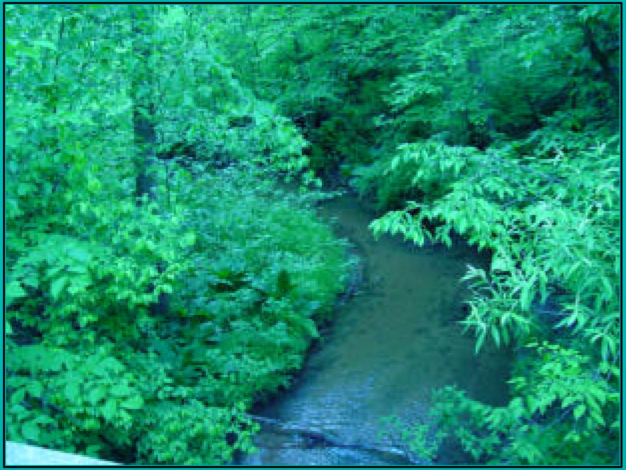
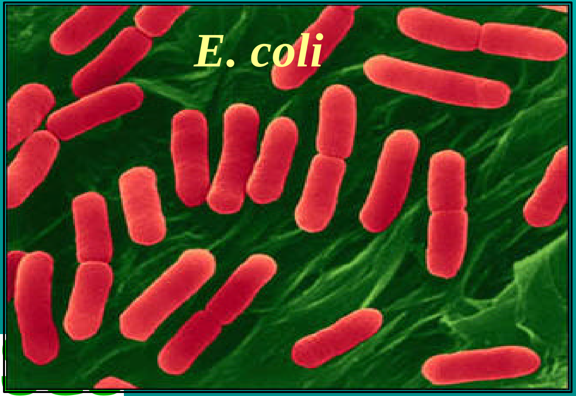
Non-Point Sources of Fecal Indicator Bacteria

R. Whitman and M. Byappanahalli
U.S. Geological Survey
Great Lakes Science Center
Lake Michigan Ecological Research Station
Porter, IN





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Microbial Research-USGS

Recreational Water Quality

- Ecology of indicator bacteria
- Predictive Modeling
- Source tracking

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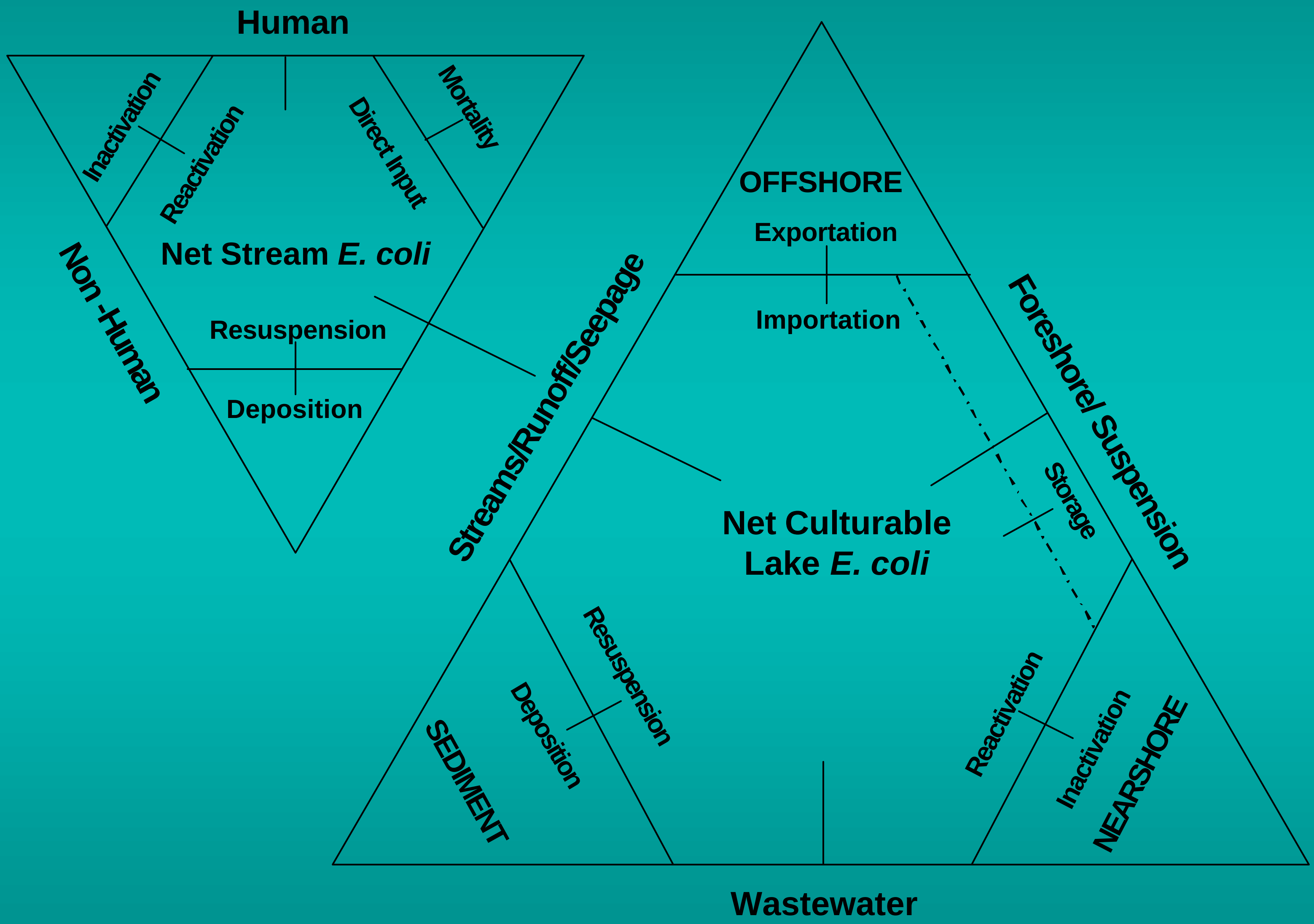
A Conceptual Diagram of *E. coli* Within and Between Stream and Beach Watersheds



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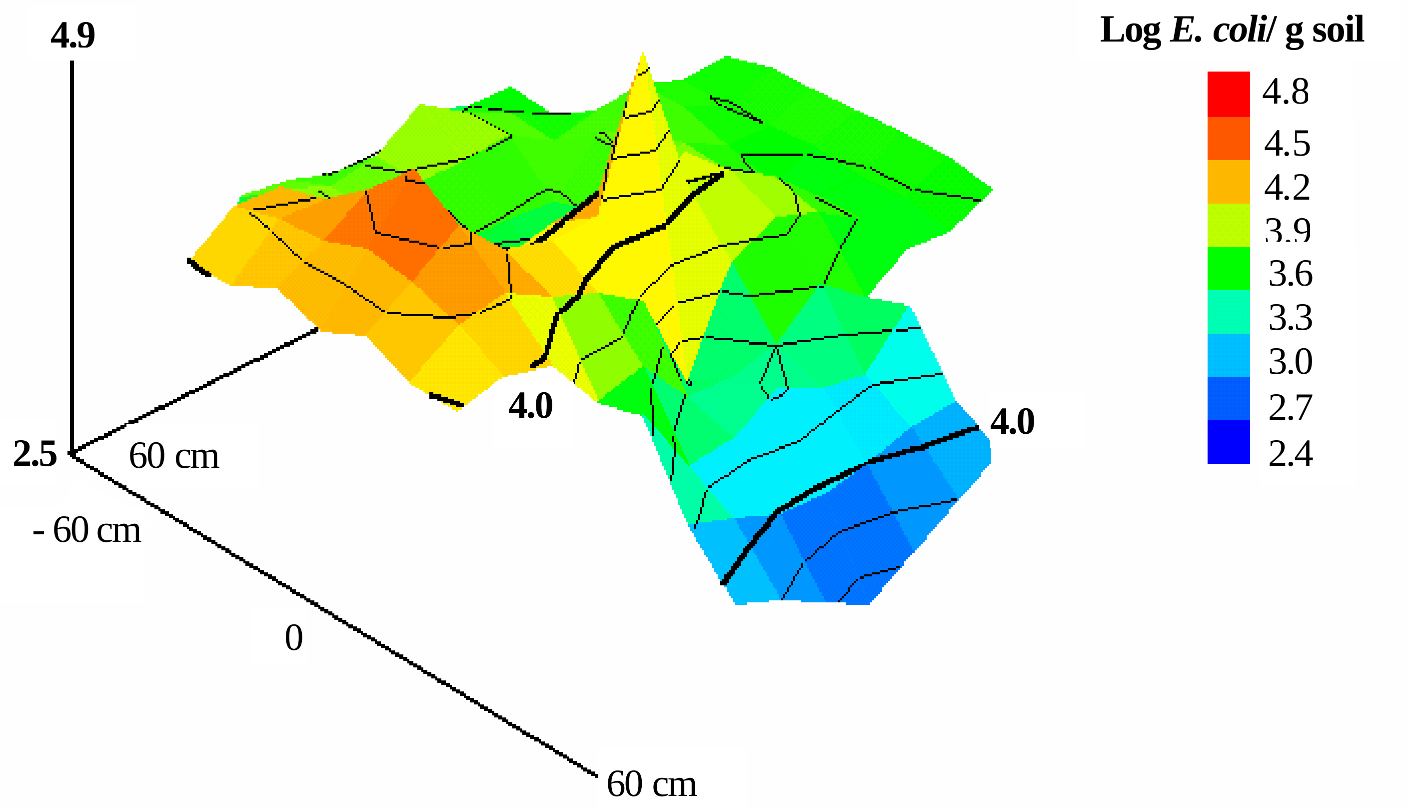
Whitman, R. L., M. B. Nevers and M. N. Byappanahalli. 2006. Examination of the Watershed-Wide Distribution of *Escherichia coli* along Southern Lake Michigan: an Integrated Approach. Appl. Environ. Microbiol. 72 (11): 7301–7310.

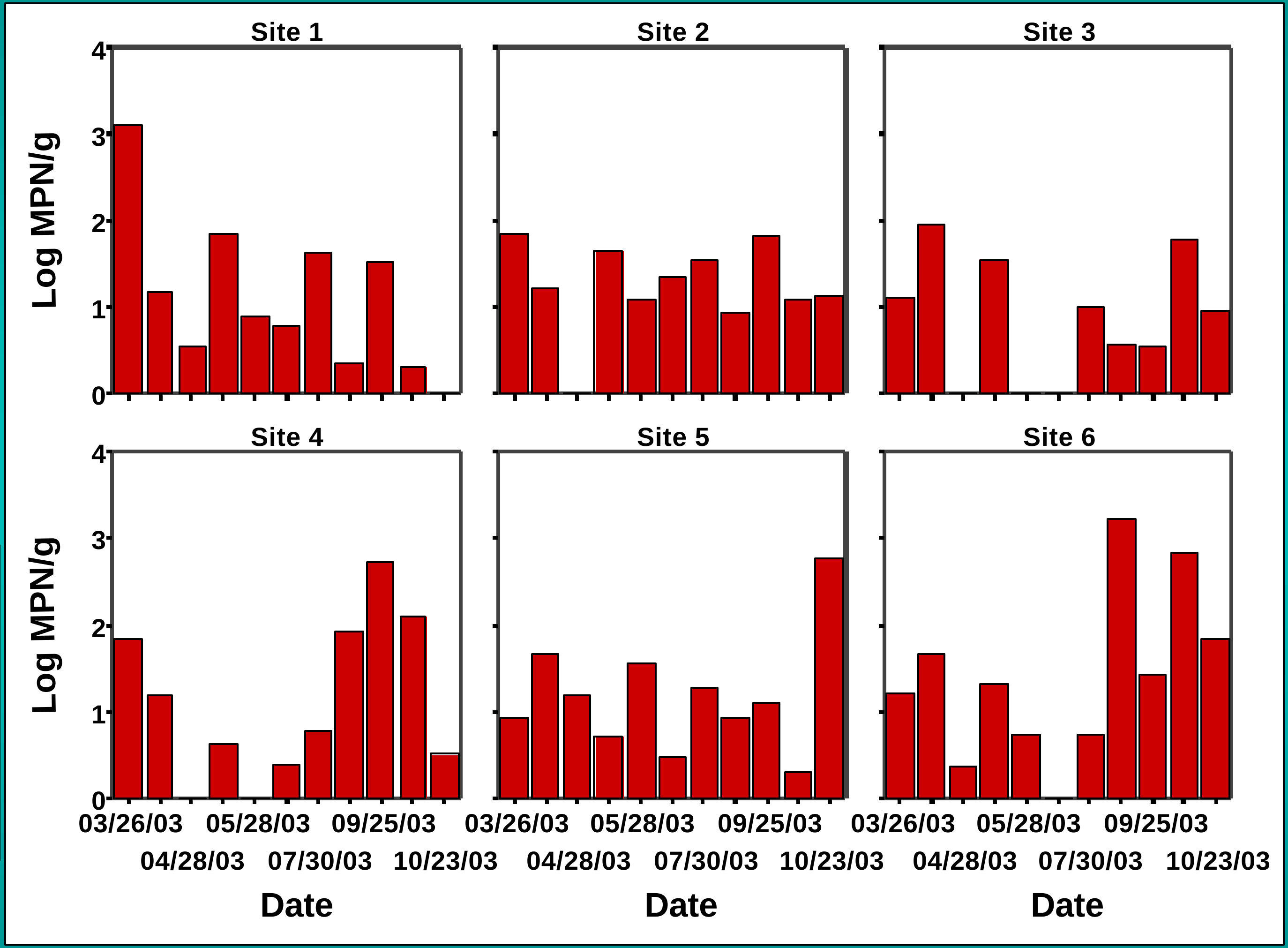
Distribution of Soil *E. coli*



Distribution of *E. coli* five months after sterilization

Whitman, R. L., M. B. Nevers and M. N. Byappanahalli. 2006. Examination of the Watershed-Wide Distribution of *Escherichia coli* along Southern Lake Michigan: an Integrated Approach. Appl. Environ. Microbiol. 72 (11): 7301–7310.

E. coli is Commonly found in Forest Soils in All Seasons



Byappanahalli M. N., R. W. Whitman, D. A. Shively, M. J. Sadowsky and S. Ishii. 2006. Population structure, persistence, and seasonality of autochthonous *Escherichia coli* in temperate, coastal forest soil from a Great Lakes watershed. Environmental Microbiology 8 (3), 504–513.

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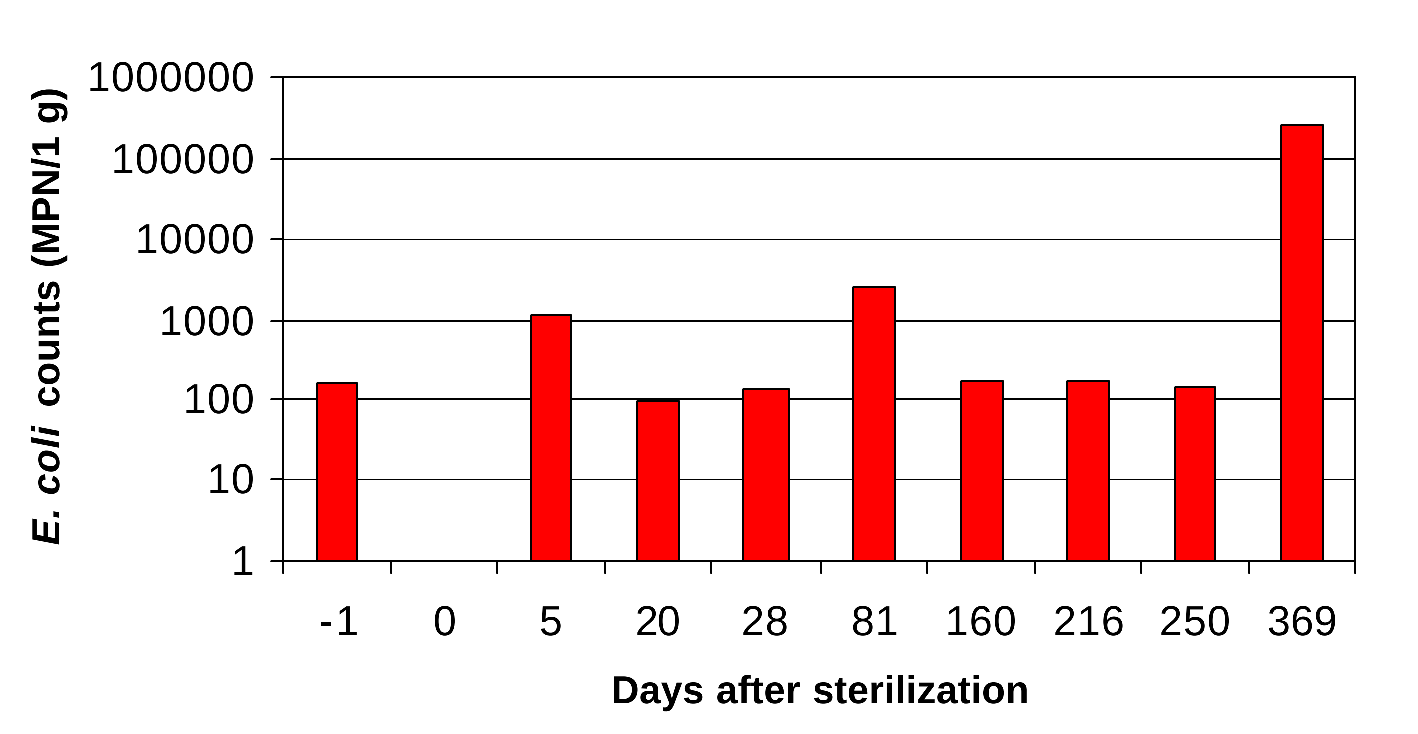
Recovery and Persistence of Soil *E. coli*



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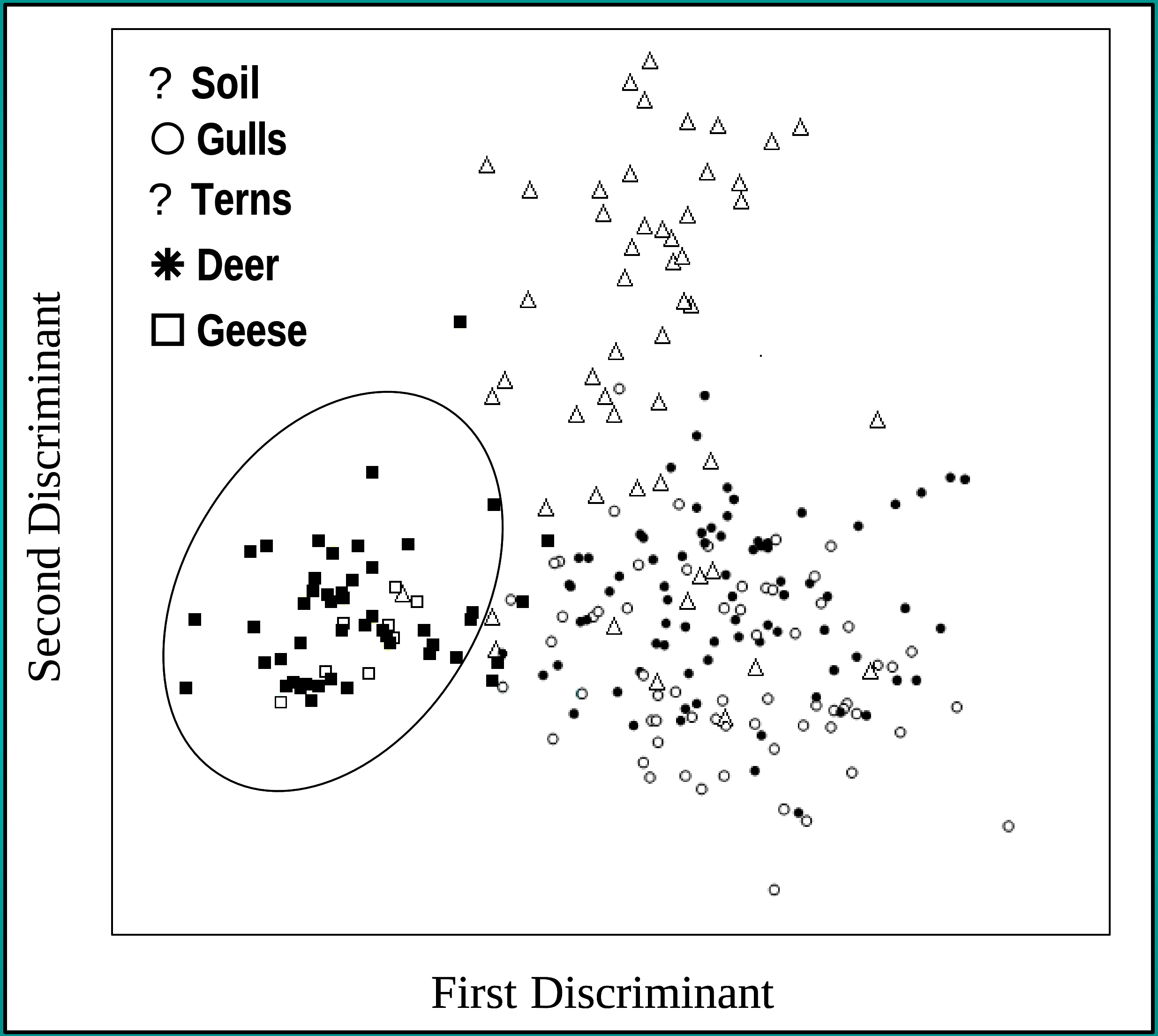
Adapted from: Whitman, R. L., M. B. Nevers and M. N. Byappanahalli. 2006. Examination of the Watershed-Wide Distribution of *Escherichia coli* along Southern Lake Michigan: an Integrated Approach. Appl. Environ. Microbiol. 72 (11): 7301–7310.

Soil E. coli strains are genetically distinct from animal strains



Byappanahalli M. N., R. W. Whitman, D. A. Shively, M. J. Sadowsky and S. Ishii. 2006. Population structure, persistence, and seasonality of autochthonous *Escherichia coli* in temperate, coastal forest soil from a Great Lakes watershed. Environmental Microbiology 8 (3), 504–513.

E. coli of Stream Water and Sediments are Correlated

Stream Water-A
Stream Sand-B
Margin Sand-C
Sand @ 1 m from margin-D
Soil @ 4 m from margin-E

Connected Lines Indicate Significant Correlation (Spearman rho, $p=0.05$, $n=15$)

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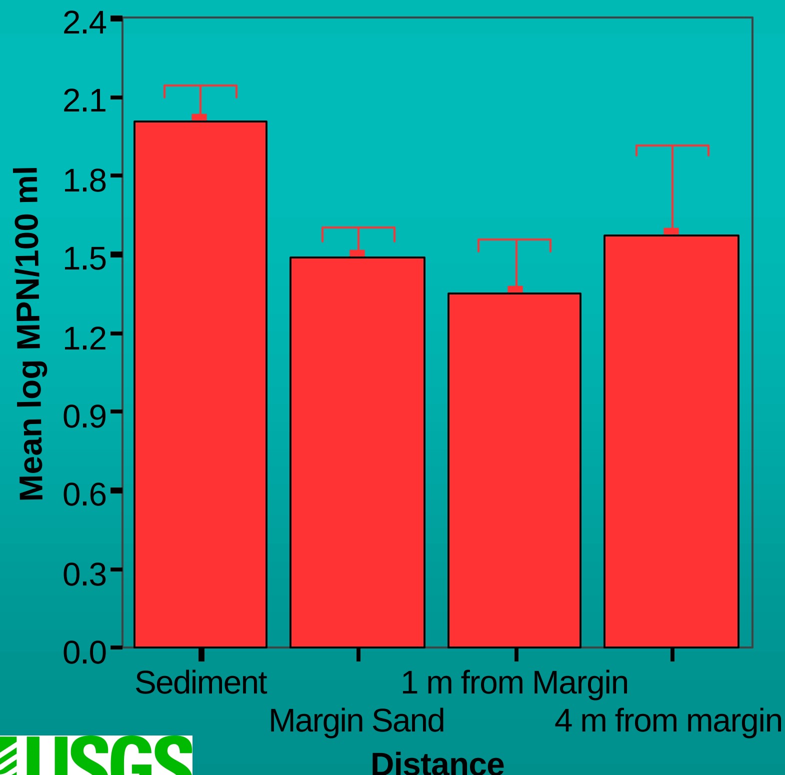
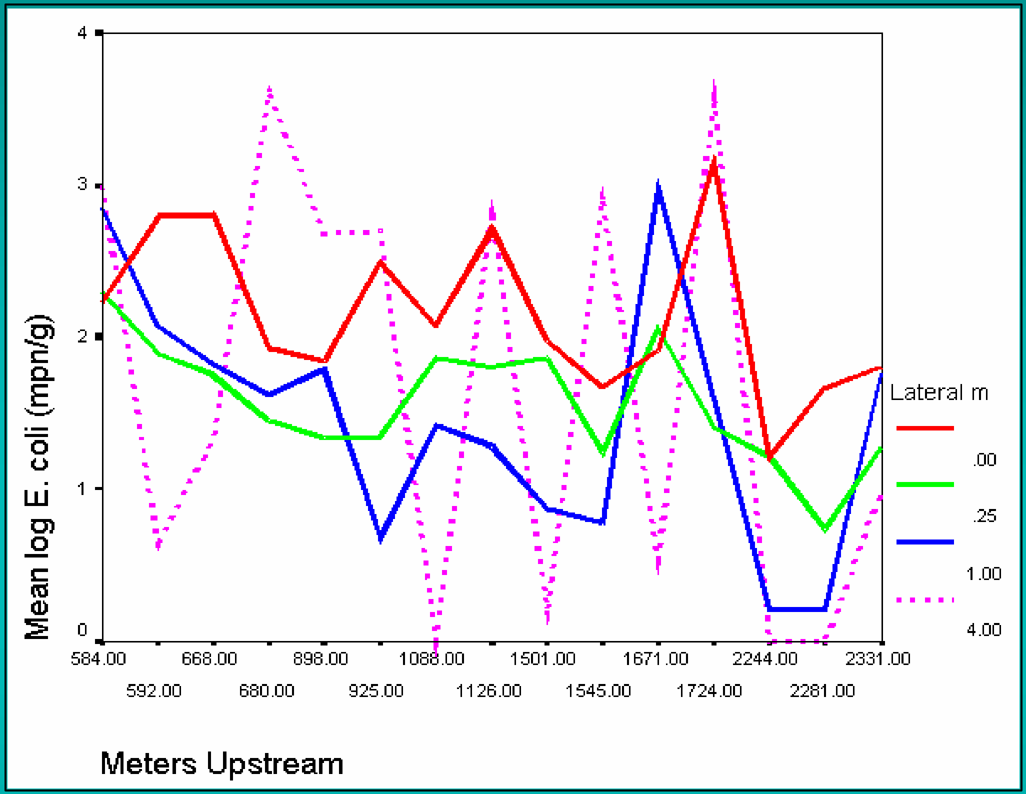
Whitman, R.W., M. Fowler, D.A. Shively and M.N. Byappanahalli. 2002. Distribution and characterization of E. coli within the dunes creek watershed, Indiana Dunes State Park. Report for: Indiana Department of Natural Resources, Indiana Dunes State Park.

E. coli is Found in Stream Sediments

Sediments are highest (p=0.05) trending lower further from the streambed





Variation increases with distance from streambed

Whitman, R.W., M. Fowler, D.A. Shively and M.N. Byappanahalli. 2002. Distribution and characterization of E. coli within the dunes creek watershed, Indiana Dunes State Park. Report for: Indiana Department of Natural Resources, Indiana Dunes State Park.

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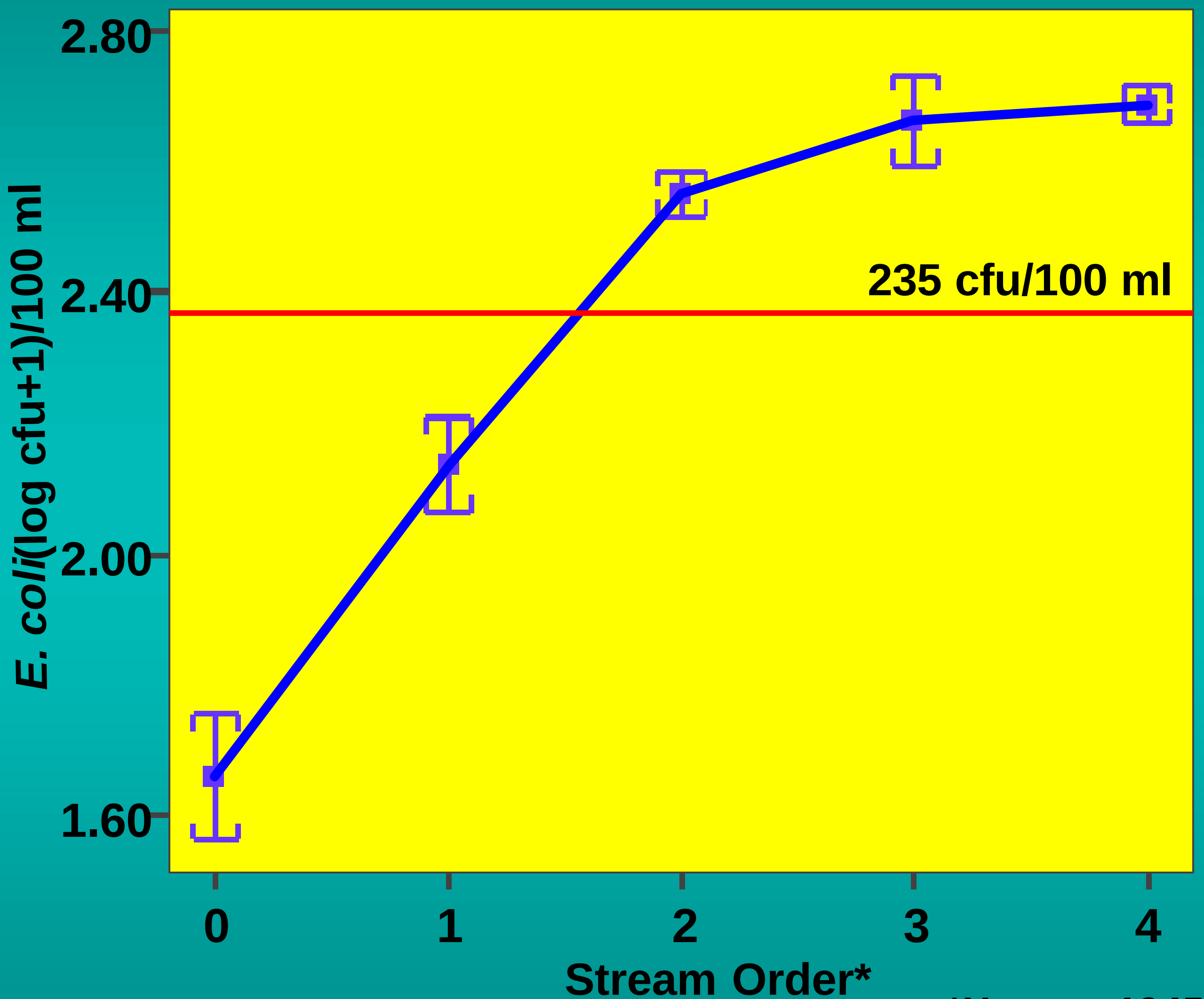
E. coli in Dunes Creek Increases With Stream Order (1999-2000)

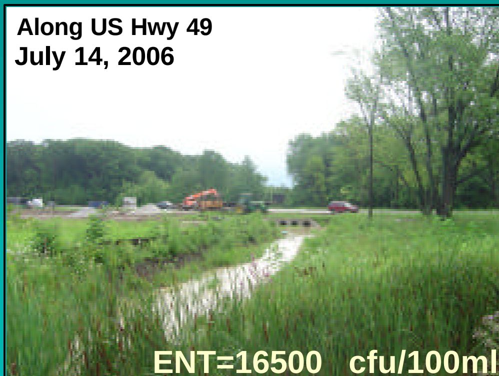


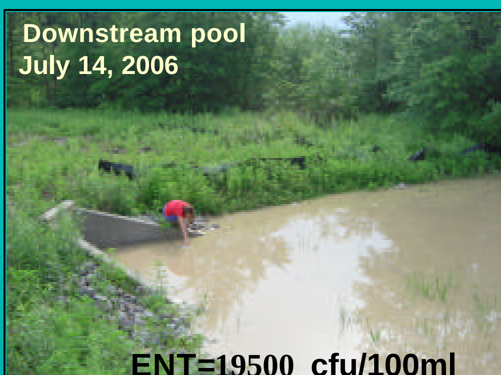
*Horton, 1945

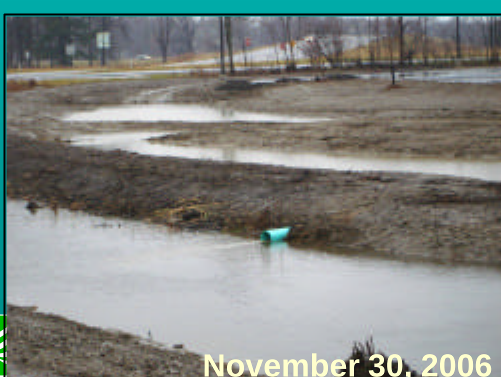
Byappanahalli, M., Fowler, M., Shively, D., and Whitman, R. (2003) Ubiquity and persistence of *Escherichia coli* in a midwestern coastal stream. *Appl Environ Microbiol* 69: 4549–4555.

Creek Construction Influences FIB

New Visitor Center Area







Wetland Restoration Area, SP

Inflow

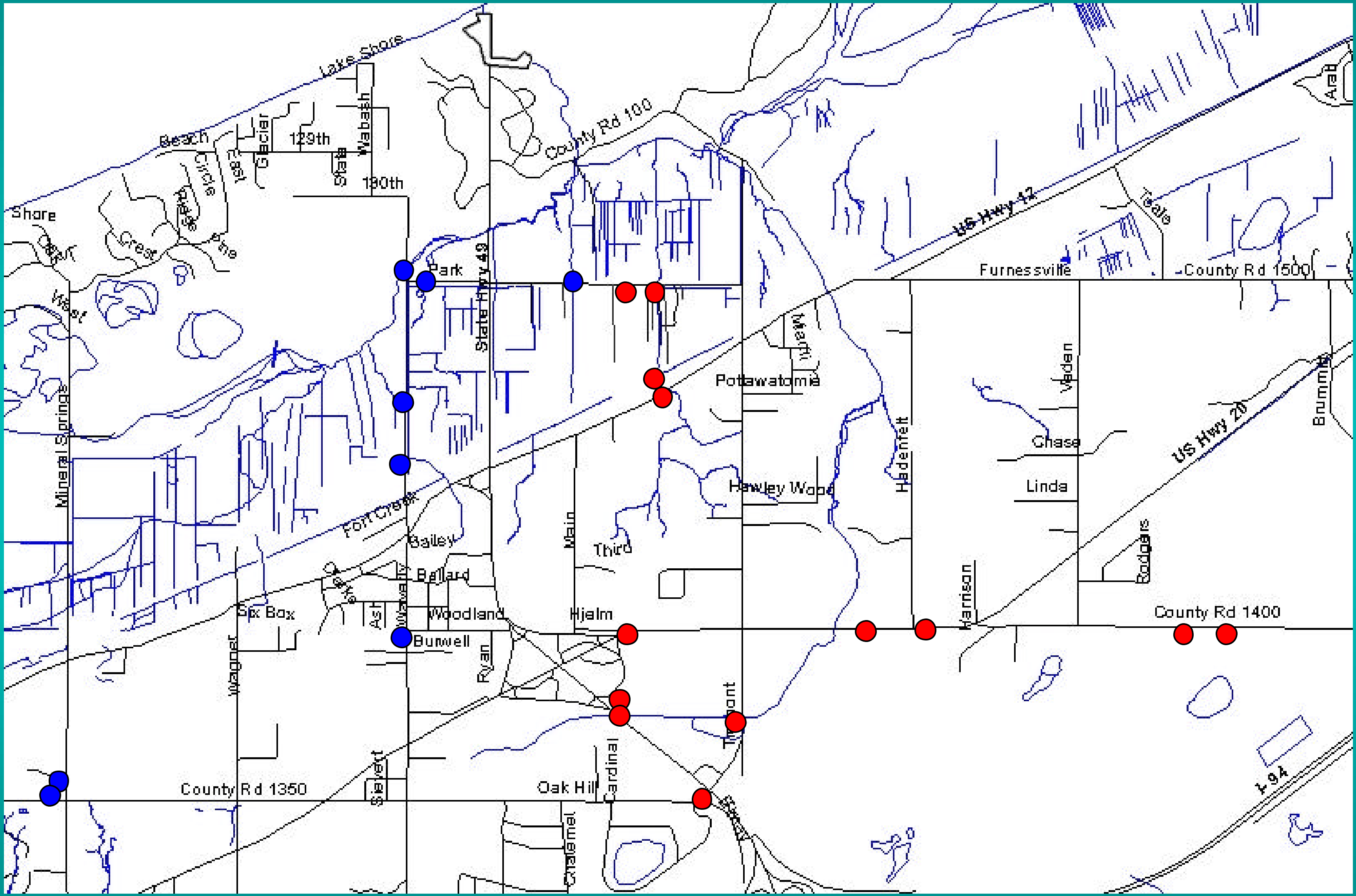
Outflow

New Daylight Area, SP

Inflow

Outflow

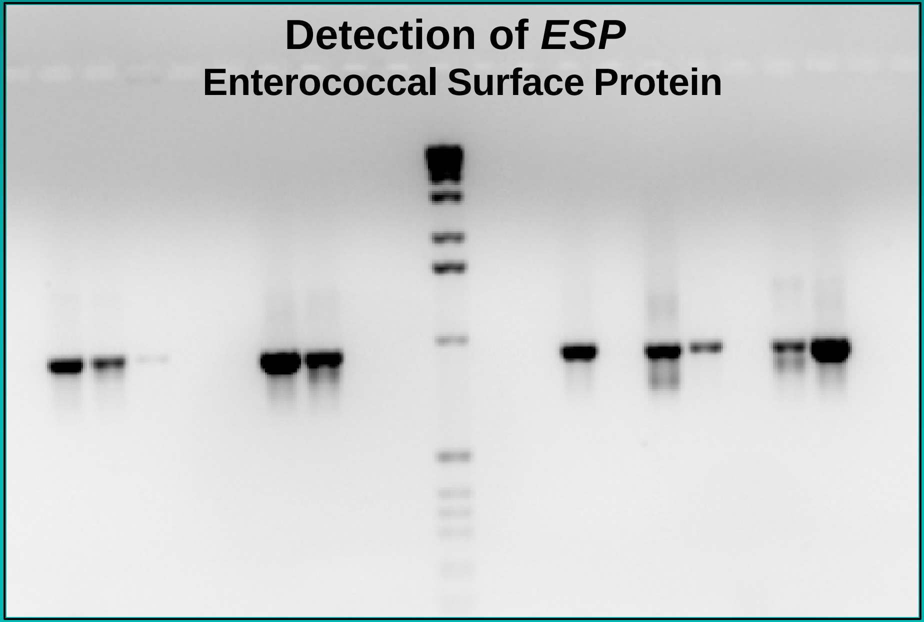
Dunes Creek Watershed

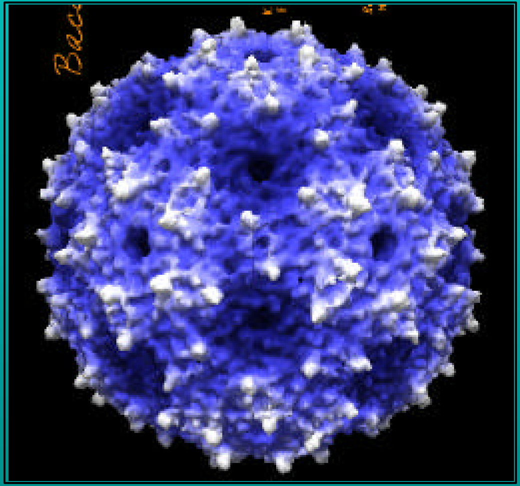


Eastern branch of Dunes Creek

Western branch of Dunes Creek

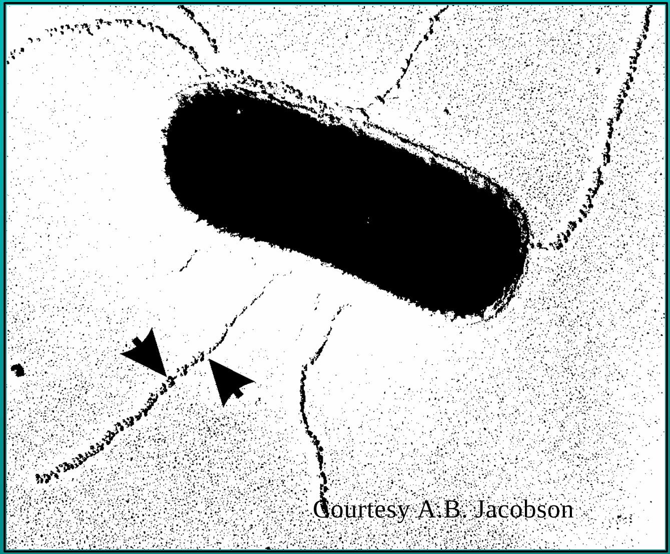
Storm Run-off Increases Detection of Human Markers: Enterococcal surface protein (*ESP*) gene and coliphages

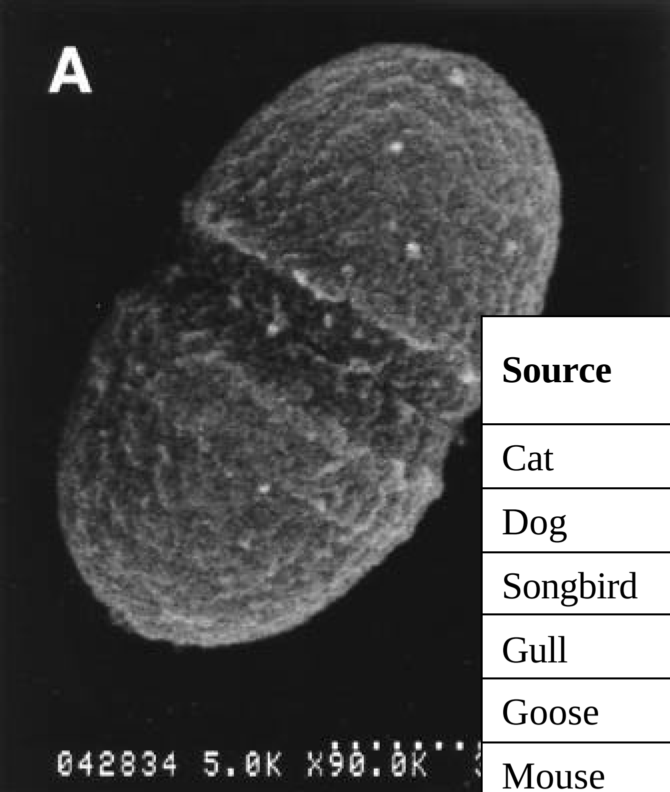




Valegard et al. Licensed for use, Inst. for Molecular Virology.
(linked to http://www.bocklabs.wisc.edu/images/ms2.jpg). 20 July 2001.

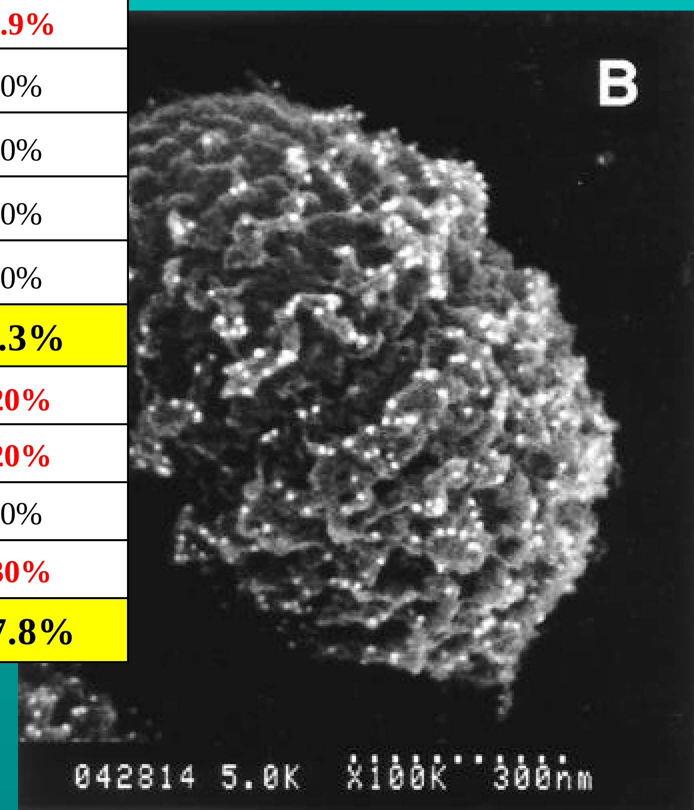
The detection of Male Specific FRNA Coliphage





ESP gene is not limited to human fecal sources

Source	No. of samples	Shankar esp_{fs}*	Scott esp_{fm}**
Cat	34	0%	0%
Dog	43	0%	**20.9%**
Songbird	55	**9.1%**	0%
Gull	34	**29.4%**	**2.9%**
Goose	18	0.0%	0%
Mouse	22	**13.6%**	0%
Raccoon	23	0%	0%
Deer	4	0%	0%
Total animals	**233**	**7.7%**	**4.3%**
Sewage influent	5	**100%**	**20%**
Sewage effluent	5	**100%**	**20%**
Pit toilet	15	**80%**	0%
Septic trucks	20	**30%**	**30%**
Total human	**45**	**62.2%**	**17.8%**



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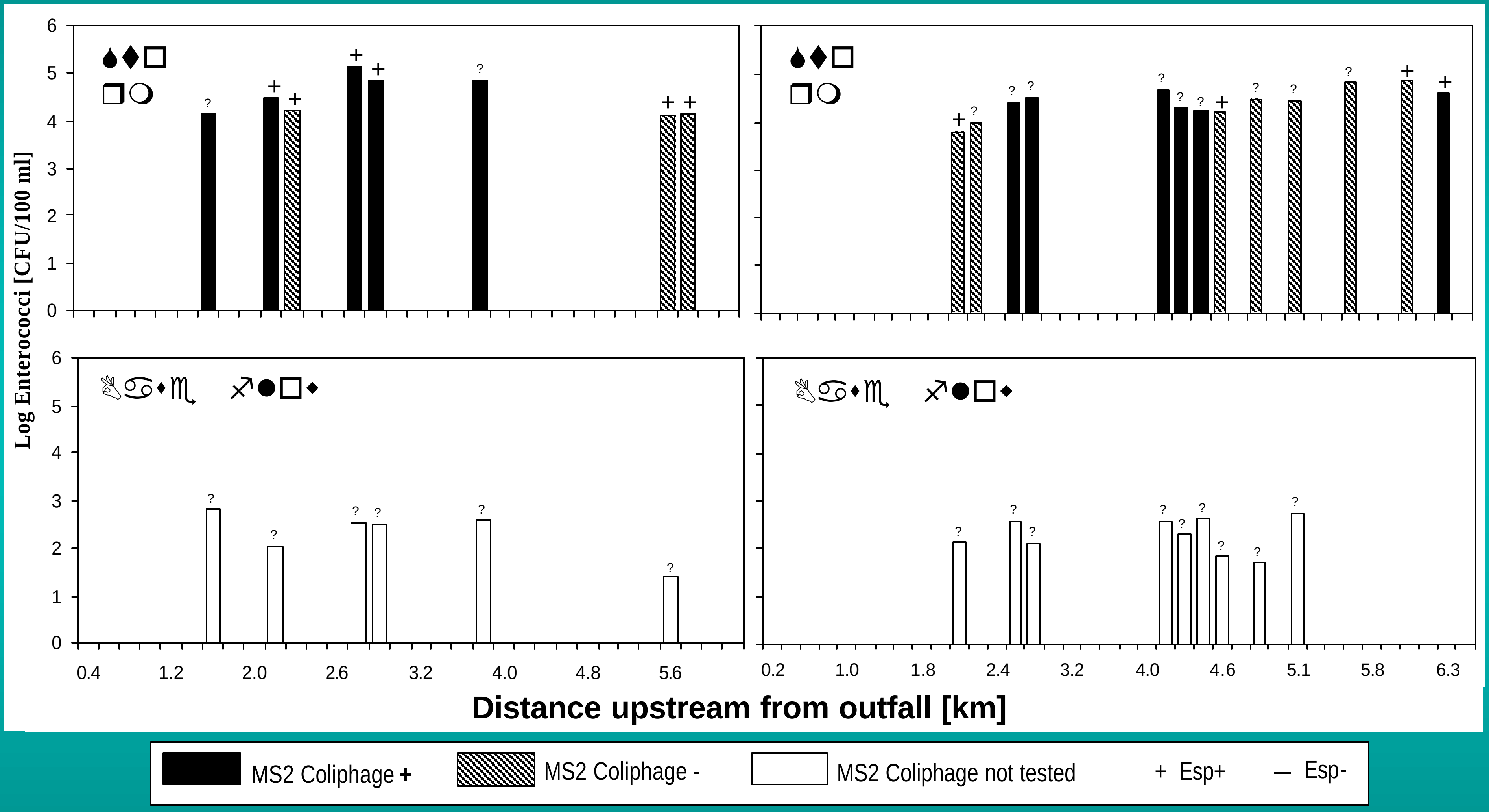
* Shankar et al. 1999. Infection and Immunity. 67(1): 193–200
** Scott et al. 2005. Environ. Sci. Technol. 39, 283-287

DUNES CREEK

WEST BRANCH / EAST BRANCH



Ø Esp+ frequency is 52% during storm

ØThere is no pattern in ENT, Esp+ and MS2+ with the distance from creek's outfall

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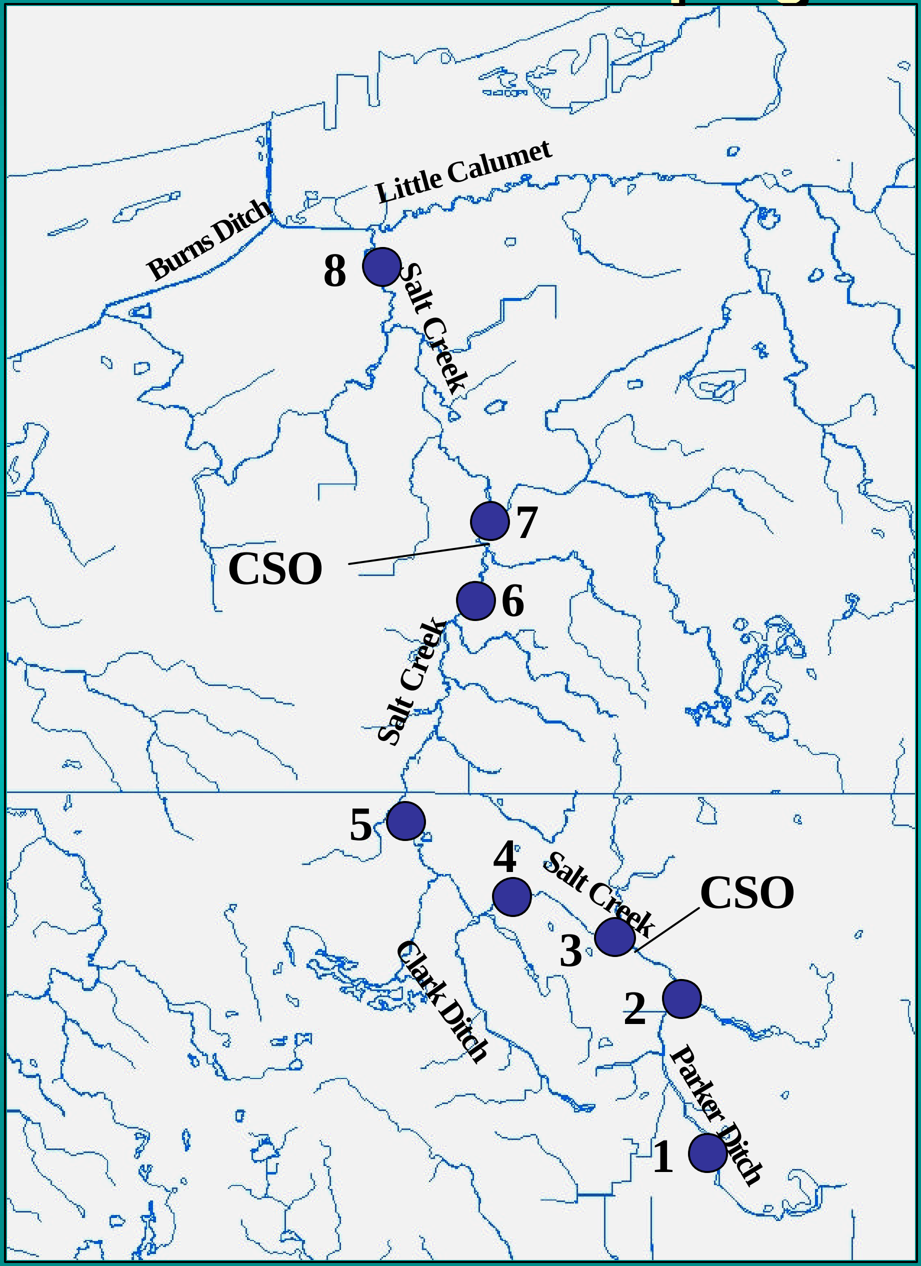
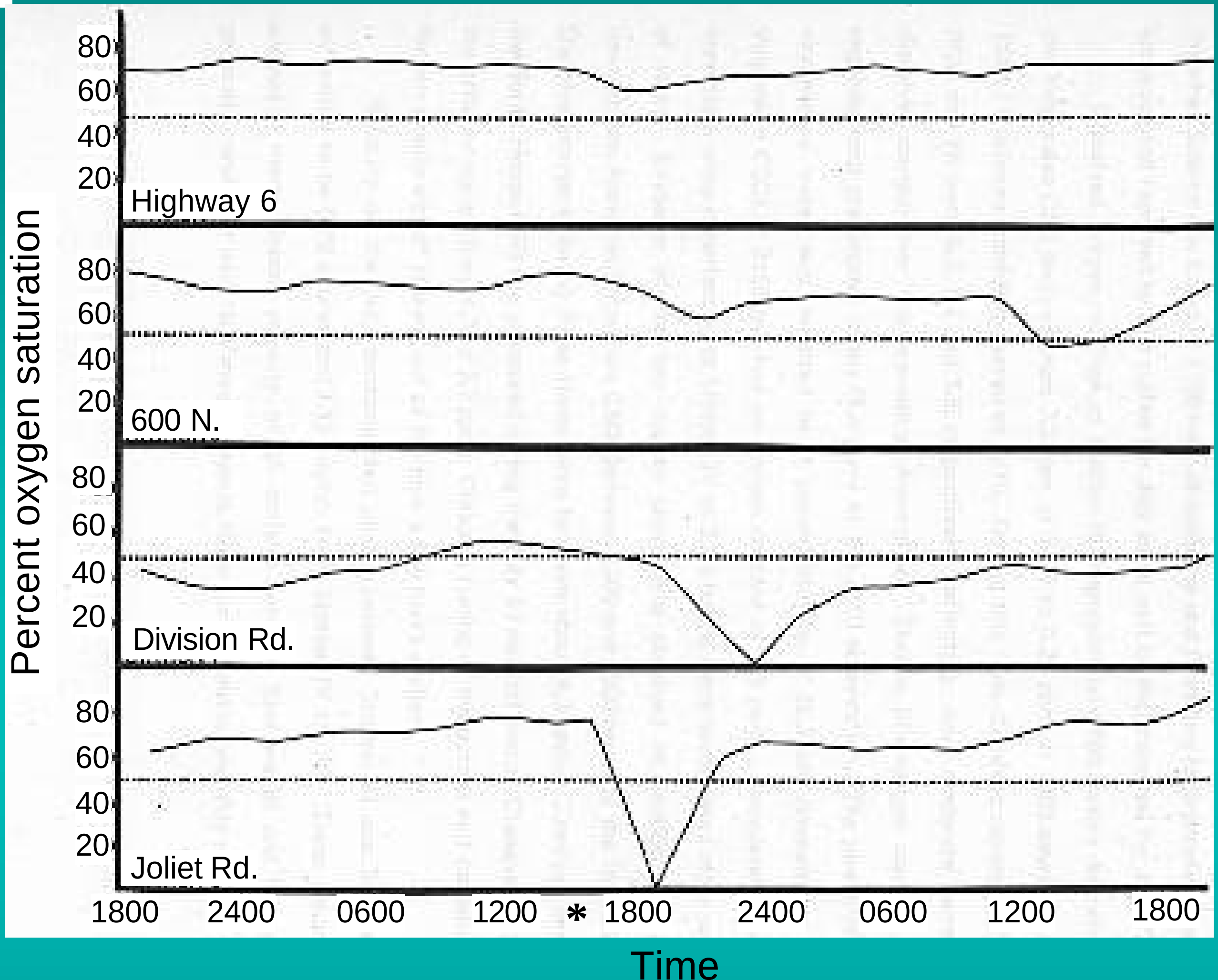
Evidence of Sewage Release

Salt Creek Sampling Stations



Whitman, R. L. 1981. Environmental quality assessment of Salt Creek Porter County, Indiana

Two Day Diurnal Analysis of Oxygen Saturation, Salt Creek



Station	Distance from origin (km)	Disatnce from CSO (km)
Division Rd.	5.6	-5.1
Joliet Rd.	6.9	0.5
600 N.	14.4	12.6
Highway 6	17.4	17.4

*** Rainfall event (0.2 in) July 26, 1980 from 1500 to 1640 h**

Whitman, R. L. 1981. Environmental quality assessment of Salt Creek Porter County, Indiana

Conclusions

- ***E. coli*** **is commonly found in forest soils throughout the year, making soil a significant source.**
- **Stream sediments are a source of** ***E. coli*** **to stream water during resuspension.**
- **Storm run-off introduces sources and may indicate the presence of human influence.**
- **Reconstruction of creek's channel should consider ecology of FIB.**
- **Enterococci concentration raises substantially during storm conditions, delivering more bacteria to the beach.**
- ***Esp*** **gene is not limited to human derived samples; it has been found in domesticated animals and wildlife.**

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Sources of Beach *E. coli*

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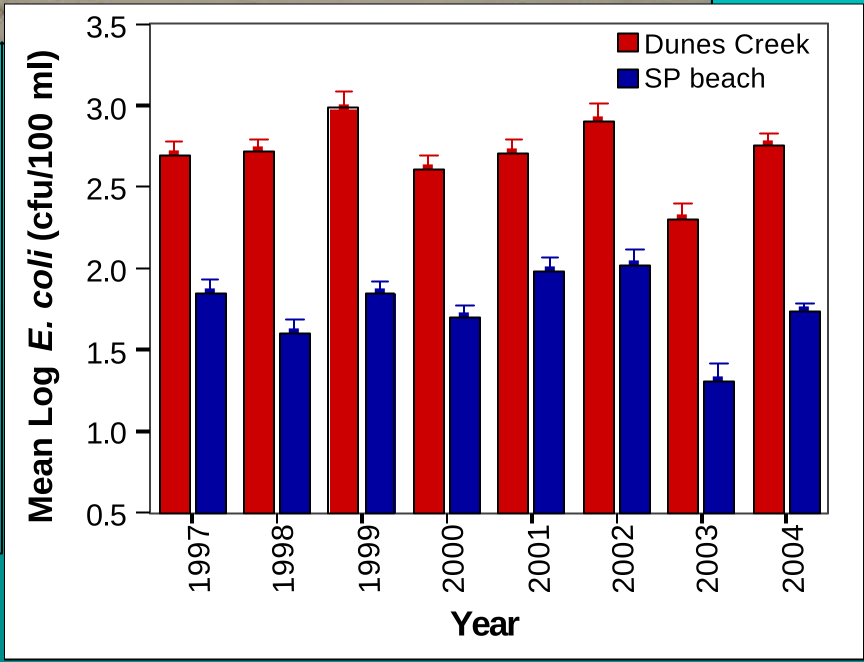
Stream Outfalls Affect Beach Water Quality



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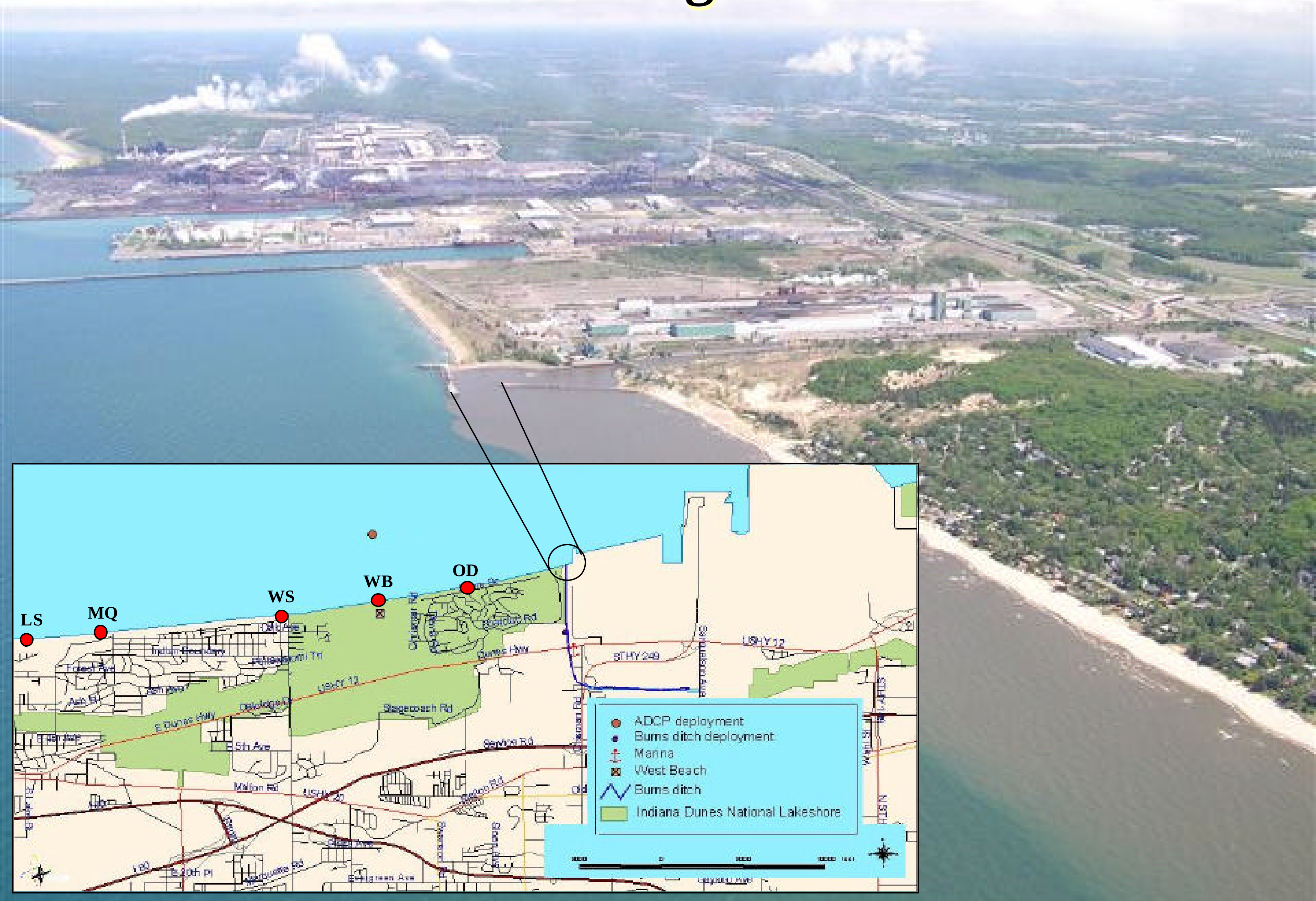
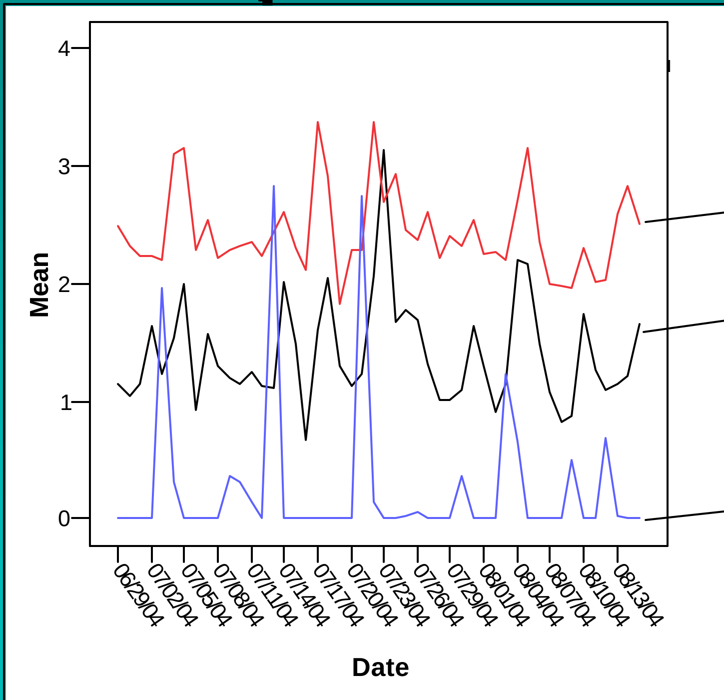
Burns Ditch Outfall at Ogden Dunes



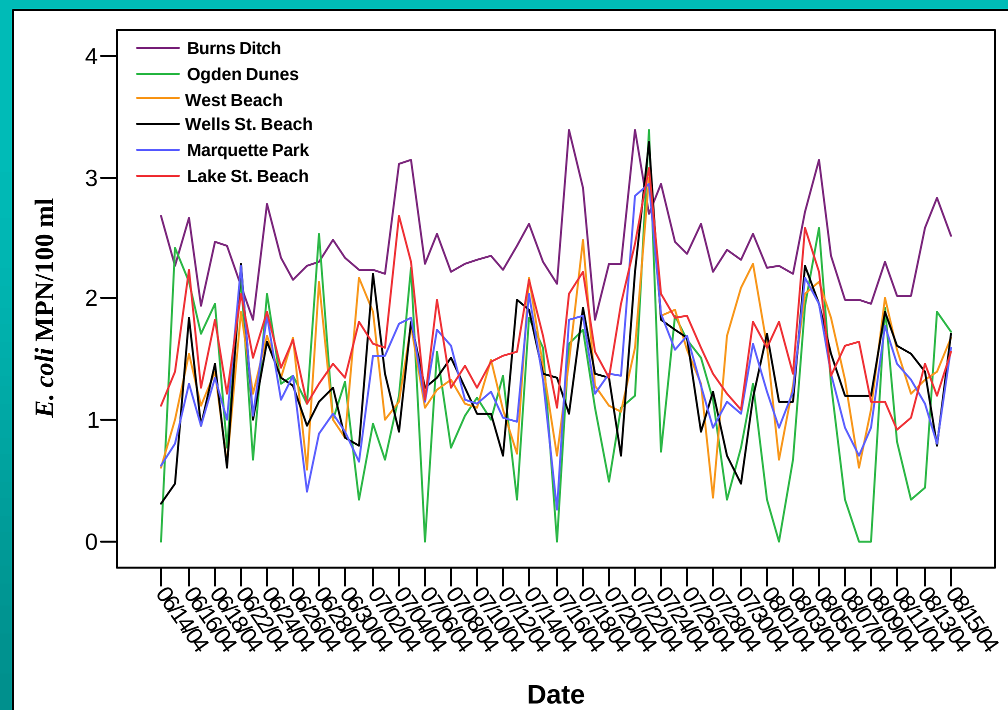
Impact of Burns Ditch on Westward Beaches



Burns Ditch log *E. coli*

Mean log beach *E. coli*

Total precipitation



Nevers, M. B., and R. L. Whitman. 2005. Nowcast modeling of *Escherichia coli* concentrations at multiple urban beaches of southern Lake Michigan. Water Res. 39:5250–5260.

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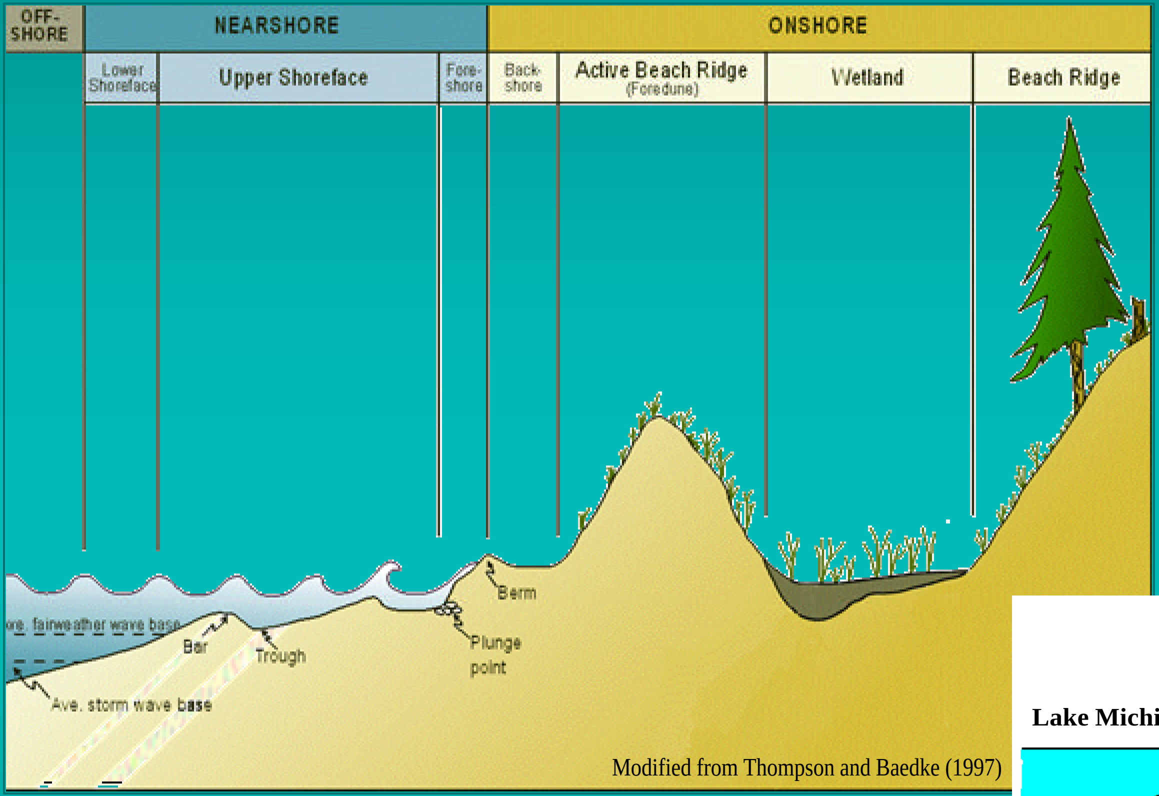
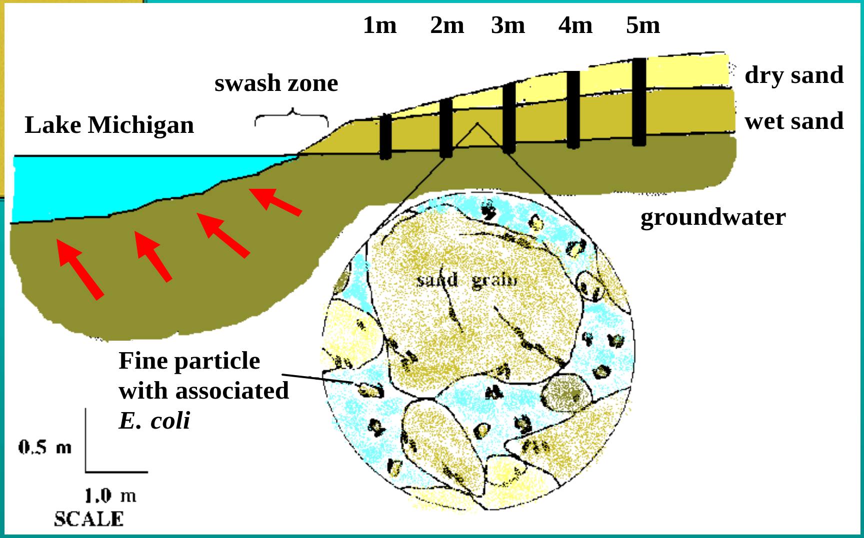
Local Non-Point Sources



Bacteria can be integrated into foreshore sand from human and animal waste and plant material.



Sand harbors *E. coli* where it may persist and grow, making foreshore sand a potential sink or source to beach water.

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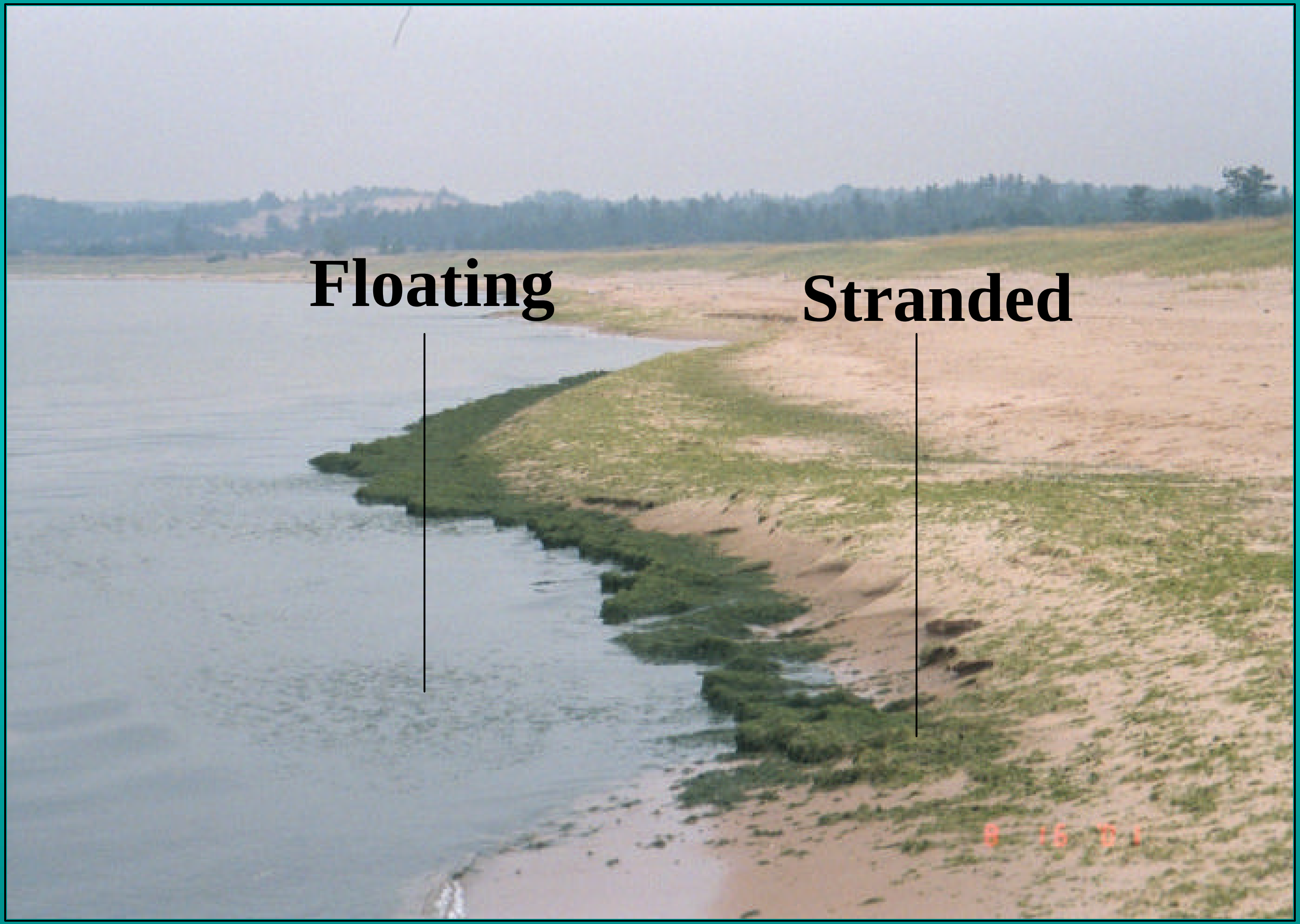
Cladophora Commonly Accumulates in the Great Lakes



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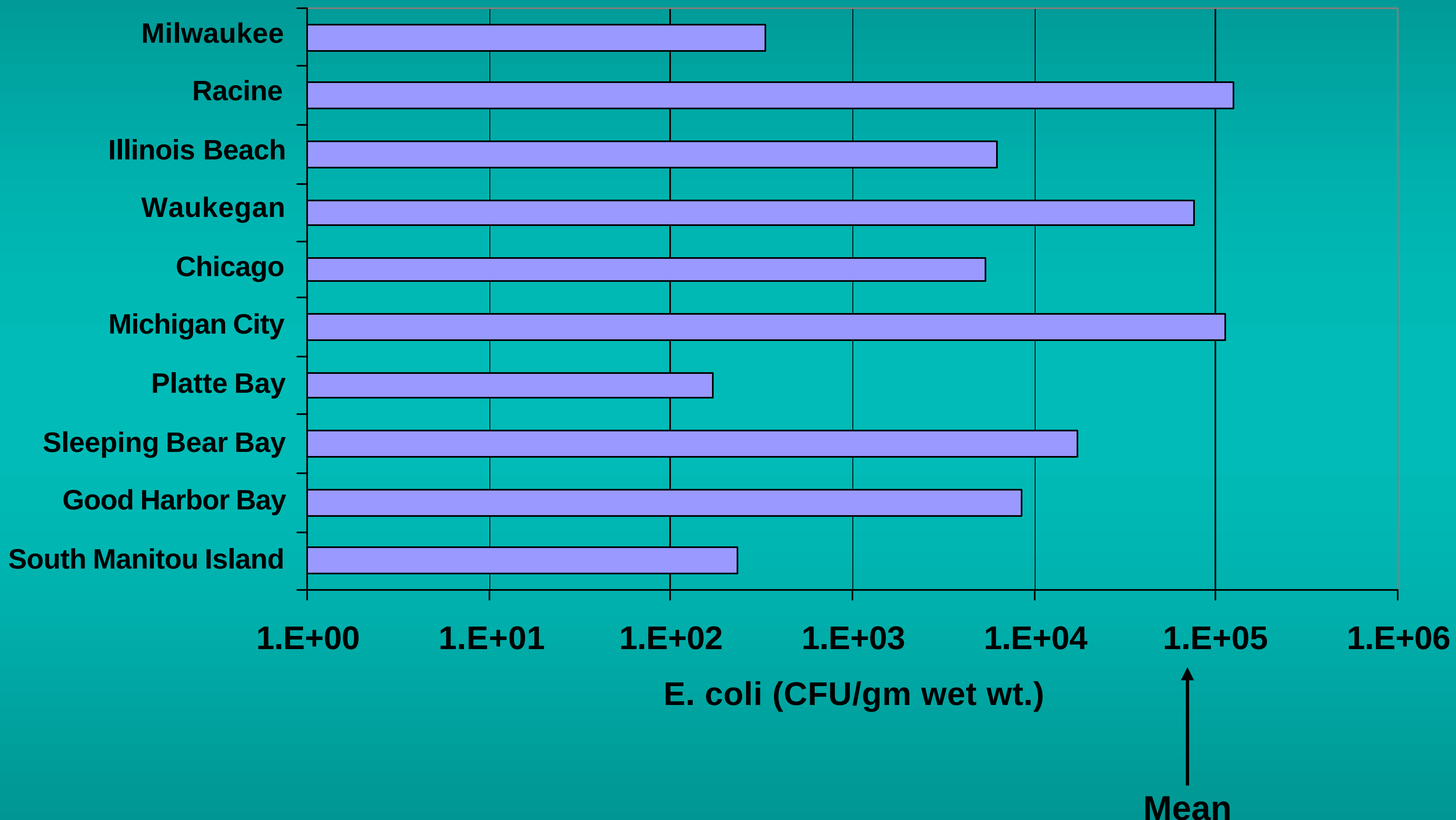
Concentration of *E. coli* Washed From *Cladophora*



Whitman, R.L., Shively, D.A., Pawlik, H., Nevers, M.B. and Byappanahalli, M.N. (2003) Occurrence of Escherichia coli and enterococci in Cladophora (Chlorophyta) in nearshore water and beach sand of Lake Michigan. Appl. Environ. Microbiol. 69, 4714-4719.

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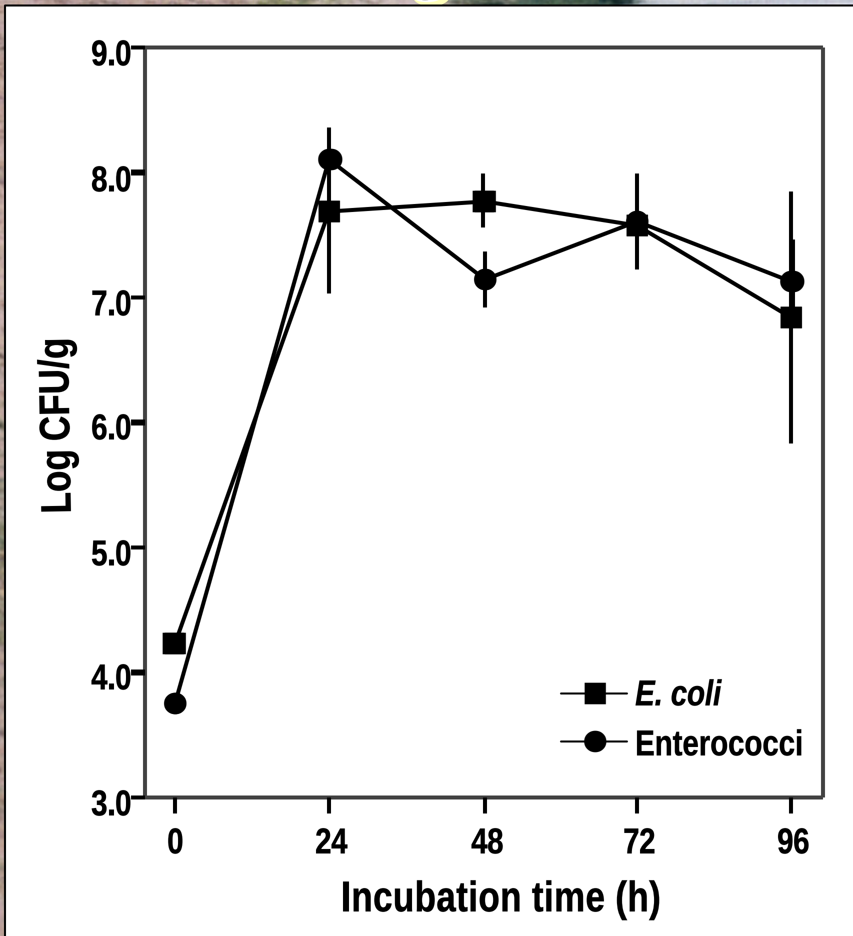
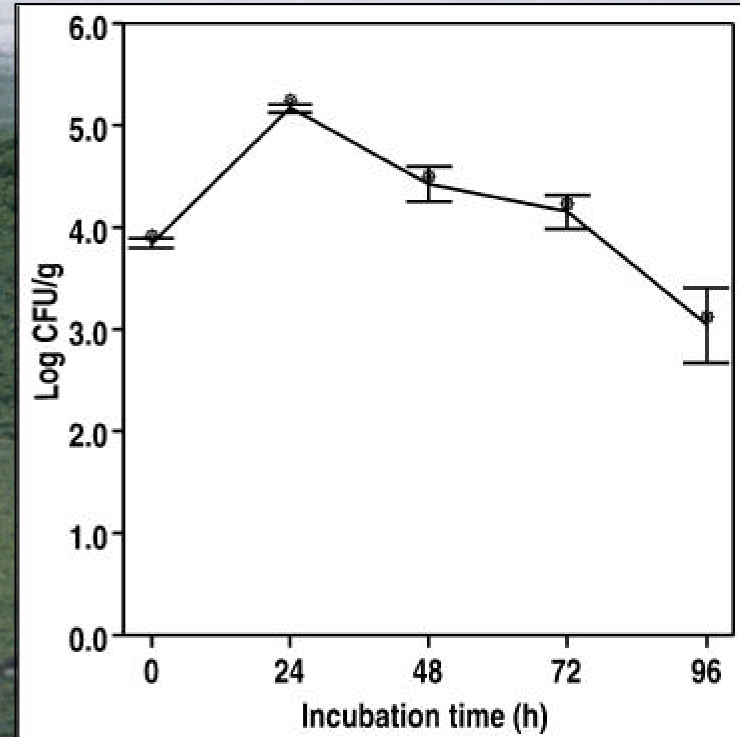
Cladophora Harbors *E. coli* and May Be Integrated into Foreshore Sand



Persistence of *E. coli* and enterococci in Cladophora mats



Growth of *E. coli* in *Cladophora*-laden sand

Byappanahalli, M. N., D. A. Shively, M. B. Nevers, M. J. Sadowsky, and R. L. Whitman. 2003. Growth and survival of *Escherichia coli* and enterococci populations in the macro-alga *Cladophora* (Chlorophyta). FEMS Microbiol. Ecol. 46:203–211.

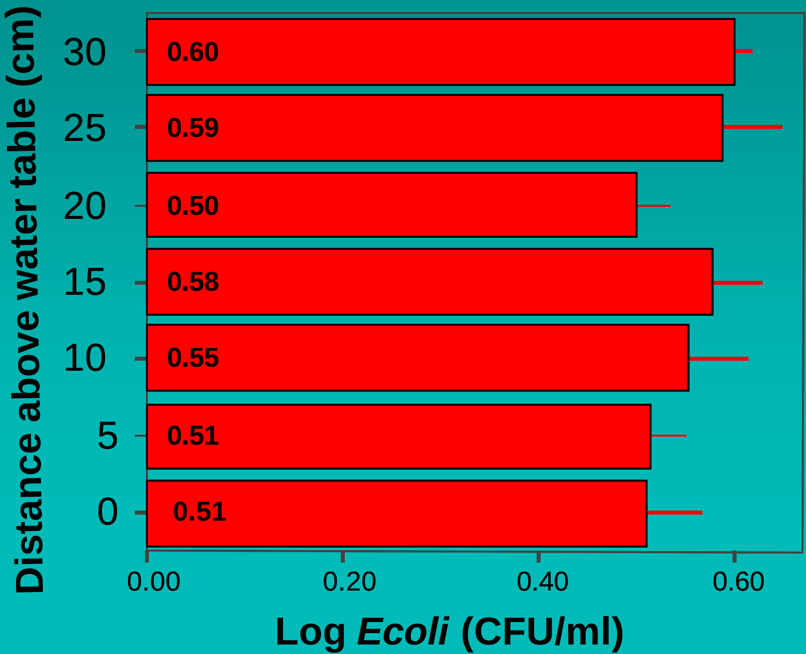
Gulls May Increase *E. coli* Concentrations in Sand and Beach Water

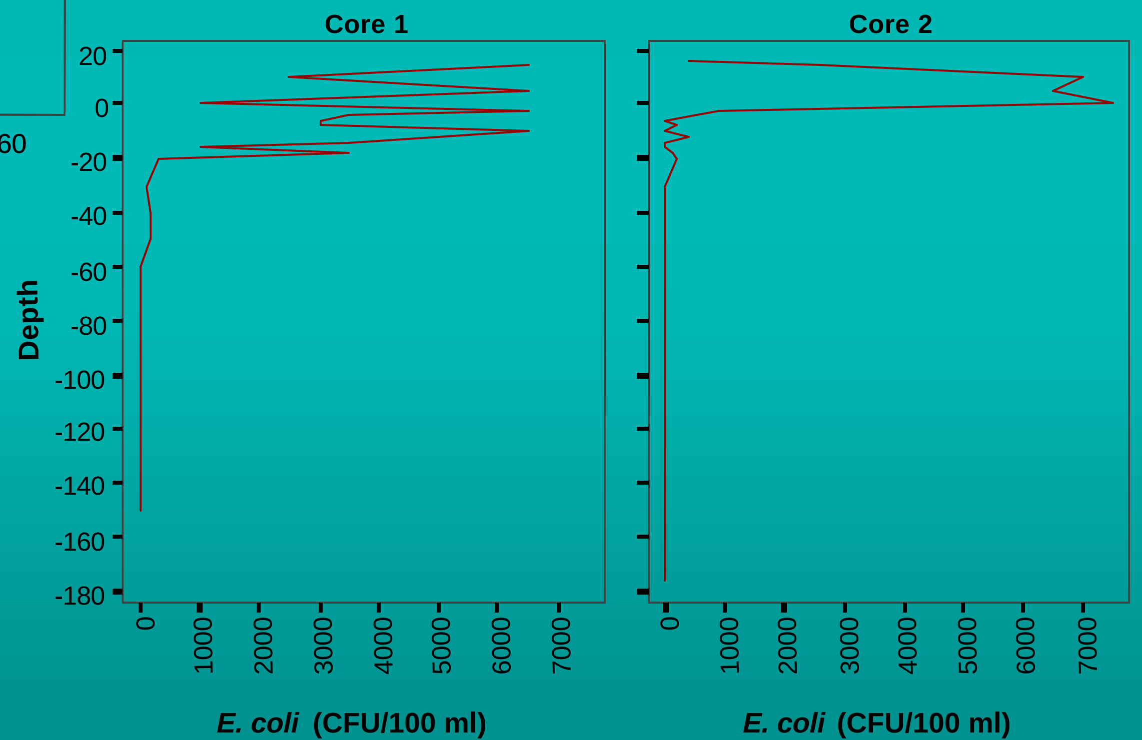
	# gulls unlagged, P values	# gulls lagged 1 day, P values
Foreshore sand	0.133	0.000*
Submerged sand	0.972	0.046
45 cm water AM	0.224	0.004*
90 cm water AM	0.037	0.001*
45 cm water PM	0.916	0.167
90 cm water PM	0.432	0.008

Critical p value Bonferroni corrected =0.006

Whitman, R.W., T.G. Horvath, M.L. Goodrich, M.B. Nevers, M.J. Wolcott and S.K. Haack. 2001. Characterization of *E. coli* levels at 63rd Street Beach. Report for City of Chicago.

Vertical Distribution of Sand *E. coli*





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E. coli in Sands Collected in Lake Water and 1 to 5 m Inland From Shore

ANOVA

Log *E. coli* (CFU) in sand per 100 cc					
	sum of squares	df	mean square	F	Sig.
Between groups	9.041	5	1.808	4.457	0.001
Within groups	57.609	142	0.406		
Total	66.65	147			

Log *E. coli* (CFU) in sand per 100 ml

Duncan			
Distance		Subset for alpha = 0.05	
	N	1	2
lake water	25	1.9526	
5 m	25		2.42
4 m	25		2.4761
3 m	25		2.5335
2 m	25		2.7252
1 m	23		2.6307

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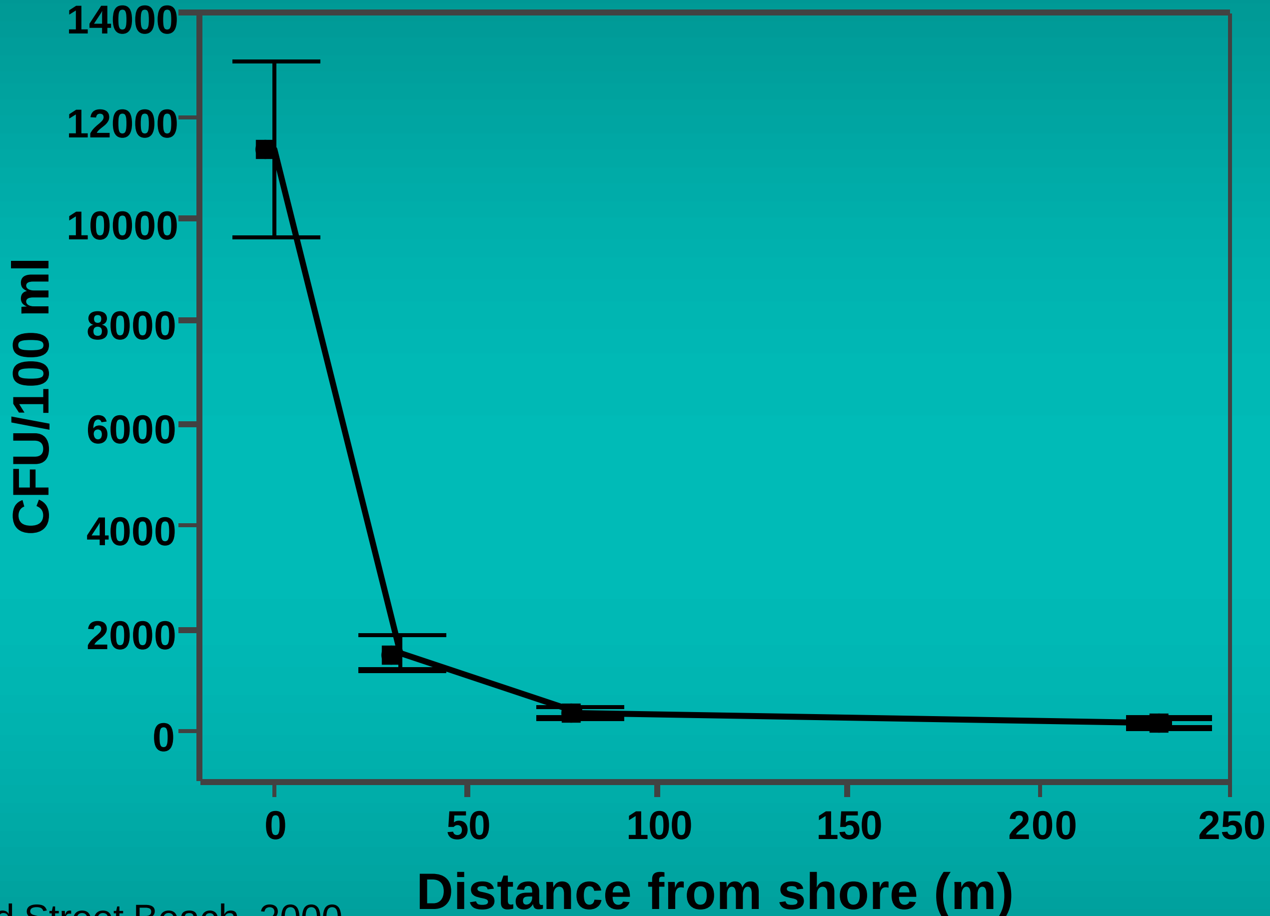
Adapted from: Whitman, R. L., M. B. Nevers and M. N. Byappanahalli. 2006. Examination of the Watershed-Wide Distribution of *Escherichia coli* along Southern Lake Michigan: an Integrated Approach. Appl. Environ. Microbiol. 72 (11): 7301–7310.

E. coli Concentrations are Highest in Sand and Diminish in Water With Distance From Shore



Chicago 63rd Street Beach, 2000

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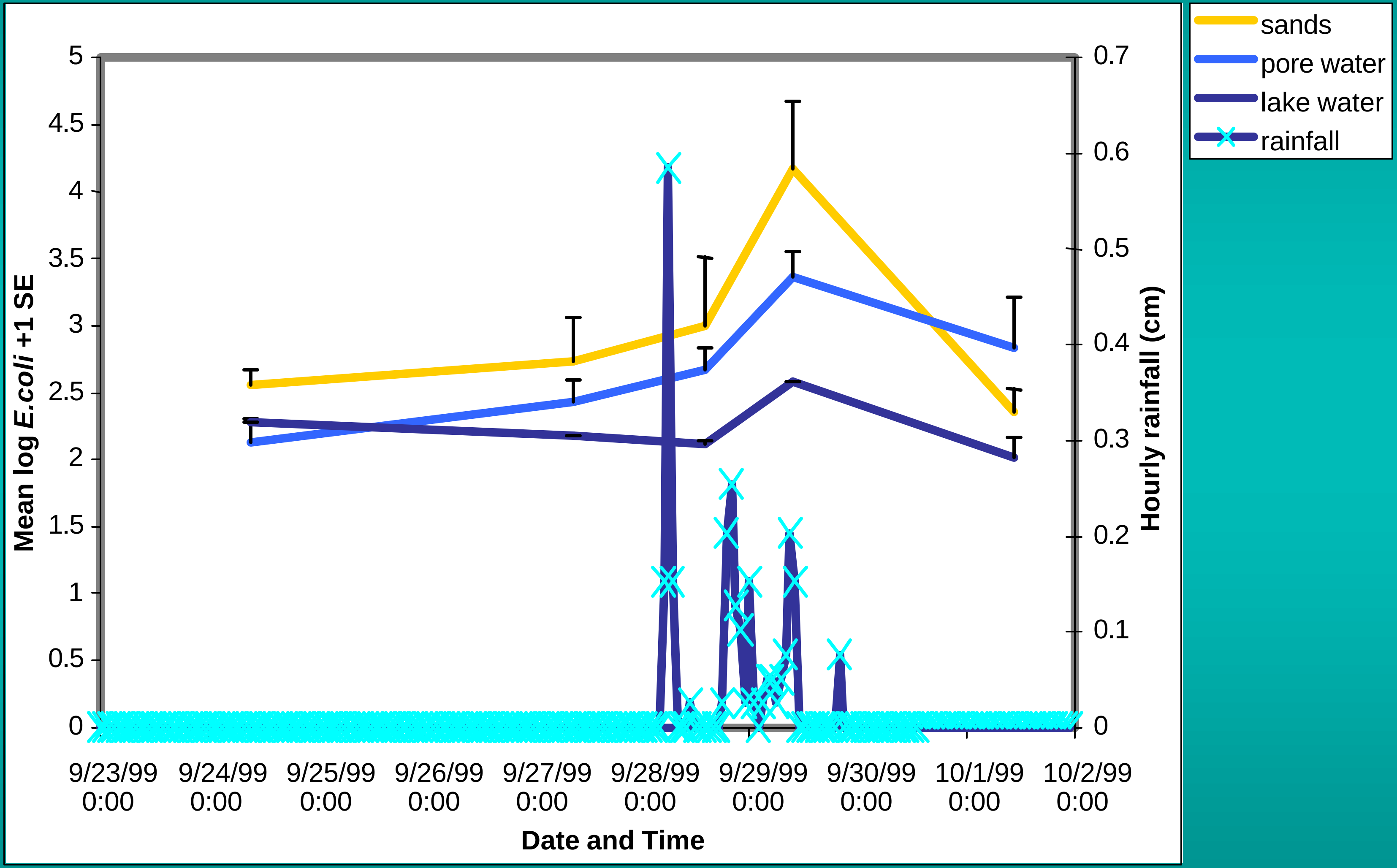
Whitman, R.L., Nevers, M.B., 2003. Foreshore sand as a source of Escherichia coli in nearshore water of a Lake Michigan beach. Appl. Environ. Microbiol. 69, 5555–5562.

E. coli Concentrations of Lake Water, Pore Water, and Sand With Rainfall



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Whitman R. L., M. B. Nevers and M. N. Byappanahalli. 2006. Examination of the Watershed-Wide Distribution of *Escherichia coli* along Southern Lake Michigan: an Integrated Approach. Appl. Environ. Microbiol. 72 (11): 7301–7310.

Nearshore Energy (waves and currents) Can Influence Sources

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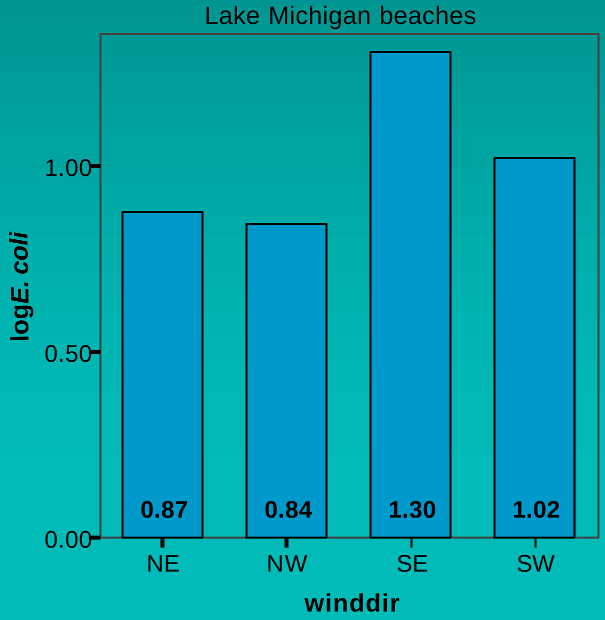
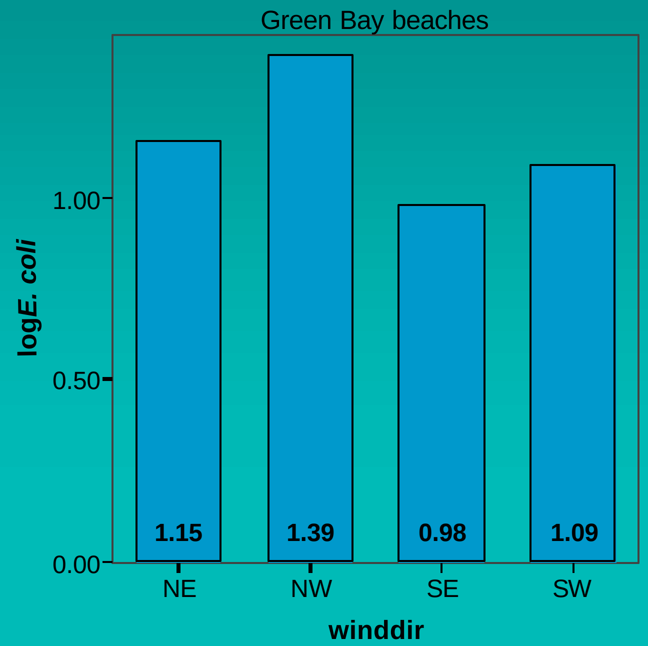
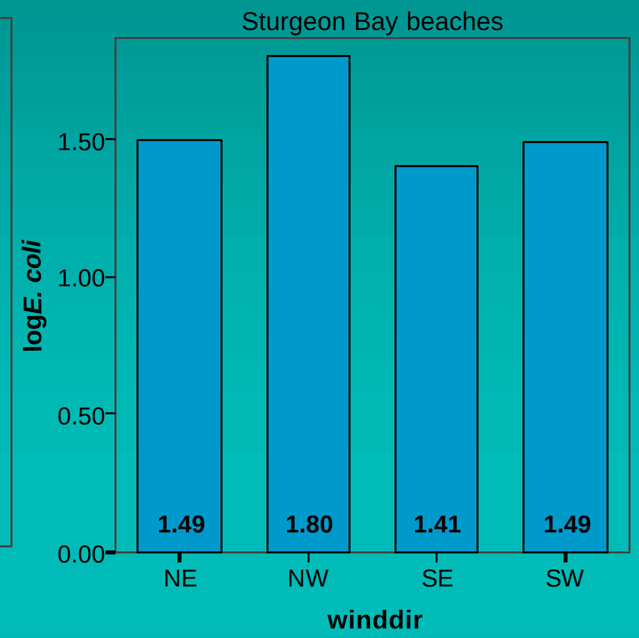
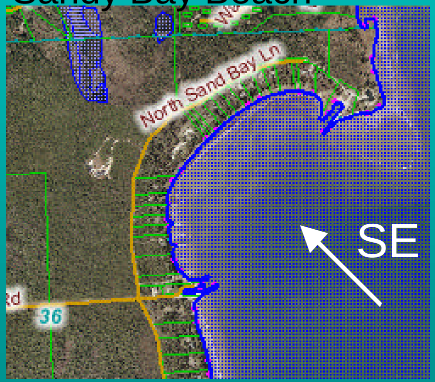
Impact of Wind Direction on Mean *E. coli* Counts





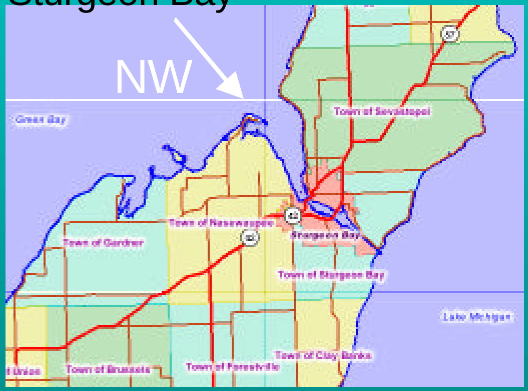


Sandy Bay Beach



Fish Creek Beach

Sturgeon Bay



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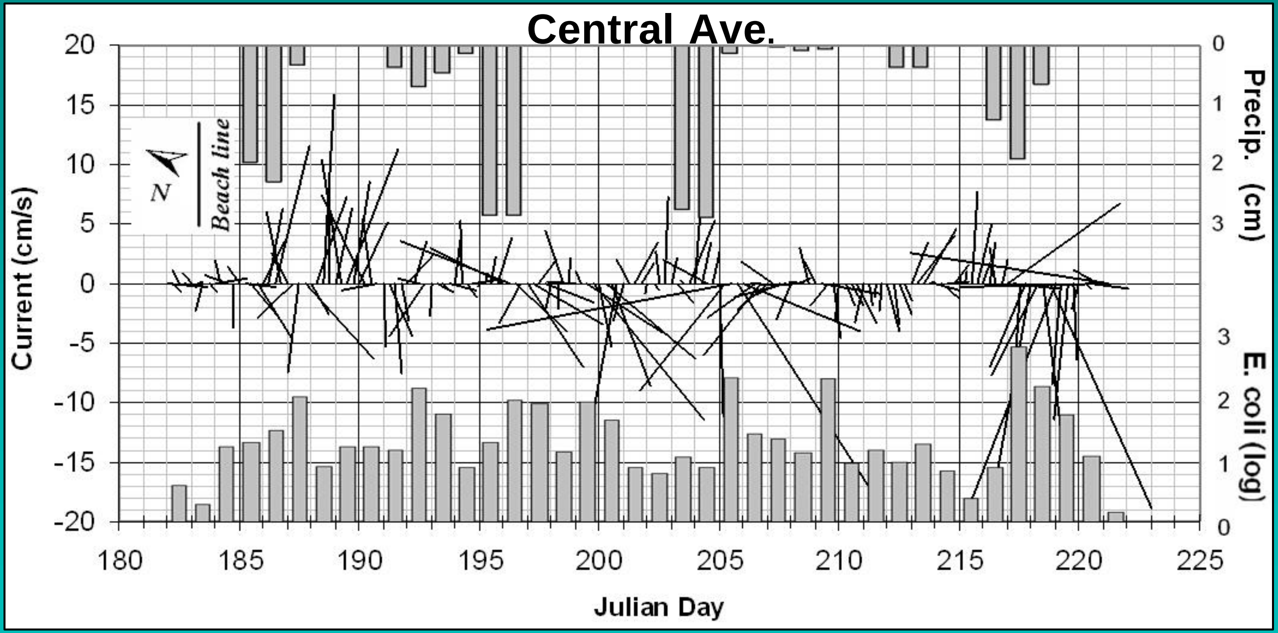
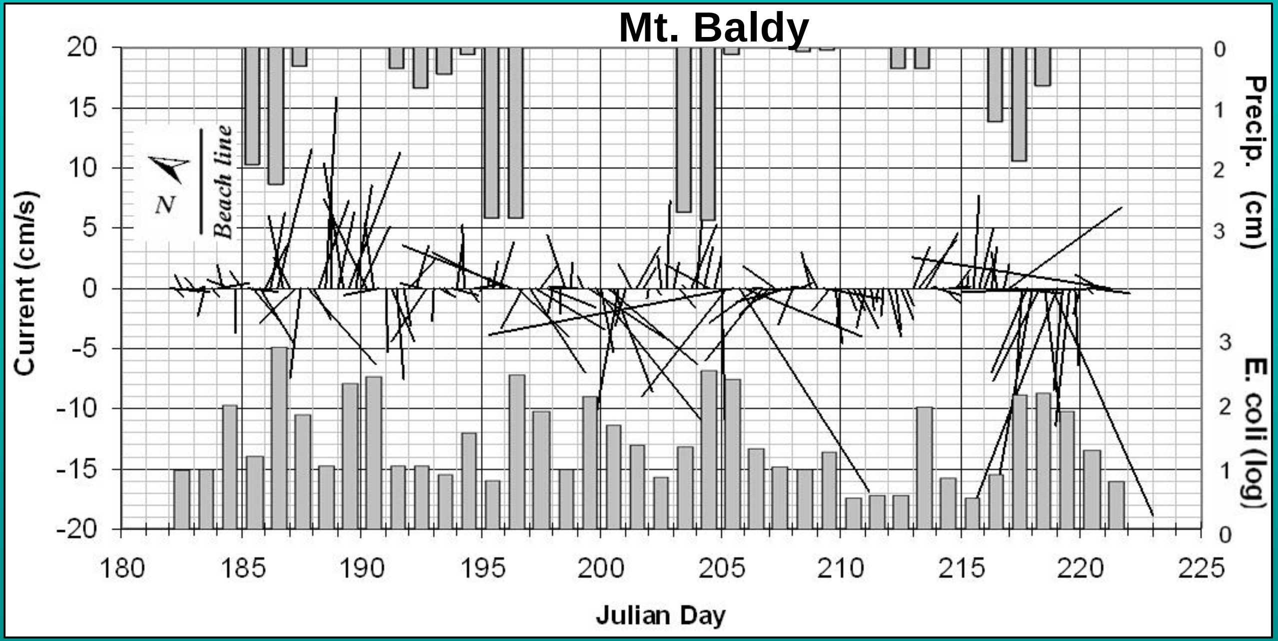
Whitman, R. L., M. B. Nevers. 2005. Recreational Water Quality of Door County Beaches 2003-2004: A Study of Factors Affecting *E. coli* Occurrence. Report to Door County Soil and Water Conservation Department.

Current Direction and *E. coli* Concentrations





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Adapted from: Nevers, M.B., R.L. Whitman, W. E. Frick, and G. Zhongfu. In Review. Concurrent influence of two coastal creeks on *E. coli* concentration at swimming beaches of southern Lake Michigan.

Conclusions

- **Stream outfalls are a source of FIB to beach water**
- **Sand is a sink or source of FIB to nearshore beach water**
- ***E. coli* commonly occurs and may grow in *Cladophora* mats**
- **Number of gulls on the beach shore impacts FIB concentrations in the sand**
- **Wind, waves, and currents influence sources**

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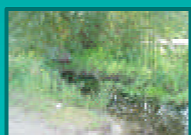
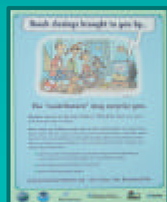
Partitioning of *E. coli* Within a Beachshed

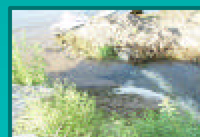
A Conceptual Diagram of *E. coli* Within and Between Stream and Beach Watersheds

Stream

Bacterial inputs from animal defecation, storm runoff, and human activities may be deposited to riparian soils and stream sediments, where they may colonize and persist.

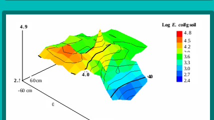




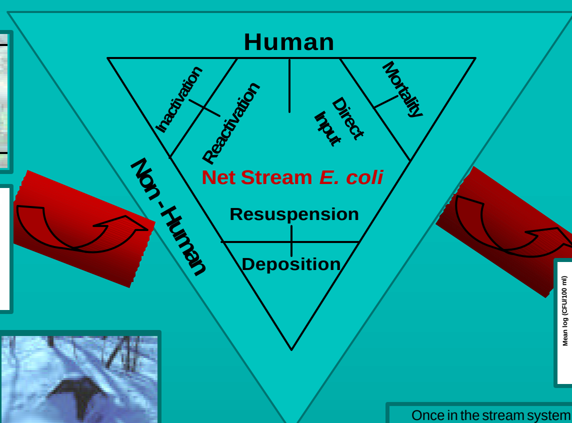


Days after sterilization	*E. coli* counts (MPN g^{-1})
-1	1.54×10^2
0	< 1
5	1.11×10^3
20	9.5×10^1
28	1.34×10^2
81	> 2.42×10^3
160	1.66×10^2
216	1.71×10^2
250	1.40×10^2
369	2.50×10^5

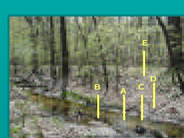
E. coli recolonization of forest soil in a 0.05 m^2 area



Distribution of *E. coli* five months after sterilization

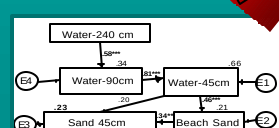


Once in the stream system, bacteria are in continual or episodic flux between exposed water and the submerged sediment, shore, and groundwater interface.

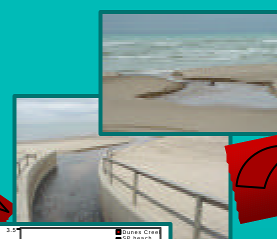


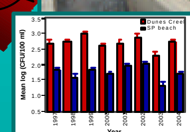
Stream Water-A
Stream Sand-B
Margin Sand-C
Sand (1 m from margin)-D
Soil (4 m from margin)-E

Future Challenge: Define Fluxes and Budgets



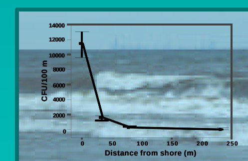
Stream to Lake



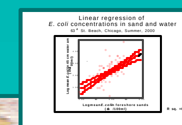


Animal and human waste and bacteria-laden plants can be integrated into foreshore sand. Resuspension can occur through wave action and runoff.

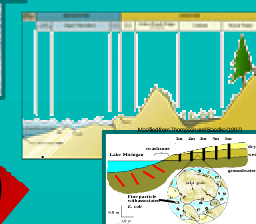
Lake

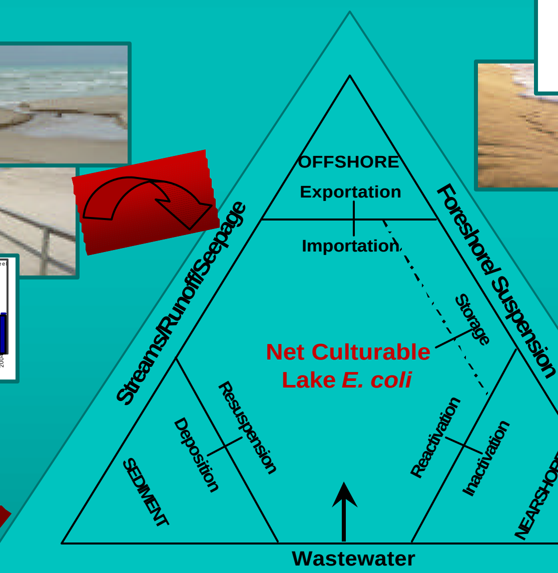


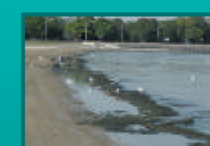
Nearshore energy (waves and currents) defines importation and exportation.

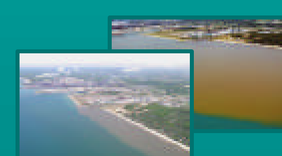


Sand harbors *E. coli* where it may persist and grow, making foreshore sand a potential sink or source to beach water.

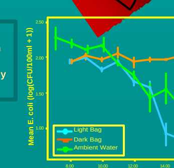


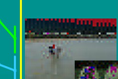






Sunlight inactivates *E. coli*; recovery and net increase from importation may cause diurnal, seasonal, daily and even hourly variation.





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Adapted from: Whitman, R. L., M. B. Nevers, and M. N. Byappanahalli. 2006. Watershed-wide distribution of *Escherichia coli* along southern Lake Michigan: An integrated approach. Applied and Environmental Microbiology. 72(11): 7301–7310.

science for a changing world

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