Cryptosporidium Removal by Bank Filtration

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Presentation Outline

- How is *Cryptosporidium* Removal by Bank Filtration Addressed in the USA?
- How are the Hazards Evaluated Using Surrogate or Indicator Organisms?
- What are the elements of a study design to predict *Cryptosporidium* removal by bank filtration?

Publications

Data Presented Here are Published in:

- Schijven, Berger and Miettinen (2003) Removal of Pathogens, Surrogates, Indicators and Toxins Using Riverbank Filtration *in Riverbank Filtration: Improving Source Water Quality (Ray, Melin & Linsky, eds.) Kluwer, 73-116.*
- Berger (2002) Removal of *Cryptosporidium* Using Bank Filtration *in Riverbank Filtration: Understanding Contaminant Biogeochemistry and Pathogen Removal, (Ray, ed.) NATO Science Series, Kluwer, 85-121.*

Definitions: as used in this presentation

- **Ground Water Under the Direct Influence of Surface Water (GWUDI)** = Well water containing substantial proportions of recent surface water; regulated as surface water
- **Bank Filtration** = Subset of GWUDI sites; natural filtration is determined to be an effective alternative/supplement to conventional treatment (coagulation, sedimentation and rapid sand filtration or direct filtration)

U.S. Drinking Water Regulations

- Under the proposed LT2ESWTR, Bank Filtration is a pre-treatment alternative for systems that filter but have high *Cryptosporidium* concentrations in the raw water (nationwide criteria). http://www.regulations.gov/fredpdfs/03-18295.pdf
- Under existing regulations (SWTR alternative treatment provisions), any State or Primacy Agent can grant Bank Filtration credit for Giardia or Crypto removal so a system may avoid constructing a filtration plant (based on site-specific data).
- Three Site-Specific SWTR and IESWTR Examples:
  - 2.5 log *Giardia* removal credit for Sonoma County, CA
  - 2.0 log *Giardia* removal credit for Kearney, NE
  - 2.0 log *Cryptosporidium* conditional removal credit for Casper, WY (demonstration study required)

Draft Proposed LT2ESWTR Bin Requirements Table

Bin Number	Mean *Cryptosporidium* concentration*	Additional treatment requirements
1	*Crypto* < 0.075/L	No action
2	0.075/L ≤ *Crypto* < 1.0/L	1-log
3	1.0/L ≤ *Crypto* < 3.0/L	2.0 logs (with 1-log disinfection)
4	*Crypto* ≥ 3.0/L	2.5 logs (with 1-log disinfection)

* Bin classification based on:

– **Total oocyst count, unadjusted for recovery (Method 1622/23); Highest 12 month RAA, or 2 year mean if 48 samples**

Bank Filtration - Design Requirements for Crypto Log Removal Credit (Proposed LT2ESWTR)

- **For vertical wells**
  - **25 foot separation distance between river and wellhead receives 0.5 log credit (construction and operation requirements must also be met)**
  - **50 foot separation distance between river and wellhead receives 1 log credit (construction and operation requirements must also be met)**
  - **Separation distance is defined as the map distance between the 100 year return period elevation or floodway boundary (as on a FEMA flood hazard map) and the wellhead of a vertical well**

Bank Filtration - Design Requirements for Crypto Log Removal Credit (Draft Proposed LT2ESWTR)

- For horizontal wells
  - horizontal well laterals must be separated from the normal-flow river-bottom by either 25 or 50 feet (for 0.5 or 1.0 log credit)
  - construction and operation requirements must also be met

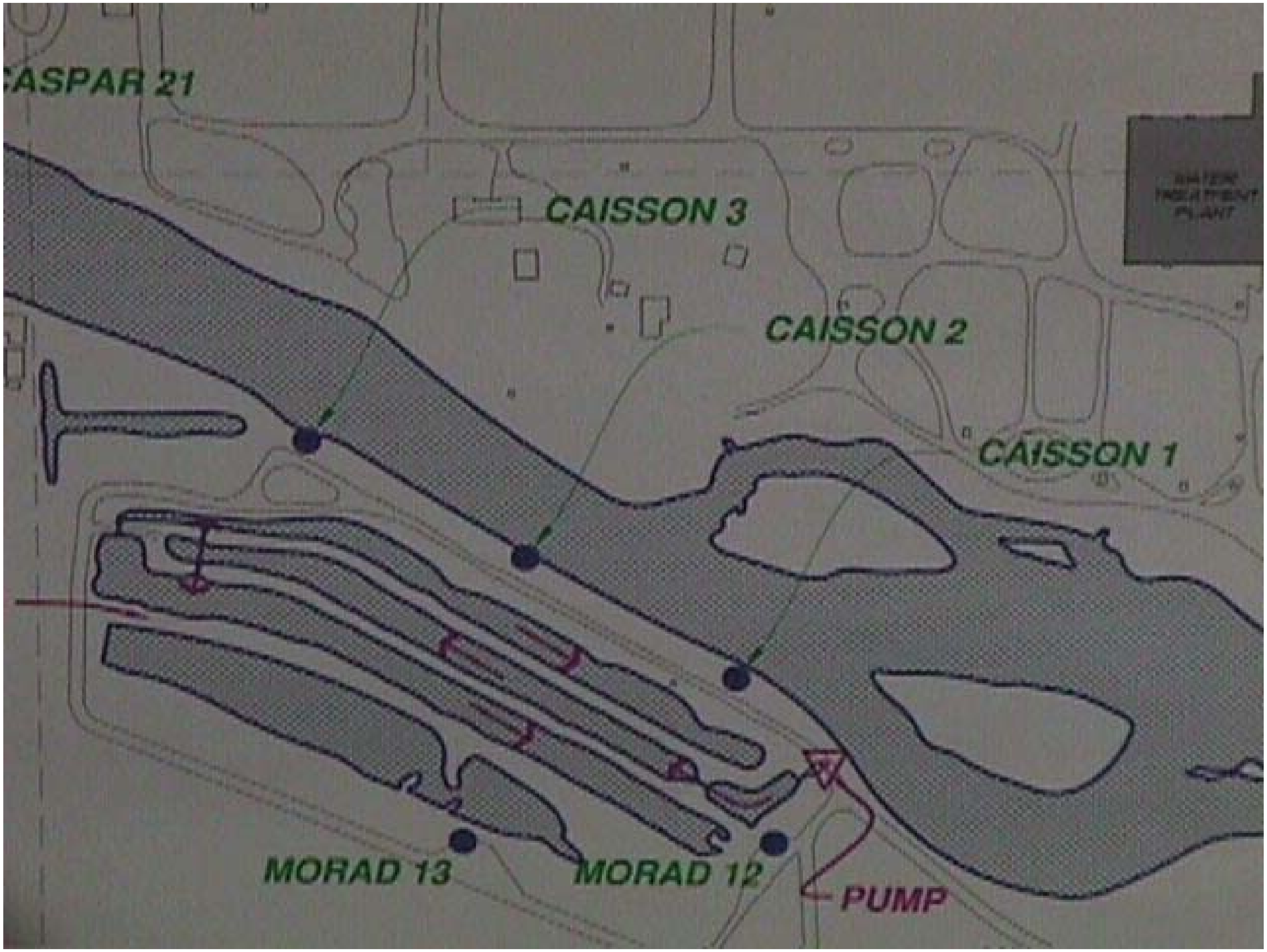
Bank Filtration - Other Design Requirements for Crypto Log Removal Credit (Draft Proposed LT2ESWTR)

- unconsolidated, predominantly sandy aquifer
- well site drill core must be sent to an engineering laboratory for sieve analysis
- each recovered cored interval should be sieved to determine if at least 10% of the grains are less than 1.0 mm diameter
- at least 90% of the sieved, recovered, cored intervals must meet the 10% fine grained requirement

Casper, Wyoming Alternative Filtration Study

- December 10, 2001 – Conditional approval for two-log Cryptosporidium removal – expires January 1, 2004. Eighteen month study planned beginning in July, 2002.
- August 27, 2002 – Due to drought, conditional approval extended to January 1, 2005.
- Combined artificial recharge and bank filtration operation

CASPAR 10
CASPAR 8
CASPAR 5
CASPAR 19
NO
CASPAR 9
CASPAR 6
CASPAR
CASPAR 20
CASPAR 7
PUMP
CASPAR 21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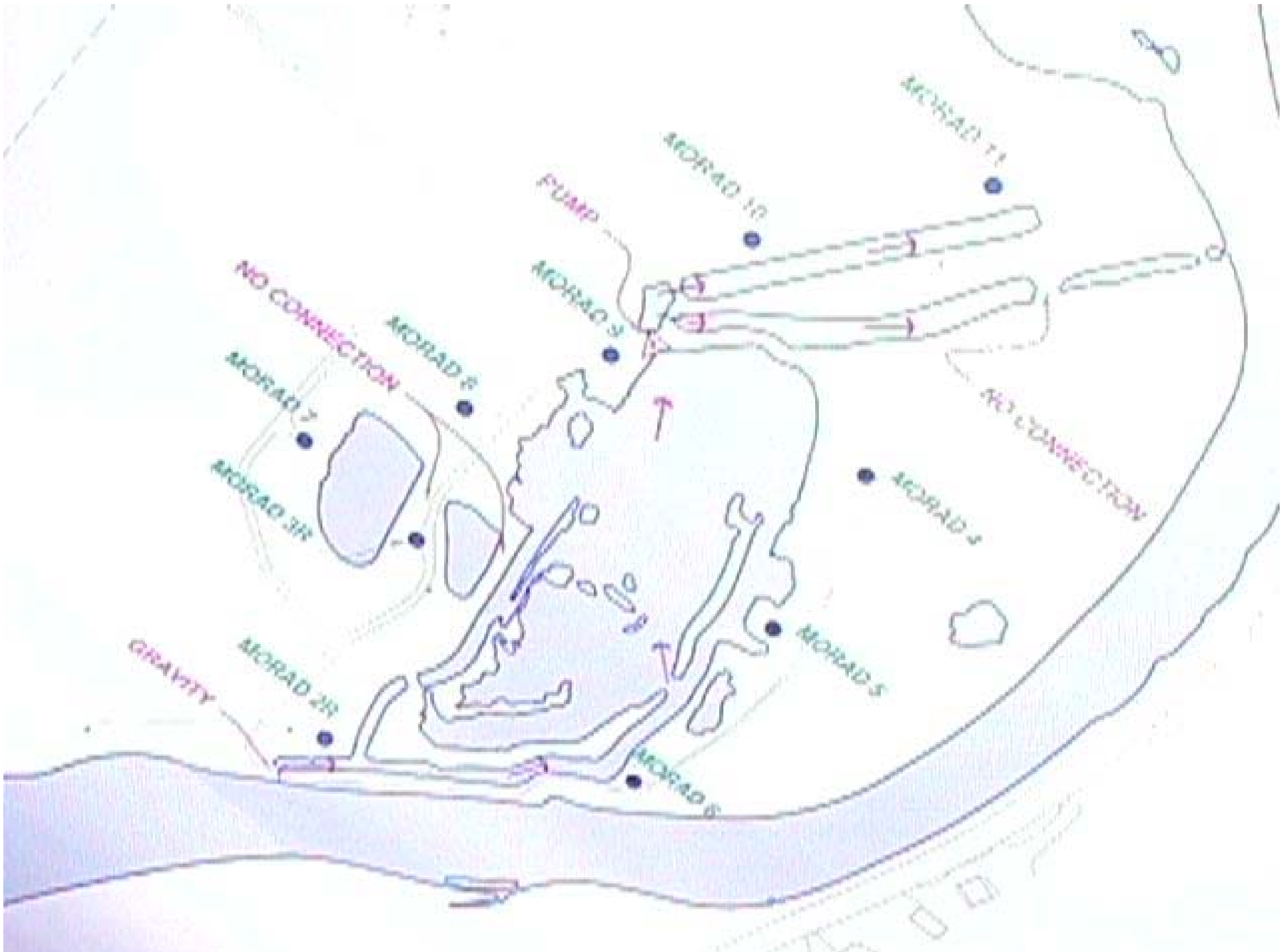

MORAD 11
MORAD 10
PUMP
MORAD 9
NO CONNECTION
MORAD 8
MORAD 7
MORAD 3R
NO CONNECTION
MORAD 4
MORAD 5
GRAVITY
MORAD 2R
MORAD 6

Cryptosporidium Removal Study Protocol, Casper, WY During Normal Flow (drought conditions)

Parameter	Unit Cost Including Shipping	8-Month Interim Sampling Frequency (9/02-4/03)		Number of Samples				Total Cost by Parameter
				River	Caisson 3	1 vertical well	Total Number of Samples	
Temperature	$0	5	per week	160	160	160	480	$0
Turbidity	$0	Continuous						$0
Total Coliform	$35	1	per week	32	32	32	96	$3360
MPA	$225	1	per month	8	8	8	24	$5400
Aerobic Spores	$50	1	per week	32	32	32	96	$4800
Enterococci	$45	1	per week	32	32	32	96	$4320
Cryptosporidium Giardia	$395	1	per month	8	8	8	24	$9480
Coliphage				0	0	0	0	
TOTAL								**$27360**

Working Hypothesis: Variable Riverbank Filtration Efficiency Suggests a Possible Hazard

- Filtration efficiency may vary throughout the water-year
- Lower efficiency during periods of high water stage due to channel scour
  - removes some or all protective sediment layer
  - reduces travel distance to well intake, especially for horizontal wells

"Possible Failures" of Riverbank Filtration:

- Chalk Aquifer - North Thames, UK, 1997 (Willocks et al., 1999)
  - 345 confirmed cases; 22% of potential controls excluded because of GI illness; 746,000 customers, 354,000 people received over 90% of their water from the Clay Lane well
- Grand River alluvial aquifer - Kitchener-Waterloo, Ontario, Canada, March, 1993 (Craun, et al., 1998)
  - 193 confirmed cases; 23,900 - 100,000 illnesses
  - One well (Woolner K81) possibly presumptive Cryptosporidium positive during outbreak (25 -35 m deep; 10 m setback distance
  - One well (Ontario River Well #2) possibly presumptive *Cryptosporidium* positive in Sept., '93

Other Possible Riverbank Filtration "Failures"

- Torbay, Devon, UK - Horizontal well, Littlehempston River Gravels (Craun et al., 1998; Gray, 1998)
  - 1992 outbreak: 108 cases of Cryptosporidiosis (one horizontal well sample positive for Crypto in 1992)
  - 1995 outbreak: 575 cases of Cryptosporidiosis (outbreak investigation implicated lack of coagulation and settling treatment for bank filtered water subjected only to filtration treatment)

Other Possible Riverbank Filtration Infiltration Gallery "Failures"

- Talent, Oregon - Infiltration gallery under Bear Creek (Leland et al, 1993)
  - 1992 outbreak: 31 cases of Cryptosporidiosis
- Ogose, Japan – 2 m deep infiltration gallery + conventional filtration (Yamamoto et al., 2000)
  - 1996 outbreak: 125 lab-confirmed cases of Cryptosporidiosis; 9,140 total cases
  - 12 oocysts/l measured in tap water

Cryptosporidum Occurrence in Wells

- Hancock et al., (1998)
  - oocysts in 7 of 149 vertical wells
  - oocysts in 5 of 11 horizontal wells
  - oocysts in 2 of 4 infiltration galleries
  - Note: Likely that the horizontal wells and infiltration galleries were emplaced in sand and gravel aquifers

Cryptosporidium Mobility in Porous Media - Inferences from occurrence in wells

- Horizontal well F (Hancock, unpub.)
  - 2 of 6 samples positive for *Cryptosporidium*
  - Breakthrough Crypto concentration: 17/100 gallons and 3/100 gallons; Giardia breakthrough concentration (1 sample) = 34/100 gallons
  - water intake: 87 feet below ground surface
  - 50 feet from surface water

Cryptosporidium Mobility in Porous Media - 2. Occurrence in well F (Hancock, unpub.)

Month	Cryptosporidium per 100 gallons	Giardia per 100 gallons	Diatoms per gallon
March	ND	ND	.01
March	ND	ND	.13
April	3	ND	88.7
June	ND	ND	242
December	17	34	90
December	ND	ND	.12

Cryptosporidium Mobility in Porous Media - Occurrence in Kitchener well

- Kitchener-Waterloo, Ontario River Well #2 Cryptosporidium possibly presumptive positive, Sept., 1993
  - well depth (vertical well) = 80 feet
  - about 30 feet from surface water
  - Grand River Cryptosporidium Concentrations
    - Range: 77 to 2075/100 liters
    - Mean: 319/100 liters

Wells with *Cryptosporidium*
(Hancock, unpub.)

Well ID	Sample No.	Crypto/100 gallons	Distance to SW (feet)	Well Depth (feet)	Giarda/100 gallons	Diatoms/100 gallons	MPA Score
A	1	19			8	147	84
	2	2			ND	19	41
B	1	8			ND	0	30
	2	13			6	96	80
C	1	2			ND	111	37
	2	10			7	19	66
	3	19			ND	1	41
D	1	2	200	20 V	ND	2	33
E	1	57		450 V	454	298	108
F	1	17	50	87 H	34	900	103
	2	3			ND	887	51
G	1	1998			ND	0	35
H	1	30	26400	110 V	ND	24326	82
I	1	1453	50	100 V	ND	0	53
J	1	70		150 V	ND	nt	
K	1	1		90 V	ND	nt	
L	1	32	800	42 H	ND	nt	
M	1	ND	380	29	2	0	21

How are Surrogates and Indicators Used to Evaluate the Potential Cryptosporidium Hazard?

Cryptosporidium Surrogates

- Giardia, other coccidian protozoa
- Total coliform, fecal coliform and *E. coli*
- Aerobic spores (Endospores) e.g. *Bacillus subtilus*
- Anaerobic spores e.g. sprores of sulphite-reducing *Clostridium perfringens* or *Clostridium bifermentans*
- Microscopic Particulate Analysis (MPA) - Used Mainly for GWUDI of SW Determination
  - diatoms, other green algae, vegetative debris
  - rotifers; nematodes; crustacean and insect parts
  - fungal spores and pollen; inorganic particles

Pathogen and Indicator Sizes

VIRUSES	SIZE RANGE
Enteroviruses	20-30 nm
Hepatitis A virus	27 nm
Norwalk virus	27 nm
Enteric Adenovirus	68-85 nm
Rotavirus	70 nm
Reovirus	75-80 nm

PROTOZOA	SIZE RANGE
Microsporidium	1.5-4 μm
Cryptosporidium parvum	4-7 μm
Giardia	8-18 μm
Cyclospora	8-10 μm
Isospora	20-30 μm
Entamoeba histolyica	10-15 μm
Entamoeba coli	10-35 μm
Balantidium coli	40-65 μm
Amoebas	10-600 μm
Flagellates	2-60 μm
Ciliates	10-300 μm

BACTERIA	SIZE RANGE
Escherichia	1-6 μm
Ground water bacteria	0.1-1.4 μm
Clostridium perfringens	3-9 μm
Clostridium perfringens spores (anerobic)	0.3-0.4 μm
Aerobic spores	0.5-10 μm
Klebsiella	0.6-6 μm
Campylobacter	.25-1.7 μm
Streptococcus faecalis (Enterococci)	.5-10 μm

ALGAE	SIZE RANGE
Diatoms	10-120 μm
Acanthes	10 μm
Asterionella	30 μm
Cyanophytes	3-9 μm
Chlorophytes (Green)	2-100 μm
Botrydium (Yellow-Green)	1-2 μm
ROTIFERA (females)	70-500 μm
NEMATODA	100-1000 μm
INSECTA Water Fleas	.25-3 mm
CRUSTACEA Eggs	50-150 μm

Protozoa and Surrogate Sizes

PROTOZOA	SIZE (μm)	SURROGATE	SIZE (μm)
Cryptosporidium parvum oocyst	2 - 6	Total Coliform	~ 0.5 – 6
Giardia lamblia cyst	8 - 18	*E. coli*	0.5
Cyclospora sp.	8 - 10	*C. perfringens*	2 - 19
Microsporidia	1.5 - 4	*C. perfringens spore*	0.3 – 0.4
		C. bifermentans	1 - 11
		C. bifermentans spore	1.2
		B. subtilus	2 - 5
		B. subtilus spore	0.5 – 2.0

MPA Analysis

- Element of US EPA SWTR Guidance
- Used to help determine which ground-water supply wells are GWUDI (induced inflow from surface water with ground water travel-times < 30-45 days)
- These ground water wells are regulated as if they are directly using surface water

Cryptosporidium Surrogate Evaluation (Hancock et al., 1999

- Sites positive for *Giardia* and/or *Cryptosporidium*: Data from 19 vertical wells, springs, horizontal wells, and infiltration galleries
- Best indicators (component of MPA):
  - Diatoms *Navicula* and *Synedra*
  - Crustacean and insect parts

Variable Filtration Efficiency: Kearney, Nebraska Diatom Data from 5 Wells + River

- June
- #1 *Synedra* 1.2/gallon
- #2 Unknown 47/gallon
- #3 *Synedra* 720/gallon
- #4 *Synedra* .01/gallon
- #5 *Synedra* 64/gallon
- River *Centrales* 3,000,000/gallon

- July
- #1 *Pennalesl Melosira* .03/gallon
- #2 *Synedra* .64/gallon
- #3 *Pennales* .02/gallon
- #4 *Synedra* .35/gallon
- #5 *Fragilaria* .01/gallon
- River *Centrales* 5,000,000/gallon

Kearney,Nebraska: Diatom Data from 5 Wells + River (continued)

- August
- #1 Pennales .07/gallon
- #2 not detected
- #3 Pennales .02/gallon
- #4 not detected
- #5 not detected

- September
- #1 not detected
- #2 not detected
- #3 not detected
- #4 not detected
- #5 not detected
- River unknown 20,000,000/gallon

Kearney,Nebraska: Diatom Data from 5 Wells + River (Continued)

- October
- #1 Pennales .06/gallon
- #2 not detected
- #3 not detected
- #4 not detected
- #5 not detected
- All Kearny, Nebraska data from: Heinemann et al., 1996 (unpublished CH2M Hill report to the City of Kearny)

Insights from Kearney Data

- Peak poor well-water quality (Atrazine) period in late May and early June (biological monitoring data not available until late June)
- Well diatom concentrations decreased over the summer as river diatom concentrations increased (highest MPA scores reported for late June)
- *Synedra* breakthrough occurred only in June, coincident with the poor water quality period (*Synedra* co-occurs with Crypto)
- **Removal of Crypto surrogates less efficient during poor water quality period**

What does the Controlled Field Test Data Using Surrogates and Indicators Tell Us About Microorganism Removal in the Subsurface?

Riverbank Filtration Log Removal of Bacterial Indicators

	Rhine at Remmerden (Havelaar et al., 1995)	Meuse at Zwijndrecht (Havelaar et al., 1995)	Meuse at Roosteren (Medema et al., 2000)			Ohio at Lousiville (vertical travel to a collector well lateral) (Wang et al., 2000)				Wabash at Terra Haute (travel to a collector well) (Arora et al., 2000)
Travel distance [m]	30	25	13	25	150	0.6	1.6	3	16	
Travel time [days]	15	63	7	18	43					
Total Coliform	≥ 5.0	≥ 5.0								
Thermotolerant Coliform Bacteria	≥ 4.1	≥ 4.1	4.1	4.5	6.2					
Aerobic Endospores						2.0	2.0	2.0	3.0	
Spores of Sulphite-Reducing Clostridium	≥ 3.1	≥ 3.6	3.3	3.9	5.0					3.4

Log Removal of Viral and Bacterial Indicators (Data from Schijven et al. 1998; Havelaar et al. 1995; Medema et al. 2000)

	Riverbank filtration					Dune rechar	
	Rhine at Remmerden	Meuse at Zwijndrecht	Meuse at Roosteren			Heemsker	
Travel distance [m]	30	25	13	25	150	2	4
Travel time [days]	15	63	7	18	43	1	2
FRNAPH	6.2		3.9	5.1	7.3	3.1	4
SOMCPH			4.0	5.9	6.7		
Enteroviruses	≥2.6	≥ 2.7	1.7				
Reoviruses	≥ 4.8	≥ 4.7	2.8				
TOTCOL	≥ 5.0	≥ 5.0				0.85	
THCOL	≥ 4.1	≥ 4.1	4.1	4.5	6.2	0.86	
SSRC	≥ 3.1	≥ 3.6	3.3	3.9	5.0	1.9	
FSTREP	≥ 3.2	≥ 3.5					

- Data from Medema et al. 2000 and Wang et al 2000 suggests that highest removal occurs during passage across the groundwater/surface water interface

After passage across the interface, lesser removal occurs

	Across SW-GW Interface	Within Aquifer
C. perfringens spores	3.3 log removal over 40 feet	0.6 log removal over 37 feet
B. subtilus spores	2.0 log removal over 2 feet	1.0 log removal over 50 feet

Other Porous Media Spore Transport Data:

Schijven et al. (2000): 0 log removal of *C. bifermentans* over interval from 25 to 100 feet

Medema et al. (2000): 1.1 log removal of *C. perfringens* over interval from 75 to 450 feet

Pang et al. (ms. in review): 2 log removal of *B. subtilus* in 50 m from injection point

From a Regulatory Perspective, it May be Best to Assume that the Interface is Absent (e.g. removed during flood) So the Cryptosporidium Log Removal Credit is Based only on Removal within the Aquifer

Elements of a Field Study to Determine Alternative Treatment Credit by Bank Filtration

- Identify alternative treatment technology (e.g. Bank filtration or artificial recharge)
- Compile historical surface water quality and quantity data
- Estimate flow paths, travel times and ambient ground water dilution; verify using environmental tracer data
- Design sampling strategy to capture routine and infrequent surface water flows; collect representative samples
- Install monitoring wells to measure changes along the flowpath; conduct two-well tracer tests
- Sample for a suite of pathogen and indicator organisms; choose indicators based on surface water occurrence
- In the absence of oocyst removal data, document indicator suitability as oocyst transport predictor

Conclusions

- *Cryptosporidium* is capable of migrating laterally and vertically in porous media; further in non-porous media
- Diatoms are an imperfect *Cryptospordium* indicator; However, *Synedra* presence may be better than diatom presence alone
- Using spores as a *Cryptosporidium* surrogate, for pre-treatment transport to vertical wells, it is suggested that bank filtration should be capable of achieving at least 0.5 log removal over 8 m and 1.0 log removal over 16 m
- Higher removals are likely if transport crosses an undisturbed groundwater/surface water interface