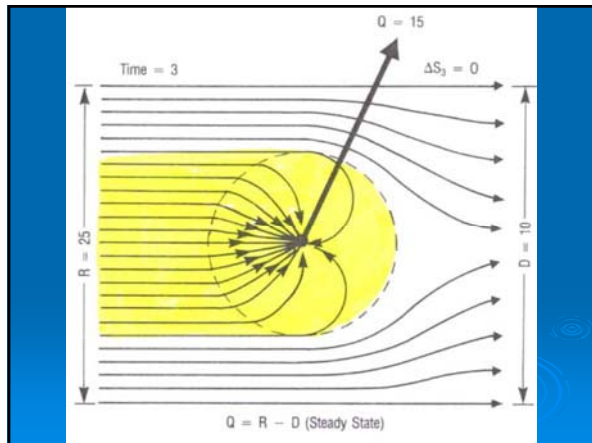


Measuring Vertical Component of Groundwater Movement

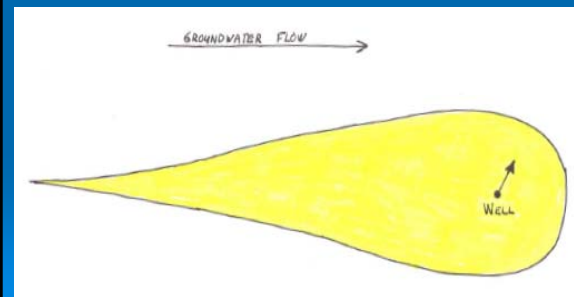


Source Water Protection: Where Does My Water Come From?

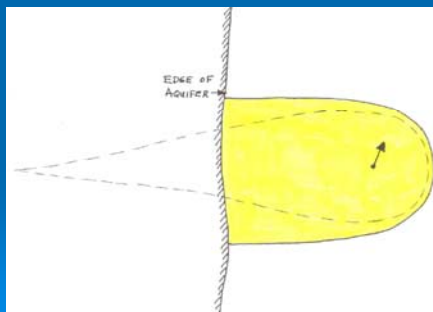
1. Recharge in the zone of influence of wells (a.k.a. source water protection zone)
 - Infiltration of precipitation within SW zone
 - Discharge from under/overlying formations
 - Surface water, natural or induced
2. Change in aquifer storage (equals zero under stable conditions)



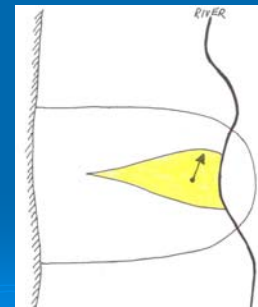
Source Water Zone of an Infinite Homogeneous Aquifer



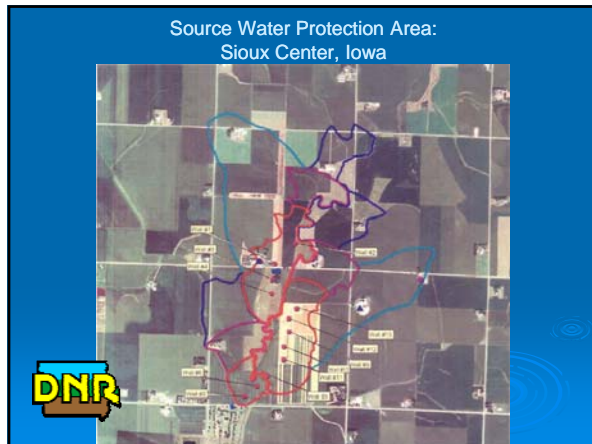
Source Water Zone of an Aquifer with Limited Extent



Source Water Zone of an Aquifer with Limited Extent



DNR



Where Does My Water Come From? Sioux Center Example

$$Q = R \text{ @ stable conditions} = I + U + S$$

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 =
 $Q - I - U = 99 \text{ mgal} = 46\% \text{ of } Q$

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. Hsieh and Richard Armstrong

Abstract

Thousands of existing underground gasoline leaks have been found throughout California. Some which a significant amount of gasoline has leaked into ground water over the past half century. The down water-soluble constituents of gasoline in benzene, and especially benzene, are found in ground water before being subjected to biodegradation. In a state-mandated program, 1,200 wells serving water supply systems throughout California were tested for a broad panel of organic contaminants, 500 of the wells tested for 100 different benzene concentrations of at least one of the contaminants tested for. Benzene concentrations of at least one benzene concentration of at least 10 ppb. Benzene findings were compared to the findings for the 1,200 wells and for 1,200 wells. While many processes influence the environmental fate of organic contaminants in ground water, the most likely explanation for the nonoccurrence of benzene is that it is destroyed near its source by biodegradation.

Introduction

Localized occurrence of chemicals in ground water in industrial and agricultural areas, but not a naturally occurring source, has been shown to affect ground water quality. Chemicals that are not naturally occurring in ground water are characterized by individual usage, at their source, signs of water utilization, and environmental processes. The most widespread chemical in ground water within the low molecular weight hydrocarbon chemical class is benzene, which is a volatile, colorless, odorless, and water-soluble chemical. Benzene is a naturally occurring chemical, and is found in ground water in a variety of concentrations. Higher molecular weight hydrocarbon compounds such as polychlorinated biphenyls and dioxins have each been water-soluble, but they are not found in ground water in the same concentrations as benzene.

Gasoline is a mixture of dozens of hydrocarbon compounds, generally having molecular weights below 150. Benzene is the most volatile component of gasoline, and is found in ground water in a variety of concentrations. Benzene is a naturally occurring chemical, and is found in ground water in a variety of concentrations. Higher molecular weight hydrocarbon compounds such as polychlorinated biphenyls and dioxins have each been water-soluble, but they are not found in ground water in the same concentrations as benzene.

most in the most water-soluble component of gasoline are typically composed of 10 to 15% of the total weight (Hsieh and Armstrong, 1998; Hsieh et al., 1997). Natural benzene is found in ground water in a variety of concentrations. Benzene is a naturally occurring chemical, and is found in ground water in a variety of concentrations. Higher molecular weight hydrocarbon compounds such as polychlorinated biphenyls and dioxins have each been water-soluble, but they are not found in ground water in the same concentrations as benzene.

Ground-Water Contamination by Benzene: Presumptions and Predictions
The natural occurrence of benzene in ground water is a well-known fact. Benzene is a naturally occurring chemical, and is found in ground water in a variety of concentrations. Higher molecular weight hydrocarbon compounds such as polychlorinated biphenyls and dioxins have each been water-soluble, but they are not found in ground water in the same concentrations as benzene.

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"While many processes influence the environmental fate of organic contaminants in groundwater, the most likely explanation for the nonoccurrence 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

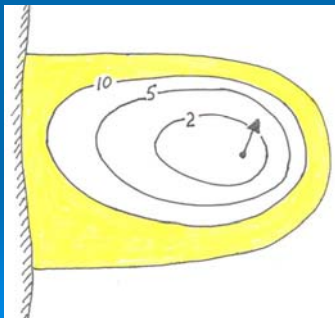
Contaminant Movement Localized Sources of Nitrate

- Accidental spills
- Incidental leaks and spills from day-to-day handling of fertilizer (1 lb. N >13,000 gal. H₂O)
- 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., NO₃, 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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