Indicator bacteria, waterborne pathogens, and practices to reduce their impact on water quality

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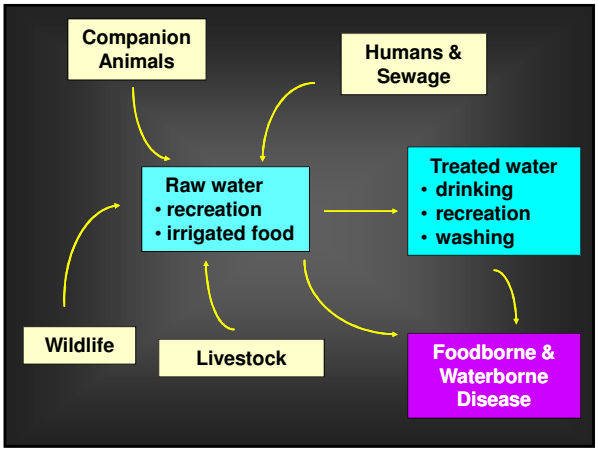


Waterborne zoonotic pathogens of *primary* concern

North American list

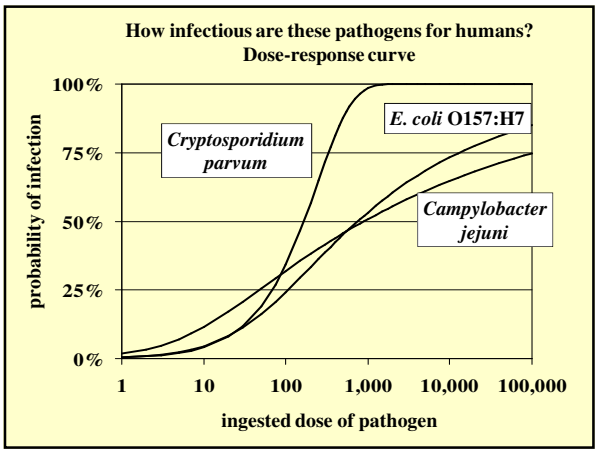
(1) pathogenic for humans
(2) shed by an animal
(3) verified cause of waterborne illness

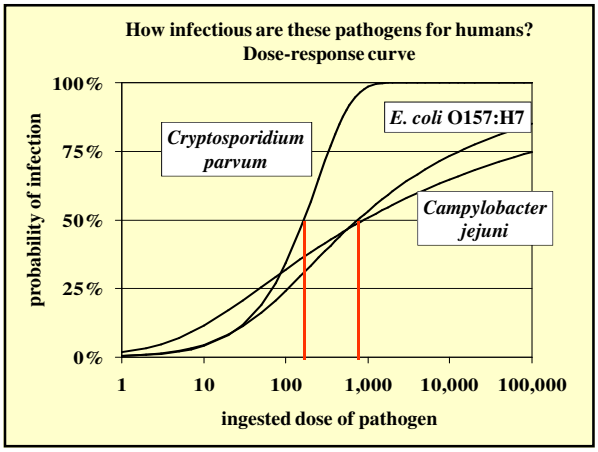
Protozoa

- *Cryptosporidium parvum*
- *Giardia duodenalis*

Bacteria

- *E. coli* O157:H7
- *Salmonella enterica*
- *Campylobacter jejuni*


How infectious are these pathogens for humans?
Dose-response curve
100%
75%
50%
25%
0%
probability of infection
Cryptosporidium parvum
E. coli O157:H7
Campylobacter jejuni
1
10
100
1,000
10,000
100,000
ingested dose of pathogen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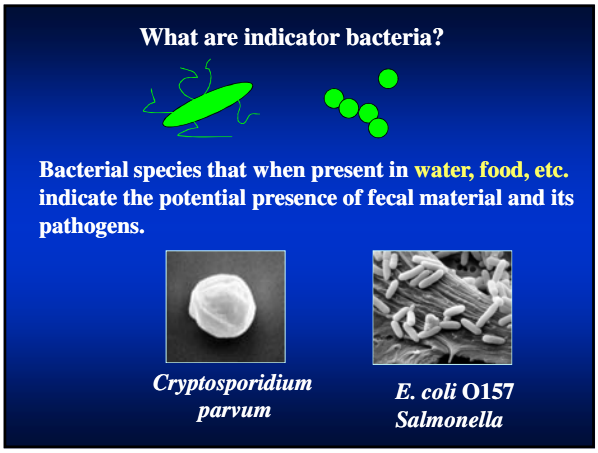
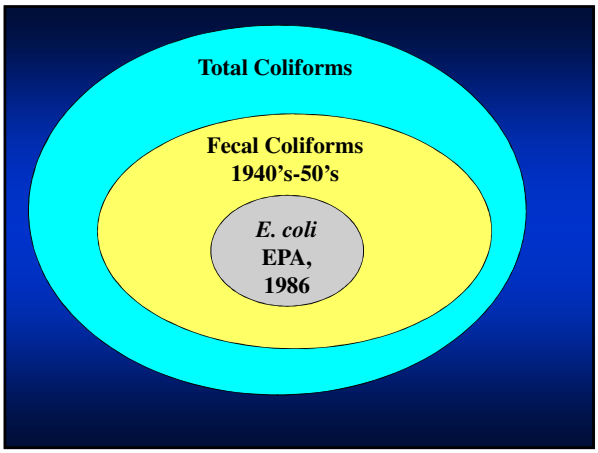
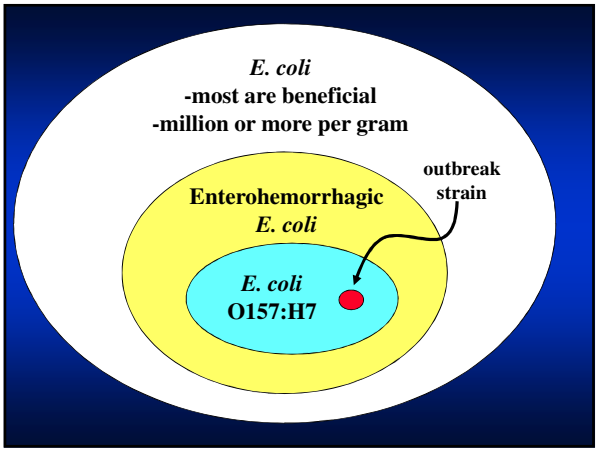
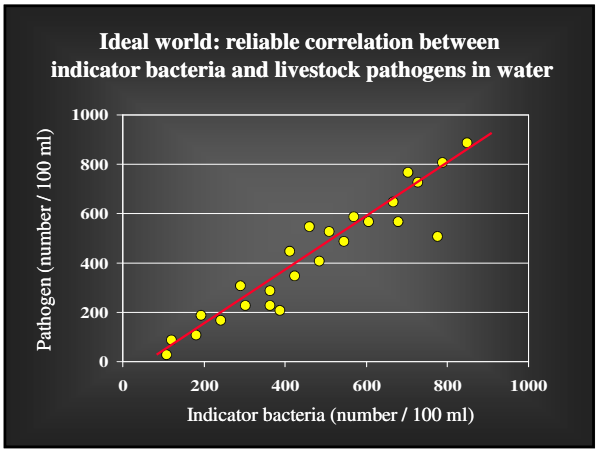
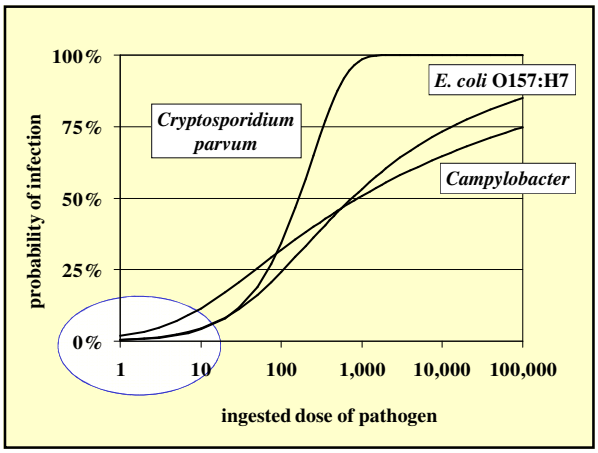
1
10
100
1,000
10,000
100,000
ingested dose of pathogen

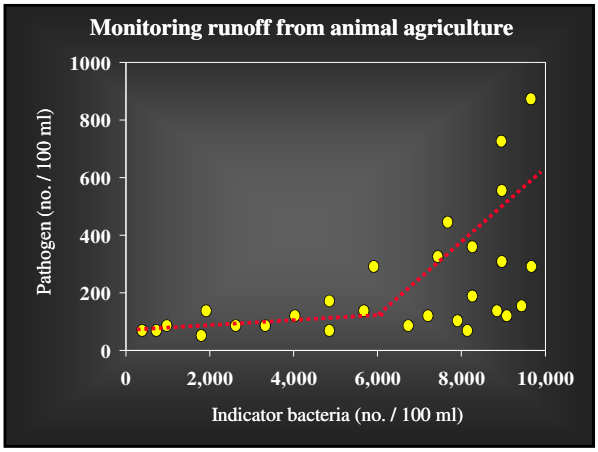

What are indicator bacteria?
Bacterial species that when present in water, food, etc. indicate the potential presence of fecal material and its pathogens.
Cryptosporidium parvum
E. coli O157
Salmonella

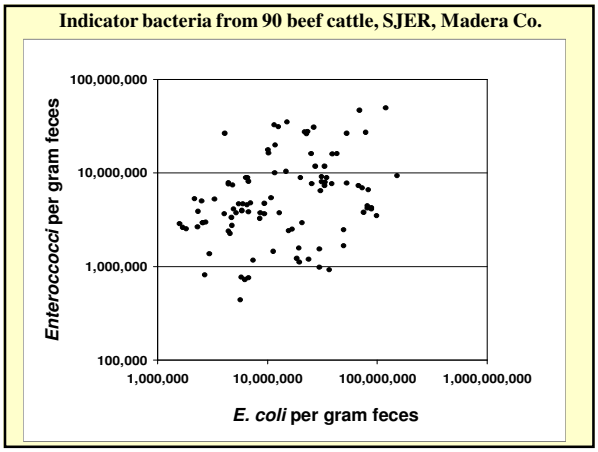

Total Coliforms
Fecal Coliforms
1940's-50's
E. coli
EPA,
1986


E. coli
-most are beneficial
-million or more per gram
outbreak
strain
Enterohemorrhagic
E. coli
E. coli
O157:H7


Ideal world: reliable correlation between
indicator bacteria and livestock pathogens in water
Pathogen (number / 100 ml)
1000
800
600
400
200
0
0
200
400
600
800
1000
Indicator bacteria (number / 100 ml)


100%
75%
50%
25%
0%
probability of infection
E. coli O157:H7
Cryptosporidium parvum
Campylobacter
1
10
100
1,000
10,000
100,000
ingested dose of pathogen


Monitoring runoff from animal agriculture
1000
800
600
400
200
0
Pathogen (no. / 100 ml)
0
2,000
4,000
6,000
8,000
10,000
Indicator bacteria (no. / 100 ml)


Indicator bacteria from 90 beef cattle, SJER, Madera Co.
100,000,000
10,000,000
1,000,000
100,000
Enterococci per gram feces
1,000,000
10,000,000
100,000,000
1,000,000,000
E. coli per gram feces

POOR CORRELATION BETWEEN INDICATORS AND LIVESTOCK PATHOGENS

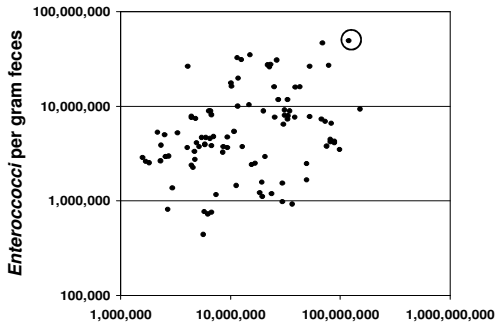
Indicator *E. coli* versus *Cryptosporidium*

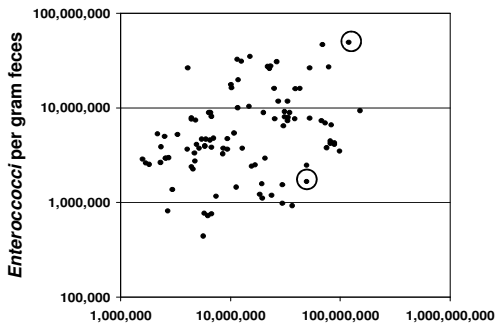
100% of cattle shedding ~50 million *E. coli* / g feces

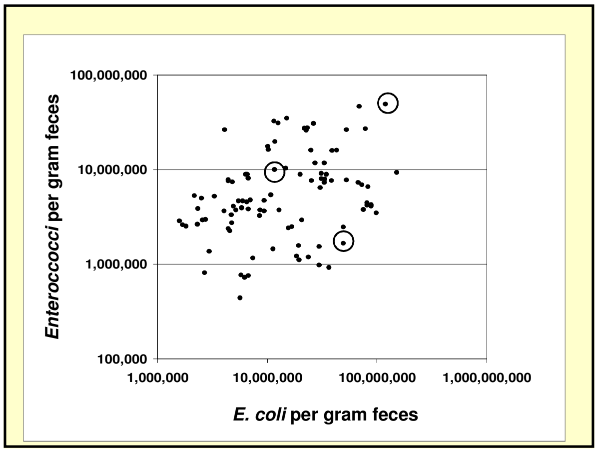
BUT

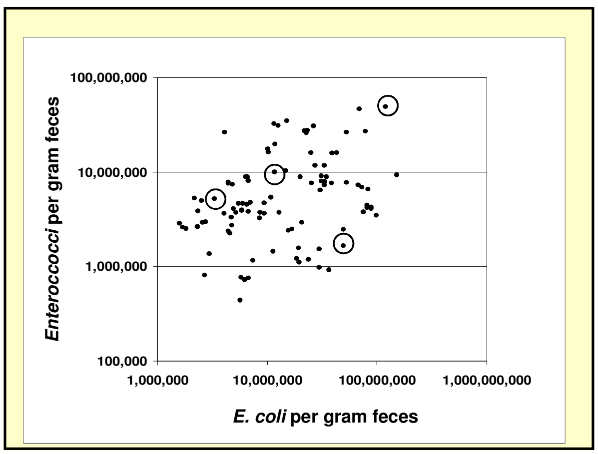
5% to 10% of cows shed *Cryptosporidium* on any day; shed 1 to 50 Crypto oocysts / g feces

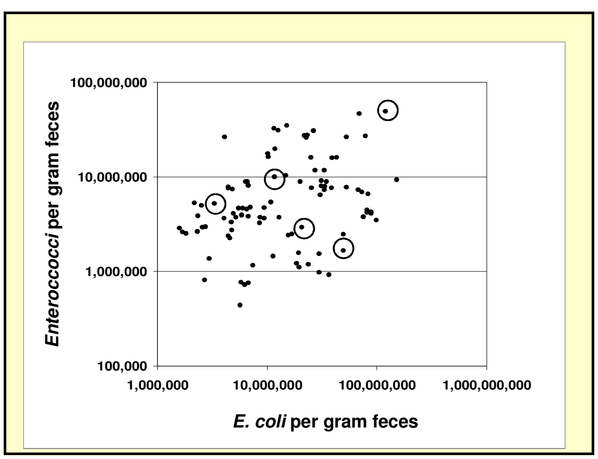
5-10% cows shed *Crypto*

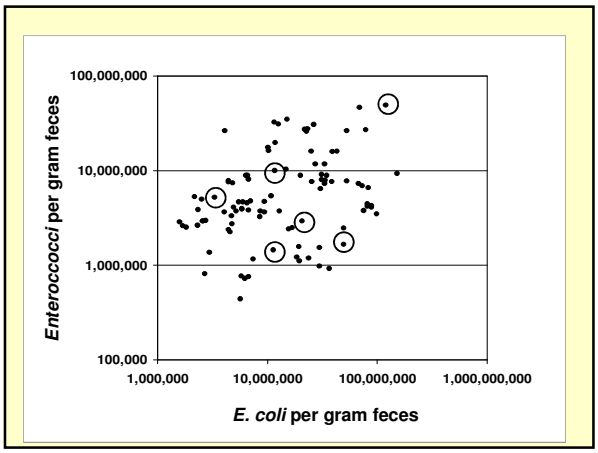


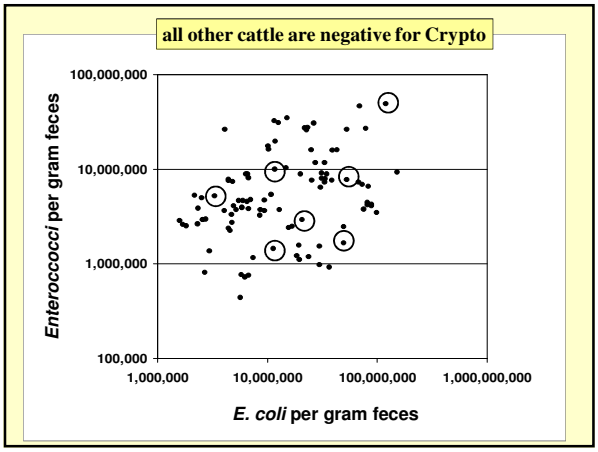



100,000,000
10,000,000
1,000,000
100,000
Enteroccocci per gram feces
1,000,000
10,000,000
100,000,000
1,000,000,000
E. coli per gram feces


100,000,000
10,000,000
1,000,000
100,000
Enteroccocci per gram feces
1,000,000
10,000,000
100,000,000
1,000,000,000
E. coli per gram feces


100,000,000
10,000,000
1,000,000
100,000
Enteroccocci per gram feces
1,000,000
10,000,000
100,000,000
1,000,000,000
E. coli per gram feces





Poor correlation between indicators and *Cryptosporidium* from cattle

Cattle shed ~50 million *E. coli* / g feces

Adults: <10 Crypto / g feces

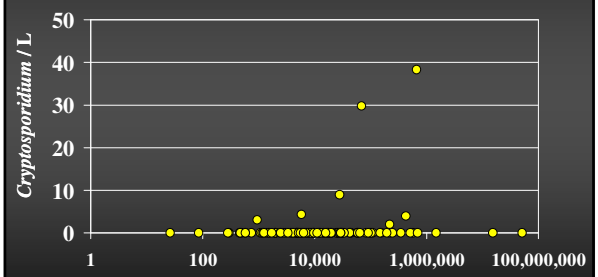
5 million *E. coli* for every Crypto oocyst

Calves: 10,000 Crypto / g feces

5 thousand *E. coli* for every Crypto oocyst

Similar problems with *Salmonella* and *E. coli* O157

Fecal coliforms and *Cryptosporidium* in ephemeral streams 2003 to 2004, Marin County, just below dairies



EXAMPLES OF STANDARDS FOR BACTERIA

***E. coli* / 100 ml**

- geometric mean <126 bacteria
- single grab sample <235 bacteria

***Fecal coliform* / 100 ml**

- geometric mean <200 bacteria
- geo-mean <14 bacteria in Tomales Bay
- keep upland runoff <250 bacteria

Animal agriculture along the coast: upland runoff

The task of staying below the indicator standard for animal agriculture

EXAMPLE

Cows shed 50 million fecal coliforms / g feces
Defecate 20 Kg per day

So, cow excretes a trillion fecal coliforms per day

Need fecal coliform <250 bacteria / 100 ml

Need to retain A LOT of fecal coliforms
or
you need A LOT of dilution

The task of staying below the indicator standard for animal agriculture

EXAMPLE

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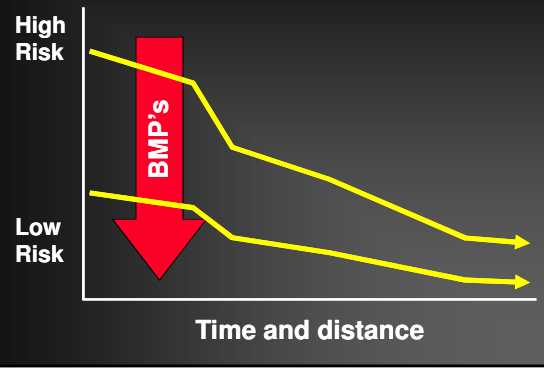
Defecate 20 Kg per day
So, cow excretes a trillion fecal coliforms per day

Need fecal coliform <250 bacteria / 100 ml

Need to retain A LOT of fecal coliforms
or
you need A LOT of dilution

Need several million gallons of water for 1 Kg feces

Beneficial Management Practices (BMPs)



Reducing waterborne pathogen risks from livestock

PROCESS	GOAL FOR BMP
pathogen loading	*prevalence & intensity, animal density*
pathogen transport: overland and subsurface	*enhance infiltration, attachment, sedimentation*
pathogen survival & replication	*enhance rate of inactivation, prevent multiplication*

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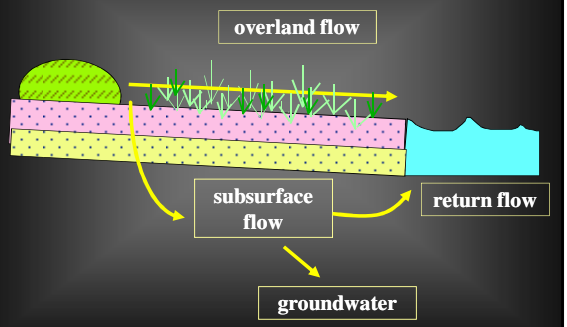
California coast and livestock production systems

How far away is safe enough?
Fencing, winter exclusion, aging manure

Filtration efficiency of vegetated buffer strips



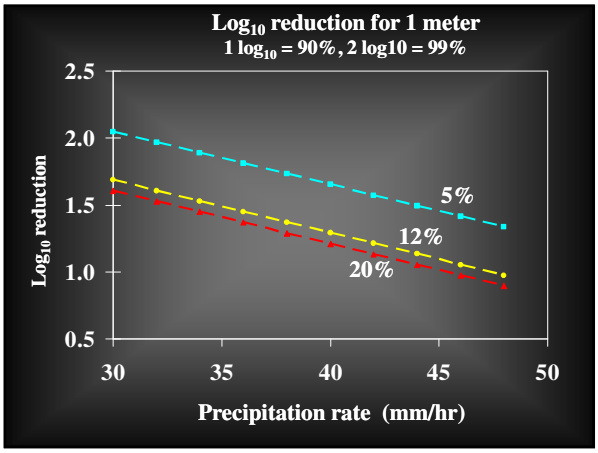
Log_{10} reduction as a measure of VBS filtration

Start with 1000 pathogens

Reduce to 100 = 90% reduction = 1 log_{10} reduction

Reduce to 10 = 99% reduction = 2 log_{10} reduction

Reduce to 1 = 99.9% reduction = 3 log10 reduction


Log10 reduction for 1 meter
1 log10 = 90%, 2 log10 = 99%
2.5
2.0
1.5
1.0
0.5
Log10 reduction
5%
12%
20%
30
35
40
45
50
Precipitation rate (mm/hr)

Predicted $\log_{10}$ reductions per meter VBS

Soil	Slope (%)	Bulk density (g/cm³) 0.7	1.0	1.3	1.7
capay silty clay	5	2.2	2.0	1.8	--
	10	3.1	2.5	1.9	--
	20	2.7	2.4	2.1	--
argonaut loam	5	--	2.4	1.8	--
	10	--	2.9	1.9	--
	20	--	2.8	2.1	--
hanford fine sandy loam	5	--	--	1.7	1.4
	10	--	--	1.7	1.0
	20	--	--	1.9	1.4

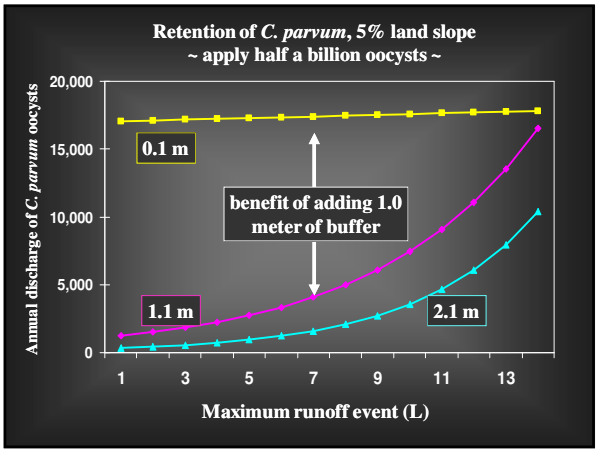
Sierra Foothill Research & Extension Center, University of California

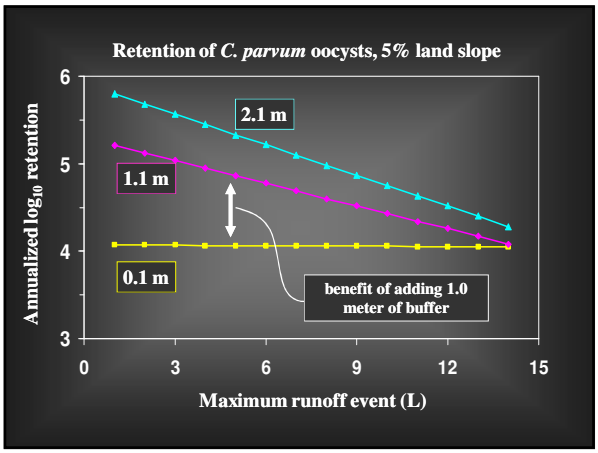
Buffer width (m)
0.1, 1.1, 2.1

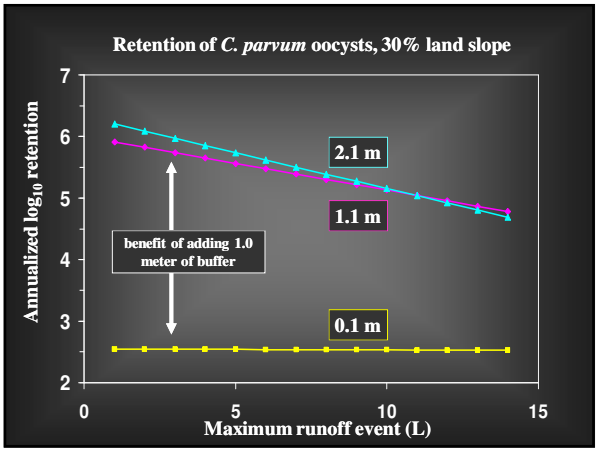
Land slope (%)
5, 20, 35

RDM (kg/ha)
225, 560, 900, 4500

2 rainfall seasons





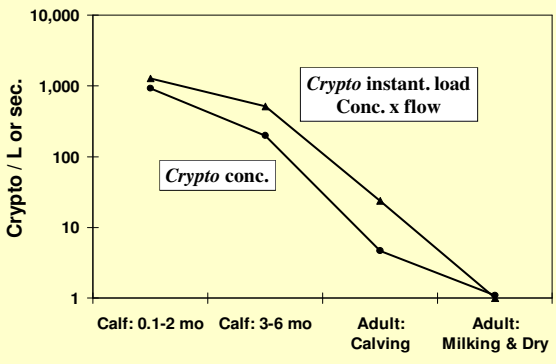


Hillslope grassland buffers can retain *E. coli* from bovine feces

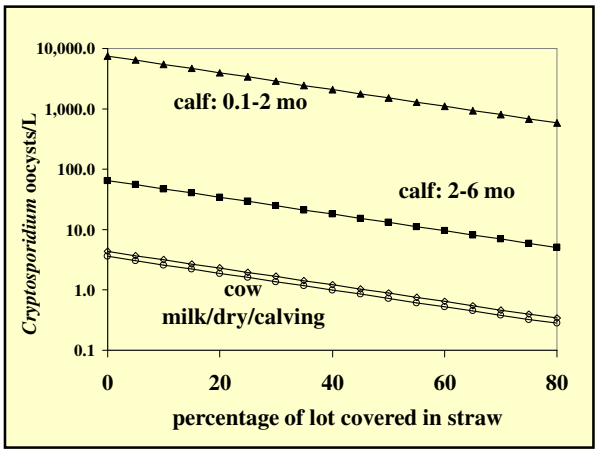
- **>95%** ***E. coli*** **retained in pat or first 10 cm (6 in) of buffer**
- **50% to 99.9% reduction in *E. coli* per meter (yard) of buffer**
- **~40% of all *E. coli* left the site during worst rainstorm event: *buffers fail at high rainfall intensity***

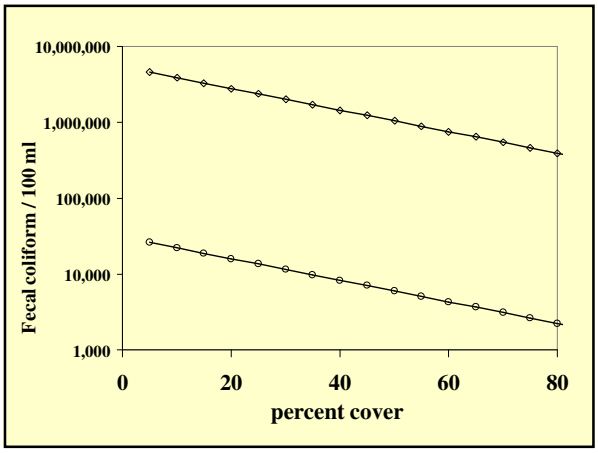
Lots (corrals, loafing areas, etc.)

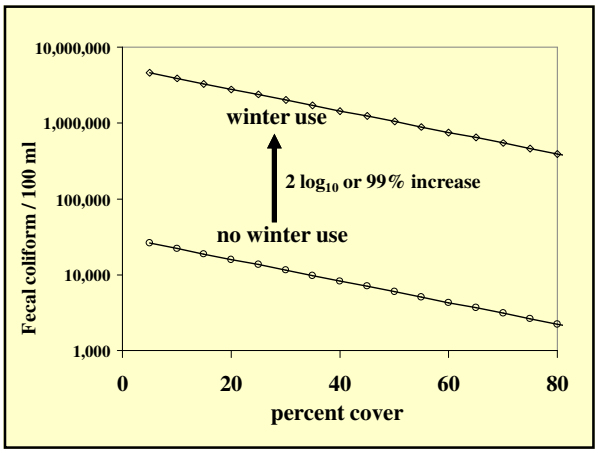
Cryptosporidium in runoff from dairy lots, Jan 2003 to Feb 2004, Marin County, California

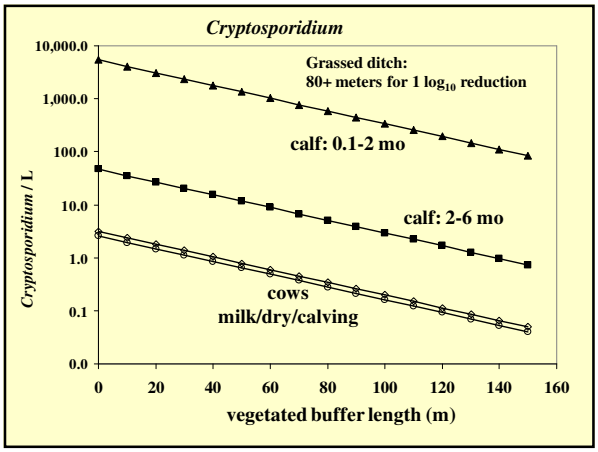


Straw mulching


10,000.0
1,000.0
100.0
10.0
1.0
0.1
Cryptosporidium oocysts/L
calf: 0.1-2 mo
calf: 2-6 mo
cow
milk/dry/calving
0
20
40
60
80
percentage of lot covered in straw


10,000,000
1,000,000
100,000
10,000
1,000
Fecal coliform / 100 ml
0
20
40
60
80
percent cover

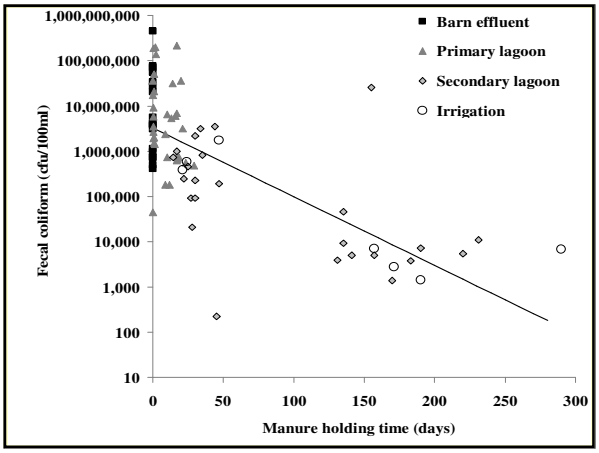

10,000,000
1,000,000
100,000
10,000
1,000
Fecal coliform / 100 ml
winter use
2 log10 or 99% increase
no winter use
0
20
40
60
80
percent cover

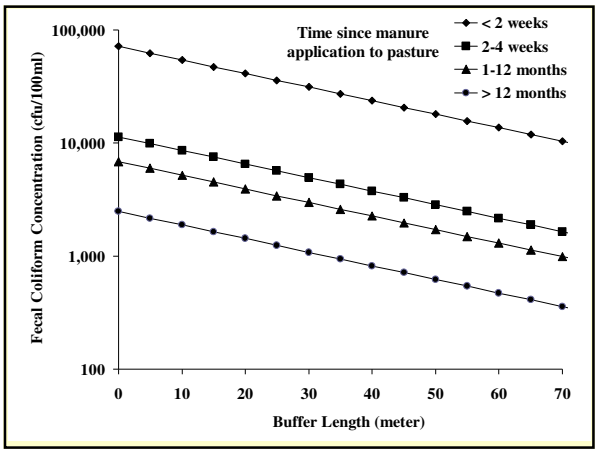

Cryptosporidium
10,000.0
1,000.0
100.0
10.0
1.0
0.1
0.0
Cryptosporidium / L
Grassed ditch:
80+ meters for 1 log10 reduction
calf: 0.1-2 mo
calf: 2-6 mo
cows
milk/dry/calving
0
20
40
60
80
100
120
140
160
vegetated buffer length (m)

Channelized ditch not very effective

Reducing the risk of waterborne microbial contamination from livestock and wildlife

PROCESS	GOAL FOR BMP
♦ *pathogen loading*	*prevalence & intensity, animal density*
♦ *pathogen transport*	*enhance infiltration, overland and subsurface attachment, sedimentation*
♦ *pathogen survival & replication*	*enhance rate of inactivation, prevent multiplication*




Time since manure application to pasture
< 2 weeks
2-4 weeks
1-12 months
> 12 months
Fecal Coliform Concentration (cfu/100ml)
100,000
10,000
1,000
100
0
10
20
30
40
50
60
70
Buffer Length (meter)