



Well Assessment Decision Support System – A Web Tool for Evaluating the Vulnerability of Public-Supply Wells

Based on the forthcoming USGS Circular: The Quality of our Nation's Water: Understanding Public-Supply Well Vulnerability to Contaminants in Groundwater by Sandra Eberts, et al

U.S. Department of the Interior
U.S. Geological Survey



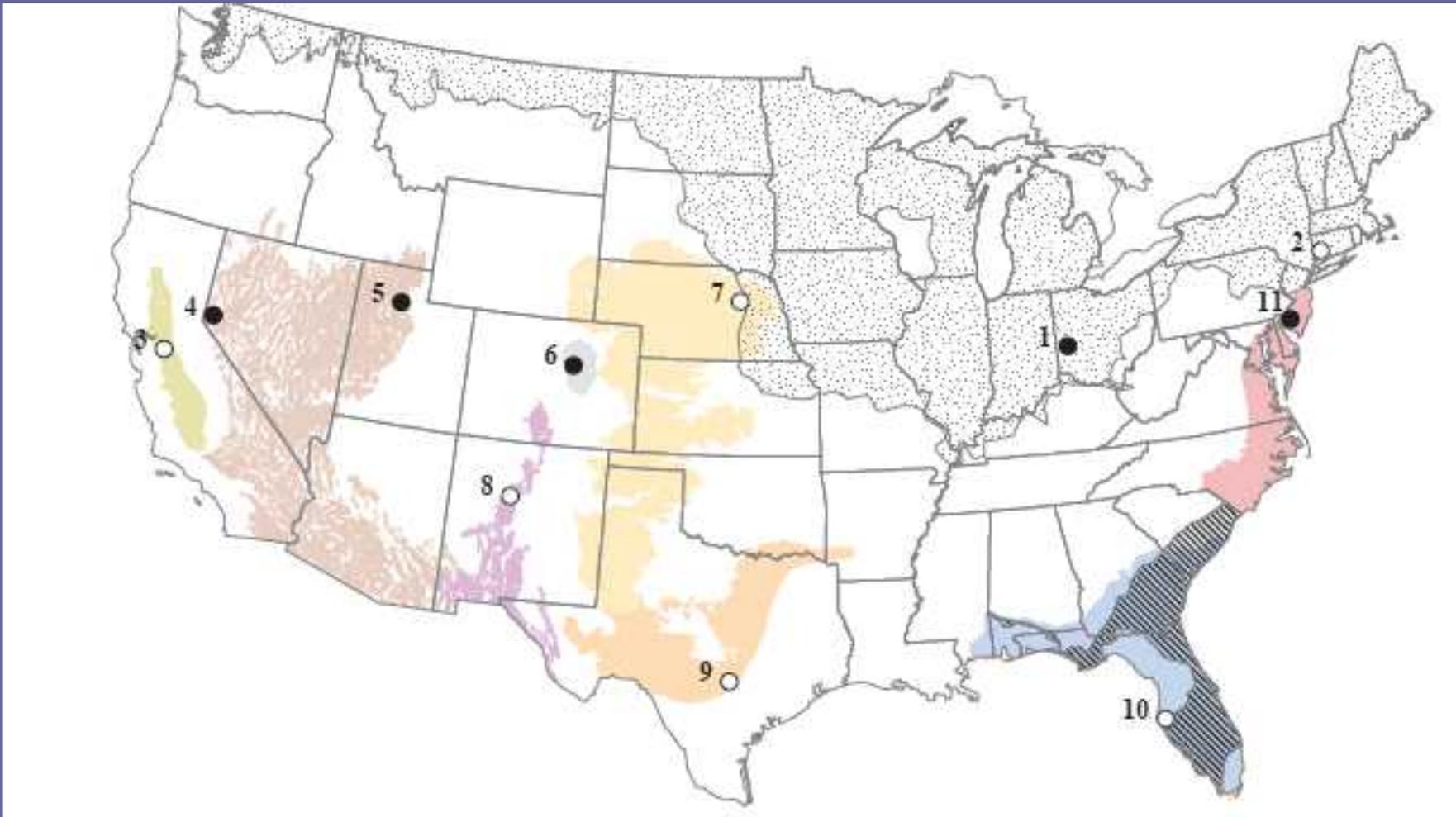
The study of public-supply well vulnerability to contamination from compounds commonly found in the environment was one of the national priority topics addressed by the National Water-Quality Assessment (NAWQA) Program in Cycle 2.

Goals included:

- Identification of dominant contaminants and their sources in representative public-supply
- Assess the effects of both natural and anthropogenic processes on the occurrence of contaminants

- Identify the factors that are most important to incorporate into public-supply well vulnerability assessments in different settings and at different spatial scales
- Develop simple methods and models for screening public-supply wells for vulnerability to contamination in unstudied areas and from newly emerging contaminants
- Increase understanding of the potential effects of water-resource development and management decisions on the quality of water from public-supply wells

Study Areas



Surrogate measures of public-supply well vulnerability

- Sources of recharge water
- Geochemical conditions
- Groundwater age mixtures
- Preferential flow pathways

Preventing contaminants from entering groundwater is the best option

Not able to prevent all contamination?

- Know what to measure
- Know what it means
- Know what actions to take

Landing Page



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Public-Supply Water Well Assessment

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Circular 15xx



The Quality of our Nation's Water: Understanding Public-Supply Well Vulnerability to Contaminants in Groundwater

About the NAWQA (National Water Quality Assessment) Program

[NAWQA program home](#)

[NAWQA TANC \(Transport of Anthropogenic and Natural Contaminants\) program home](#)

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Public-Supply Well Assessment

In 2001, the USGS National Water Quality Assessment (NAWQA) program began an intensive study of public-supply well vulnerability to contaminants in groundwater.

The study was initiated to increase understanding of anthropogenic and natural contaminants detected in the Nation's public-supply wells.

Purpose of this website

This website helps water managers assess their wells for vulnerability to contaminants in the sources of groundwater.

The website contains 4 numbered sections. Each section moves through explanations, case studies, and assessment toolboxes on potential contaminants and vulnerabilities. A checklist at the end helps you document your analysis.

All information is based on the USGS Circular 15xx, "The Quality of our Nation's Water: Understanding Public-Supply Well Vulnerability to Contaminants in Groundwater," by Sandra M. Eberts, Mary Ann Thomas and Martha L. Jagucki (2011). In case of conflicting information, the USGS Circular takes precedence over this educational website.

Assessment help



Sources of Recharge

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Sources of Recharge Water

Different sources of recharge are typically associated with different contaminants. For example:

- Urban land - water that is recharged beneath urban land is likely to have more VOCs than that recharged beneath agricultural land (Zogorski and others, 2006).
- Agricultural recharge is likely to have higher concentrations of nitrate than urban recharge (Dubrovsky and others, 2010).
- Both urban and agricultural recharge may contain pesticides, but the types may differ; simazine and prometon are more commonly associated with urban recharge, whereas atrazine and metolachlor are more commonly associated with agricultural recharge (Gilliom and others, 2006).

Public-supply wells typically integrate water from multiple sources because they are pumped at relatively high rates and have relatively long screened or open intervals. To understand well vulnerability, it is important to understand the sources of recharge that contribute to a well, the relative contribution from each source, and the contaminants associated with each source.

Zone of Contribution



The well in the upper figure draws in water that was recharged in an urban area (red arrows). Contaminants associated with shallow groundwater in urban areas are VOCs, nitrate, and urban-use pesticides.

Entire Checklist

1. Get Started

1.1 To get started with this questionnaire, answer the two questions below. Then, choose another questionnaire (ie, 'Source of Water') from the checklists menu. Answer any or all of the questions in the checklists. When you are finished, you may choose 'Generate Report' to create a report on well vulnerability based on your answers to the questionnaire.

1.2 What is the well name?

1.3 Have contaminants been detected in raw (untreated) water from the well?

2. Source of Water

2.1 Has the contributing area for the public-supply well been satisfactorily delineated?

2.2 Are water quality data available for shallow groundwater beneath the different sources of recharge?

3. Geochemical Conditions

3.1 Are there anthropogenic sources that greatly increase the organic carbon, or other electron donors such as pyrite, in the well's aquifer?

3.2 Is there high volume pumping of deep water at the well?

3.3 Does the well draw water from multiple aquifers?

3.4 Which, if any, anthropogenic contaminants are a concern

Toolboxes available dynamically

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[All Toolboxes](#) > Mixing equations

Sources of Recharge Toolbox:

Using Mixing Equations to Understand Sources of Water for a Public Supply Well

One straightforward way to investigate the sources of water that mix in a public-supply well is based on concentrations or ratios of conservative solutes, such as chloride and bromide, or stable isotopes, such as oxygen-18 (^{18}O) and deuterium (^2H). In groundwater, these constituents are not easily removed by geochemical processes like mineral precipitation or sorption. Therefore, changes in concentrations or ratios of conservative constituents are assumed to be related to mixing of water from different sources. If different parts of an aquifer system have distinct concentrations or ratios of conservative constituents, then the proportions of the different waters that enter a well can be estimated by using a simple mixing equation.

A simple mixing equation [binary mixing model]

$$X_1 = (C_{\text{mix}} / C_2 / C_1 - C_2) * 100$$

Where

- X_1 is the proportion of end-member 1 in the mixture (in percent)
- C_1 is concentration of end-member 1
- C_2 is concentration of end-member 2
- C_{mix} is concentration of the water mixture

C_{mix}

C_1

C_2

Result

Now fill in the checklist based on what has been learned

and background	vulnerability	vulnerability	checklists
<h2>Geochemical Conditions</h2> <p>Geochemical conditions along groundwater flow pathways—especially redox conditions, alkalinity, and pH—strongly influence the mobility and persistence of many water-quality constituents.</p> <p>They can control</p> <ul style="list-style-type: none">• whether a contaminant travels with the groundwater, or whether it degrades before reaching a well• whether reactions between the groundwater and the aquifer material lead to increased or decreased contaminant concentrations at the well <h3>Redox Conditions</h3> <h4>What are redox reactions?</h4> <p>Reduction-oxidation (redox) reactions involve the exchange of one or more negatively-charged electrons between an electron donor and an electron acceptor. The reactions are facilitated by microorganisms.</p> <h4>How does this apply to groundwater?</h4> <ul style="list-style-type: none">• In groundwater, organic carbon is typically the electron donor, and therefore organic carbon is oxidized during redox reactions.• At the same time, electron acceptors are reduced during redox reactions. Multiple potential electron acceptors are typically available in groundwater.• Oxygen is the preferred electron acceptor, but if sufficient dissolved oxygen does not exist, other electron acceptors will be used in a sequential manner on the basis of the amount of energy produced by each reaction. <p>The order in which electron acceptors are utilized is as follows:</p> <p>dissolved oxygen > nitrate > manganese(IV) > iron(III) > sulfate > carbon dioxide</p> <h4>How do redox conditions explain contaminant occurrence?</h4> <ul style="list-style-type: none">• REDOX ZONATION: Because of the sequential use of electron acceptors in groundwater, zones of differing redox conditions may exist within an aquifer. Redox zonation in aquifers accounts for some spatial variation in contaminant occurrence in groundwater.• CHANGING TOXICITY: Redox conditions of groundwater also are important because the oxidation state of some elements affects their toxicity. For example, the more oxidized form of chromium (Cr+6) is considered to be more toxic than the reduced form (Cr+3). <p>Examples: These figures illustrate how redox zonation in an aquifer, along with well location and design, can affect the redox conditions of the withdrawn water and influence which contaminants arrive at the well. It may not be</p>			<h2>Entire Checklist</h2> <ol style="list-style-type: none">1. Get Started2. Source of Water<ol style="list-style-type: none">2.1 Has the contributing area for the public-supply well been satisfactorily delineated?2.2 Are water quality data available for shallow groundwater beneath the different sources of recharge? <input checked="" type="checkbox"/> yes2.2.1 What contaminants are present in the shallow groundwater in the different areas? Nitrate <input type="text"/>2.2.2 Are there some contaminants in the shallow groundwater that have not been detected in the well? <input checked="" type="checkbox"/> yes <input type="checkbox"/> no2.2.3 Does the water quality data set (shallow groundwater and public-supply well) contain concentrations of one or more conservative constituents (nonreactive) (for example, chloride and bromide OR oxygen-18 and deuterium)? <input checked="" type="checkbox"/> yes2.2.3.1 Are concentrations or ratios of conservative constituents unique for different sources of recharge? <input checked="" type="checkbox"/> yes <input type="checkbox"/> no3. Geochemical Conditions4. Groundwater Age Mixture

Geochemical Conditions



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Geochemical Conditions

Geochemical conditions along groundwater flow pathways—especially redox conditions, alkalinity, and pH—strongly influence the mobility and persistence of many water-quality constituents.

They can control

- whether a contaminant travels with the groundwater, or whether it degrades before reaching a well
- whether reactions between the groundwater and the aquifer material lead to increased or decreased contaminant concentrations at the well

Redox Conditions

What are redox reactions?

Reduction-oxidation (redox) reactions involve the exchange of one or more negatively-charged electrons between an electron donor and an electron acceptor. The reactions are facilitated by microorganisms.

How does this apply to groundwater?

- In groundwater, organic carbon is typically the electron donor, and therefore organic carbon is oxidized during redox reactions.
- At the same time, electron acceptors are reduced during redox reactions. Multiple potential electron acceptors are typically available in groundwater.
- Oxygen is the preferred electron acceptor, but if sufficient dissolved oxygen does not exist, other electron acceptors will be used in a sequential manner on the basis of the amount of energy produced by each reaction.

The order in which electron acceptors are utilized is as follows:

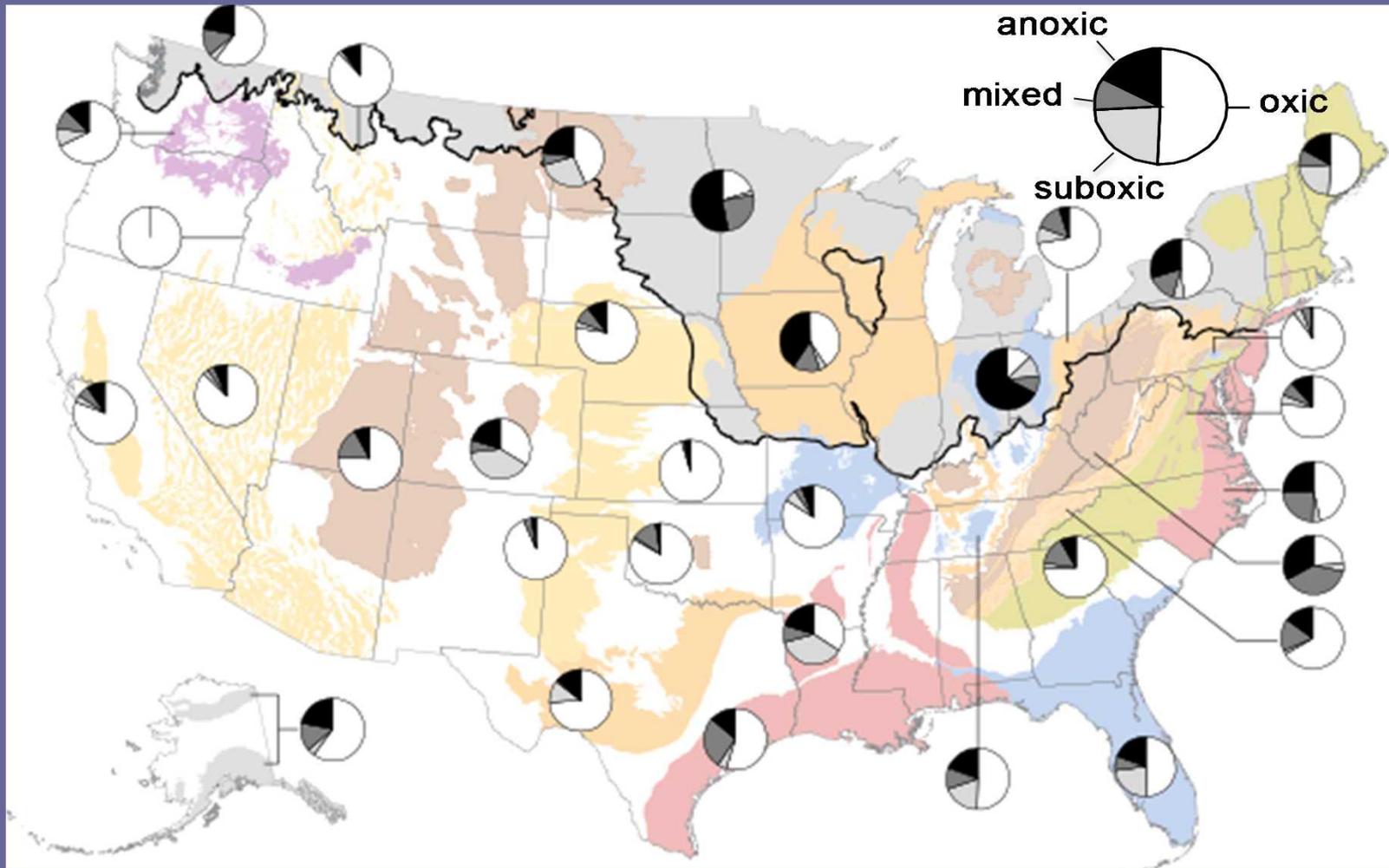
dissolved oxygen > nitrate > manganese(IV) > iron(III) > sulfate > carbon dioxide

How do redox conditions explain contaminant occurrence?

- REDOX ZONATION: Because of the sequential use of electron acceptors in groundwater, zones of differing redox conditions may exist within an aquifer. Redox zonation in aquifers accounts for some spatial variation in contaminant occurrence in groundwater.
- CHANGING TOXICITY: Redox conditions of groundwater also are important because the oxidation state of some elements affects their toxicity. For example, the more oxidized form of chromium (Cr+6) is considered to be more toxic than the reduced form (Cr+3).



Typical Regional Redox Conditions



Other toolboxes available for download

General redox category	Predominant redox process	Water-quality criteria (mg/L)					Fe ²⁺ /H ₂ S mass ratio
		O ₂	NO ₃ ⁻	Mn ²⁺	Fe ²⁺	SO ₄ ²⁻	
Oxic	O ₂ reduction	≥0.5	-	<0.5	<0.1	-	-
Suboxic		<0.5	<0.5	<0.5	<0.1	-	-
Anoxic	NO ₃ ⁻ reduction	<0.5	≥0.5	<0.5	<0.1	-	-
	Mn(IV) reduction	<0.5	<0.5	≥0.5	<0.1	-	-
	Fe(III) or SO ₄ ²⁻ reduction	<0.5	<0.5	-	≥0.1	≥0.5	-
	Fe(III) reduction	<0.5	<0.5	-	≥0.1	≥0.5	>10
	Mix Fe(III) and SO ₄ ²⁻ reduction	<0.5	<0.5	-	≥0.1	≥0.5	≥0.3 and ≤10
	SO ₄ ²⁻ reduction	<0.5	<0.5	-	≥0.1	≥0.5	<0.3
	Methanogenesis	<0.5	<0.5	-	≥0.1	<0.5	-
Mixed	Criteria for more than one redox process are met						



(McMahon and Chapelle, 2007; Chapelle and others, 2008; Jurgens and others, 2009)



Sample ID	Redox Variables	Dissolved O ₂	NO ₃ (as Nitrogen)	Mn ²⁺	Fe ²⁺	SO ₄ ²⁻	Sulfide (sum of H ₂ S, HS ⁻ , S ²⁻)	Num of Params	General Redox Category	
		Units	millig/L	millig/L	microg/L	microg/L	millig/L			millig/L
		Threshold values	0.5	0.5	50	100	0.5			none
1		7.3	9.35	21	18	6.06				
2	Clear Redox Assignments	0.1	0.05	1	24	0.4				
3		0.2	2.48	13	6	22.2				
4		0.1	0.02	64	34	5.2				
5		0.1	0.02	19.8	2010	1.86				
6	Assign Redox Categories and Processes	0.1	0.05	172	1610	0.12				
7		6.9	3.84	151	10	0.27				
8		0.5	0.05	52	158	6.14				
9		2	0.05	110	5700	0.1				
10		0.1	0.71	60	1	7.6				
11		0.1	3.9	174	15000	4.1				
12		0.1	0.6	10	200	0.2				
13		0.2	0.05	19.8	2010	1.86	7			
14		0.2	0.05	19.8	2010	1.86	2			
15		0.2	0.05	19.8	2010	1.86	0.2			
16	1.2	0.05	52	158	6.14	1				
17	0.7	0.05	52	158	6.14	0.1				
18	0.9	0.05	52	158	6.14	0.01				
19	0.2	2	19.8	2010	1.86	7				
20	0.2	2	19.8	2010	1.86	2				
21	0.2	2	19.8							
22	5.3									
23	0.2		4							

Redox Assignment

Delete cells, rows, or columns

Sample ID	Redox Variables	Dissolved O ₂	NO ₃ (as Nitrogen)	Mn ²⁺	Fe ²⁺	SO ₄ ²⁻	Sulfide (sum of H ₂ S, HS ⁻ , S ²⁻)	Num of Params	General Redox Category	Redox Process	Fe ²⁺ /Sulfide ratio	
		Units	millig/L	millig/L	microg/L	microg/L	millig/L					millig/L
		Threshold values	0.5	0.5	50	100	0.5					none
1		7.3	9.35	21	18	6.06		5	Oxic	O2		
2	Clear Redox Assignments	0.1	0.05	1	24	0.4		5	Suboxic	Suboxic		
3		0.2	2.48	13	6	22.2		5	Anoxic	NO3		
4		0.1	0.02	64	34	5.2		5	Anoxic	Mn(IV)		
5		0.2	0.05	19.8	2010	1.86		5	Anoxic	Fe(III)/SO4		
6	Assign Redox Categories and Processes	0.1	0.06	172	1610	0.12		5	Anoxic	CH4gen		
7		6.9	3.84	151	10	0.27		5	Mixed(oxic-anoxic)	O2-Mn(IV)		
8		0.5	0.05	52	158	6.14		5	Mixed(oxic-anoxic)	O2-Fe(III)/SO4		
9		2	0.05	110	5700	0.1		5	Mixed(oxic-anoxic)	O2-CH4gen		
10		0.1	0.71	60	1	7.6		5	Mixed(anoxic)	NO3-Mn(IV)		
11		0.1	3.9	174	15000	4.1		5	Mixed(anoxic)	NO3-Fe(III)/SO4		
12		0.1	0.6	10	200	0.2		5	Mixed(anoxic)	NO3-CH4gen		
13		0.2	0.05	19.8	2010	1.86	7	6	Anoxic	SO4	0.29	
14		0.2	0.05	19.8	2010	1.86	2	6	Mixed(anoxic)	Fe(III)-SO4	1.01	
15		0.2	0.05	19.8	2010	1.86	0.2	6	Anoxic	Fe(III)	10.05	
16	1.2	0.05	52	158	6.14	1	6	Mixed(oxic-anoxic)	O2-SO4	0.16		
17	0.7	0.05	52	158	6.14	0.1	6	Mixed(oxic-anoxic)	O2-Fe(III)-SO4	1.58		
18	0.9	0.05	52	158	6.14	0.01	6	Mixed(oxic-anoxic)	O2-Fe(III)	15.80		
19	0.2	2	19.8	2010	1.86	7	6	Mixed(anoxic)	NO3-SO4	0.29		
20	0.2	2	19.8	2010	1.86	2	6	Mixed(anoxic)	NO3-Fe(III)-SO4	1.01		
21	0.2	2	19.8	2010	1.86	0.2	6	Mixed(anoxic)	NO3-Fe(III)	10.05		
22	5.3						3	O2 >= 0.5 mg/L	Unknown			
23	0.2						4	O2 < 0.5 mg/L	Unknown			
24			9.35	21	18	6.06	4	OxicOrAnoxic	O2?OrNO3			
25			0.05	1	24	0.4	4	OxicOrSuboxic	O2?OrSuboxic			
26			0.02	64	34	5.2	4	AnoxicOrMixed(oxic-anoxic)	Mn(IV)-O2?			
27			0.05	19.8	2010	1.86	4	AnoxicOrMixed(oxic-anoxic)	Fe(III)/SO4-O2?			
28			0.06	172	1610	0.12	4	AnoxicOrMixed(oxic-anoxic)	CH4gen-O2?			
29			3.84	151	10	0.27	4	Mixed(anoxic)Or(oxic-anoxic)	Mn(IV)-O2?OrNO3			
30			3.9	174	15000	4.1	4	Mixed(anoxic)Or(oxic-anoxic)	Fe(III)/SO4-O2?OrNO3			
31			0.6	10	200	0.2	4	Mixed(anoxic)Or(oxic-anoxic)	CH4gen-O2?OrNO3			
32			0.05	52	158	6.14	5	AnoxicOrMixed(oxic-anoxic)	SO4-O2?	0.16		
33			0.05	52	158	6.14	0.1	5	Mixed(anoxic)	Fe(III)-SO4-O2?	1.58	
34			0.05	52	158	6.14	0.01	5	AnoxicOrMixed(oxic-anoxic)	Fe(III)-O2?	15.80	
35			52.7	30	0.13		3	Indeterminate				



Groundwater Age Mixture



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Groundwater Age Mixture

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[Young vs. Old Groundwater](#)

[Using Groundwater Age Mixture to Answer Water Quality Questions](#)

[When Groundwater Age Estimates Are Insufficient](#)

Groundwater Age Mixture Introduction

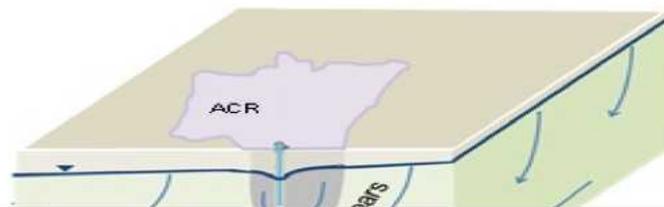
The length of time it takes for water to reach a well affects whether contaminants in the water will be detected in samples from the well. Therefore, estimating how long it has been since water from a well entered the aquifer system is a useful measure of vulnerability.

Groundwater age refers to the time that has elapsed since a parcel of water entered an aquifer system.

Groundwater age mixture is the mix of ages of the groundwater in the surrounding aquifer that is drawn into the well

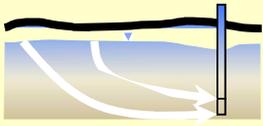
Recharge is water that infiltrates the ground and reaches the saturated zone.

As recharge is added to an aquifer system, older recharge water is pushed deeper by newer recharge water. This results in a trend of increasing groundwater age with depth—typical of most aquifer systems. However, a public-supply well will often draw water from different areas in the aquifer and get a mix of groundwater ages.



The ages can span a few years to hundreds or even thousands of years because





TOOLBOX

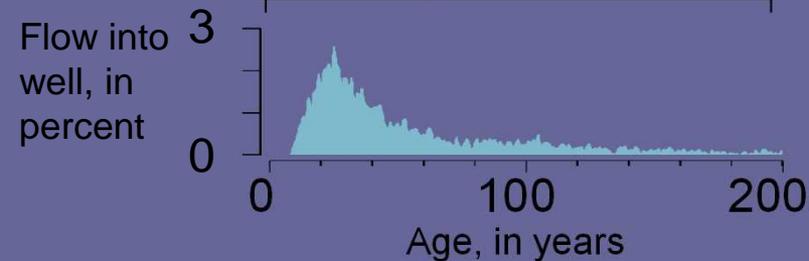
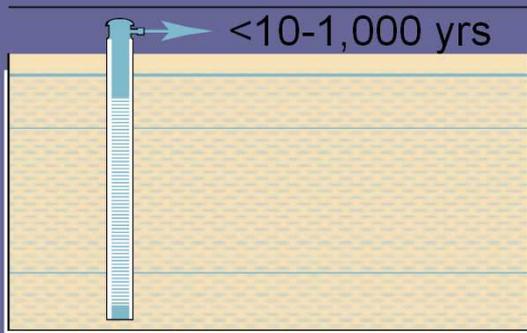
A groundwater stratigraphy model can be used to obtain a rough approximation of the age mixture in a well in the absence of tracer data.

- Models are chosen according to aquifer geometry
- Model parameter values include:
 - Aquifer thickness
 - Porosity
 - Recharge rate
 - Depth to top & length of well screen

Model for unconfined aquifer with constant thickness:

$$T_d = nD/N * \ln(D/D-d)$$

California study area



$$T_d = nD/N * \ln(D/D-d)$$

where $d = d_U + 0.01P_x(d_L - d_U)$

$n = 0.3$ (porosity)

$D = 394$ ft (depth of well)

$N = 23.6$ in./yr (recharge)

$d_U = 91$ ft (upper level of screen)

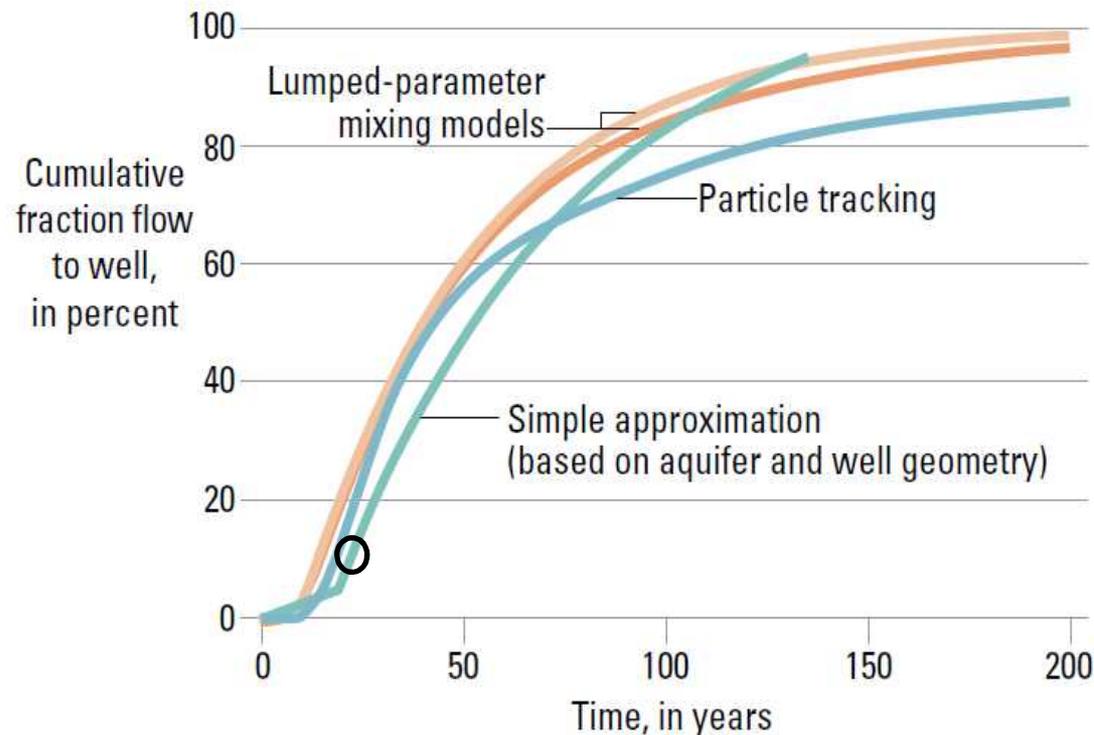
$d_L = 366$ ft (lower level of screen)

$P_x =$ percentile (0-100 percent)



TOOLBOX example

A simple approach
for estimating an age
mixture for a well



Preferential Flow Pathways

Introduction: Preferential Flow Pathways - An overriding factor

Preferential flow pathways are pathways that provide little resistance to groundwater flow, enabling water and contaminants to move relatively quickly in the subsurface.

If a stress is added to an aquifer system—such as an increase in recharge from precipitation or an increase in discharge from pumping wells—the movement of water along preferential flow pathways will be accelerated more so than along other flow pathways.

Where present, they can exert an overriding influence on the transport of anthropogenic and natural contaminants to public-supply wells.

Conduits and fractures are common in carbonate rock and allow for preferential movement of water and contaminants.



Importance

Preferential flow pathways can affect every aspect of groundwater and public-supply well vulnerability including:

- the sources of water for the well to fall into,
- how easy it is for water to move to the well,
- the mobility and persistence of contaminants in the water that enters the well

Preferential flow pathways can have the following effects:

- Preferential flow pathways can be the most important pathways for the transport of contaminants to a public-supply well.
- Preferential flow pathways can complicate the relationship between the water table and a well. For example, the youngest water in a well may not come from areas closest to the well, making it difficult to know which areas at the land surface to protect from contamination (see case study, page 72).

short-circuits, manmade hydraulic short-circuits, other?

yes

no or unsure

5.1.1.2 (go to 5.2)

no

unsure

5.2 Does the well screen of the public supply well span multiple aquifers?

yes

5.2.1 The well screen may be acting as a short circuit for water from one aquifer transferring to another. You can simulate the effects of hydraulic short-circuiting by wells by using the USGS MODFLOW model with the multi-node well (MNW) package (link to reference <http://pubs.usgs.gov/tm/tm6a30/>)

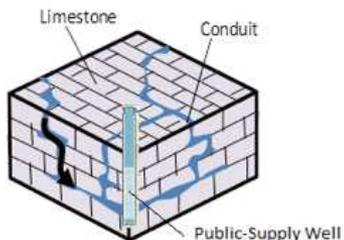
no

5.3 Choose a method to recognize the possible existence of preferential flow pathways in the aquifer and the influences these might have on the quality of water

- Review water quality data collected under differing hydrologic conditions over an extended period of time to uncover patterns in the data that would otherwise be unexpected for a public-supply well (see case study [link](#) Preferential Flow Calls Attention to the Importance of Monitoring Under Differing Hydrologic Conditions).
- Compare samples from a public-supply well with samples from monitoring wells to determine whether the chemistry of the produced water is more similar to water in an overlying or underlying aquifer than to water in the aquifer tapped by the well. Includes use of mixing models (see case study [link](#) Carefully Designed Monitoring Programs May Be Able to Detect

Types of preferential flow

Types of Preferential Flow Pathways



Hydraulic short-circuits: preferential flow pathways that enable water and contaminants to bypass aquifer material that they would otherwise flow through.

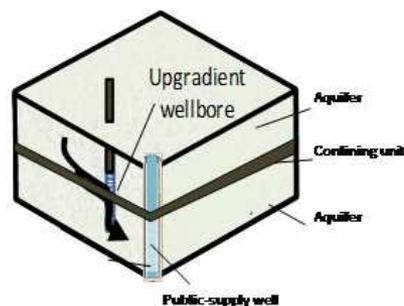
Natural hydraulic short circuits

Examples: Fractures, bedding planes, conduits and cavernous zones in bedrock. These can allow fluids to migrate quickly within an aquifer. This type of hydraulic "short-circuiting" occurs because such natural features have relatively wide openings and provide little resistance to flow. The presence and location of naturally occurring hydraulic short-circuits are generally unknown. Therefore, it can be difficult to quantify their effect on groundwater flow and contaminant transport to public-supply wells.

Man-made hydraulic short circuits (aka multi-aquifer wells)

Examples:

- Multi-aquifer wells - Wells with screens that connect multiple aquifers. These can allow water and contaminants to move rapidly across confining units that otherwise would restrict flow.
- Any well with a screen that intersects different horizons in an aquifer having different water levels.
 - Depending on the hydraulic gradient caused by different water levels, water and contaminants can move from one horizon to another through the wellbore.
 - Pumping affects water levels in an aquifer, so this movement can differ under different pumping conditions. Consequently, the quality of water from a well may change if pumping changes (refers to example on pages 78-79).
- Shortcomings in the construction or maintenance of a public-supply well. For example, breaches in the well seal or well casing can allow contaminated water to rapidly enter the well screen. (*this type of pref flow pathway was not observed during this study and is not further discussed*)

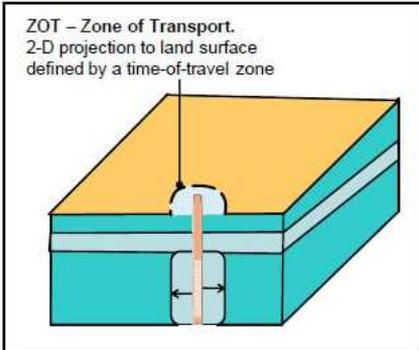


Fast flow pathways

An aquifer can be made up of different materials that have different water transmitting properties. When water travels faster through one material than another, this can create preferential flow pathways called fast flow pathways.

Interactive toolbox to estimate Zone of Transport

A simple way to gain insight into the potential for multi-aquifer wells to impact a confined-aquifer public supply well is to estimate a zone of transport (ZOT) for the well and then evaluate the likelihood that a multi-aquifer well lies within that zone. The ZOT should be defined solely on the basis of the confined aquifer traveltime across the confining unit should not be considered. This is because multi-aquifer wells within the boundary of a confined-aquifer ZOT could potentially introduce a contaminant directly into the confined aquifer, enabling the contaminant to reach the public-supply well within the time of interest.



Zone of Transport (ZOT) based on confined-aquifer traveltimes

$$ZOT = \sqrt{Qt/\phi H}$$

Where

Q is the pumping rate of well

t is the time of travel

ϕ is the porosity

H is the height (thickness) of confined aquifer

(This is the cylinder or volumetric flow equation (USEPA, 1987)).

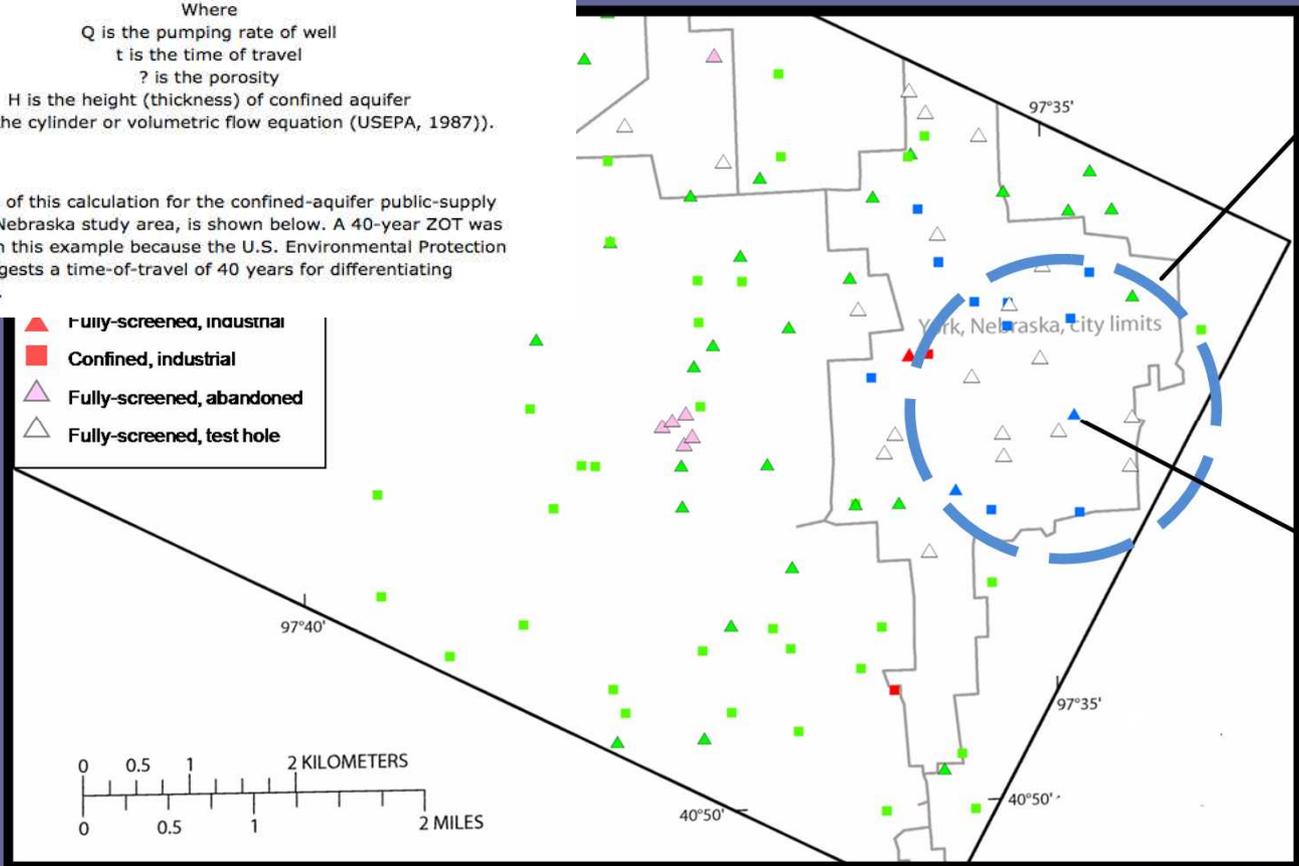
An example of this calculation for the confined-aquifer public-supply well in the Nebraska study area, is shown below. A 40-year ZOT was computed in this example because the U.S. Environmental Protection Agency suggests a time-of-travel of 40 years for differentiating

semiconfined and highly confined conditions (USEPA, 1991).

- ▲ Fully-screened, industrial
- Confined, industrial
- ▲ Fully-screened, abandoned
- ▲ Fully-screened, test hole

Simple calculation indicates that 10-15 multi-aquifer wells may impact public-supply well within 40 year ZOT

40-yr ZOT based on confined aquifer
(differs from area at water table that ultimately contributes flow to well, but indicates area worth protecting)



Many Available Toolboxes

Tool	Description	Additional Info
Sources of Recharge		
GW flow and particle tracking models coupled with land use data	Estimates percentage of simulated inflow to a public-supply well, using MODFLOW and MODPATH models	http://water.usgs.gov/software/lists/groundwater
Two-component mixing equation	Estimates relative proportions of end member waters in a mixture	Toolboxes>Sources of Recharge>Mixing Equation
Depth-interval sampling	Determines borehole flow and water quality from discrete intervals.	Izbicki and others, 1999; Izbicki, 2004

Report Generation

The screenshot displays the USGS Public-Supply Water Well Assessment website. At the top left is the USGS logo with the tagline "science for a changing world". To the right is a navigation menu with "USGS Home", "Contact USGS", and "Search USGS". Below this is a teal header with the title "Public-Supply Water Well Assessment" and a search bar. A secondary navigation bar contains links for "home", "1-Introduction and background", "2-Predicting vulnerability", "3-Relative vulnerability", "4-Complete the checklists", "Case Studies", and "Toolboxes".

The main content area is split into two columns. The left column, titled "Assessments Based on Combined Factors", contains a section "Surrogate Measures" with text explaining the importance of a multi-faceted assessment and listing four factors: (1) sources of recharge, (2) geochemical conditions, (3) groundwater age mixtures, and (4) preferential flow pathways. The right column, titled "Fire Checklist", shows a list of five items: 1. Get Started, 2. Source of Water, 3. Geochemical Conditions, 4. Groundwater Age Mixture, and 5. Preferential Flow Pathways. Under item 5, there are sub-questions: "5.1 Do preferential flow pathways exist in the aquifer that the well draws from?" with a "yes" button selected, and "5.1.1 Do you know what type of preferential flow pathways they are? For example, do you know if there are fast flow pathways, natural hydraulic short-circuits, manmade hydraulic short-circuits, other?" with "yes", "no or unsure", and "no" buttons. Below this is "5.1.1.2 (go to 5.2)" and "5.2 Does the well screen of the public supply well span multiple aquifers?" with "no" and "unsure" buttons.

At the bottom of the page, a URL "http://cida.usgs.gov/wellassessment/#" is visible, along with a browser status bar showing "Slide 19 of 22" and "100%".

Example Report

Summary for Well 1

- 1) Sources of Recharge – you indicated the recharge area contains Agricultural land use.
- 2) Geochemical - you indicated that the confined aquifer is Anoxic and the unconfined aquifer is primarily Oxic
- 3) Groundwater Age Mixture – you indicated a large proportion of old water
- 4) Preferential Flow Pathways – the existence of nearby multi-aquifer wells indicates the presence of possible preferential flow pathways

Recommendations

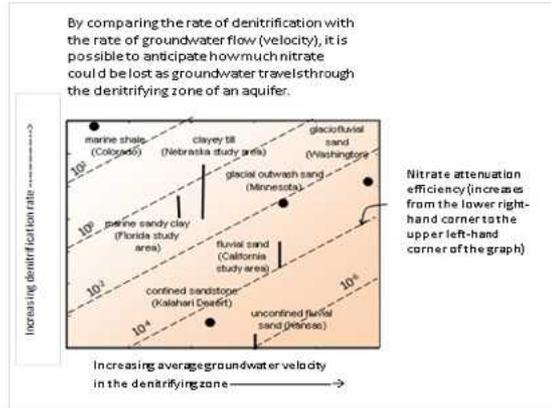
- 1) Consider using a MODFLOW model to further refine the preferential flow pathways present
- 2) Use targeted sampling to further define the proportions of water coming from the unconfined and confined aquifer systems.

Examples for Nitrate and VOC

[Combined Factors](#) > Nitrate

Relative Vulnerability to Nitrate Contamination

The relative vulnerability of aquifers and public-supply wells to nitrate contamination was evaluated for eight study areas, including three of the local-scale study areas from this investigation. The relation between the rate of denitrification and the rate of groundwater flow was used to evaluate the amount of nitrate that could be lost as groundwater travels through the denitrifying zone of each aquifer. The concept behind the approach is that nitrate can persist along flow pathways if groundwater-flow rates are high relative to denitrification rates. Conversely, nitrate in shallow groundwater may not reach a well if groundwater flow rates are low compared to denitrification rates. [Click here for details on the method.](#)



Results revealed a relation between nitrate vulnerability and depositional setting (see figure, above). The efficiency of nitrate attenuation, or removal, was observed to increase as follows: fluvial sand aquifers < glacial sand aquifers < glacial/marine clay < marine shale. This observation is most likely related to the proportions of clay and organic carbon in these types of deposits. Higher proportions of clay are typically associated with lower groundwater velocities (groundwater-flow rates), and higher amounts of organic carbon can increase denitrification rates by acting as an electron donor during redox reactions. ([link](#))

Full examples are available that explore assessments based on combined factors and identify regional patterns

Goals of the Decision Support System

- 1) Summarize what is currently known about a given public-supply well
- 2) Identify the most probable risks for a given well
- 3) Identify the most beneficial protection mechanisms for a particular well
- 4) Design strategies to prevent future contamination of supply wells
- 5) Prioritize future assessment work for a given well

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