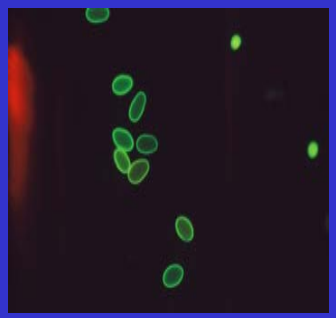
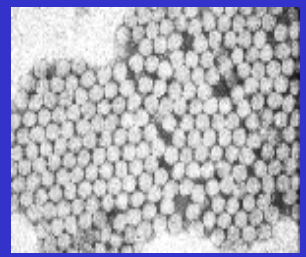
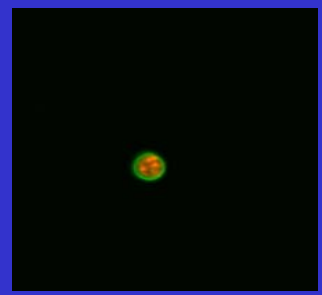
A Quantitative Microbial Risk Assessment Framework for the Great Lakes







Joan B. Rose
rosejo@msu.edu
Homer Nowlin Endowed Chair for Water Research
MICHIGAN STATE UNIVERSITY

The Great Lakes

- Provides drinking water for 60 million U.S. and Canadian citizens
- 90% of the U.S. surface supply of freshwater
- Lakes cover 94,000 square miles
- 56 billion gallons used daily for municipal, agricultural and industrial use

The Great Lakes

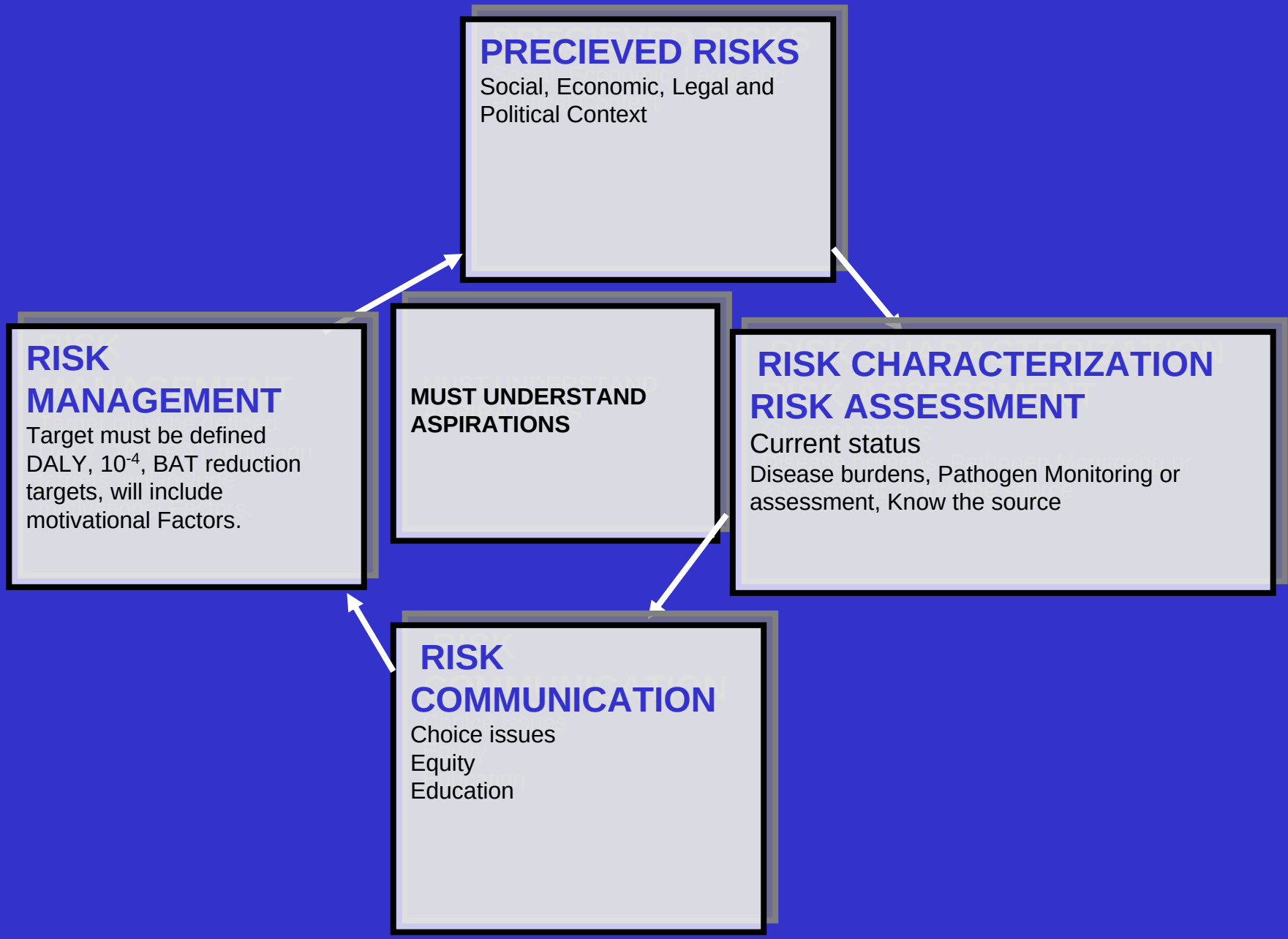
- 10,000 miles of coastline in 8 different states
- 1/10th the population of U.S. is in basin (Chicago, Detroit, Minneapolis, Milwaukee)
- $4 billion commercial and sport fishing industry
- Over 500 recreational beaches

Challenges

- **Beach closures**
- **Nonpoint source pollution**
- **Small water systems**
  - **Groundwater protection**
  - **Septic systems**
- **Lakes & streams impairment (nutrients and Bacteria)**
- **Invasive Species**

Definitions used in risk analysis

Risk assessment	The qualitative or quantitative characterization and estimation of potential adverse health effects associated with exposure of individuals or populations to hazards (materials or situations, physical, chemical and or microbial agents.)
Risk management	The process for controlling risks, weighing alternatives, selecting appropriate action, taking into account risk assessment, values, engineering, economics, legal and political issues.
Risk communication	The communication of risks to managers, stakeholders, public officials, and the public, includes public perception and ability to exchange scientific information.


PRECIEVED RISKS
Social, Economic, Legal and Political Context
RISK MANAGEMENT
Target must be defined DALY, 10^{-4}, BAT reduction targets, will include motivational Factors.
MUST UNDERSTAND ASPIRATIONS
RISK CHARACTERIZATION
RISK ASSESSMENT
Current status
Disease burdens, Pathogen Monitoring or assessment, Know the source
RISK COMMUNICATION
Choice issues
Equity
Education

Risk assessment is a method to examine qualitatively or quantitatively the potential for harm from exposure to contaminants or specific hazards.

- Monitoring and data are some of the keys to establishing risks and therefore safety goals.

Quantitative Risk Assessment QRA

- Tool used to estimate adverse health effects associated with specific hazards.
- Elicits a statistical estimate or probability of harm.
- Used for risk management decisions.

NATIONAL ACADEMY OF SCIENCES RISK ASSESSMENT PARADIGM

- **HAZARD IDENTIFICATION**
  Types of microorganisms and disease end-points
- **DOSE-RESPONSE**
  Human feeding studies, clinical studies, less virulent microbes and health adults
- **EXPOSURE**
  Monitoring data, indicators and modeling used to address exposure
- **RISK CHARACTERIZATION**
  Magnitude of the risk, uncertainty and variability

Evolution of QMRA

<1980

Indicator approaches used
Suggesting that some level of contamination below which one is safe

1980's

Initial Dose Response Concepts
Application in development of EPA Rules

1988

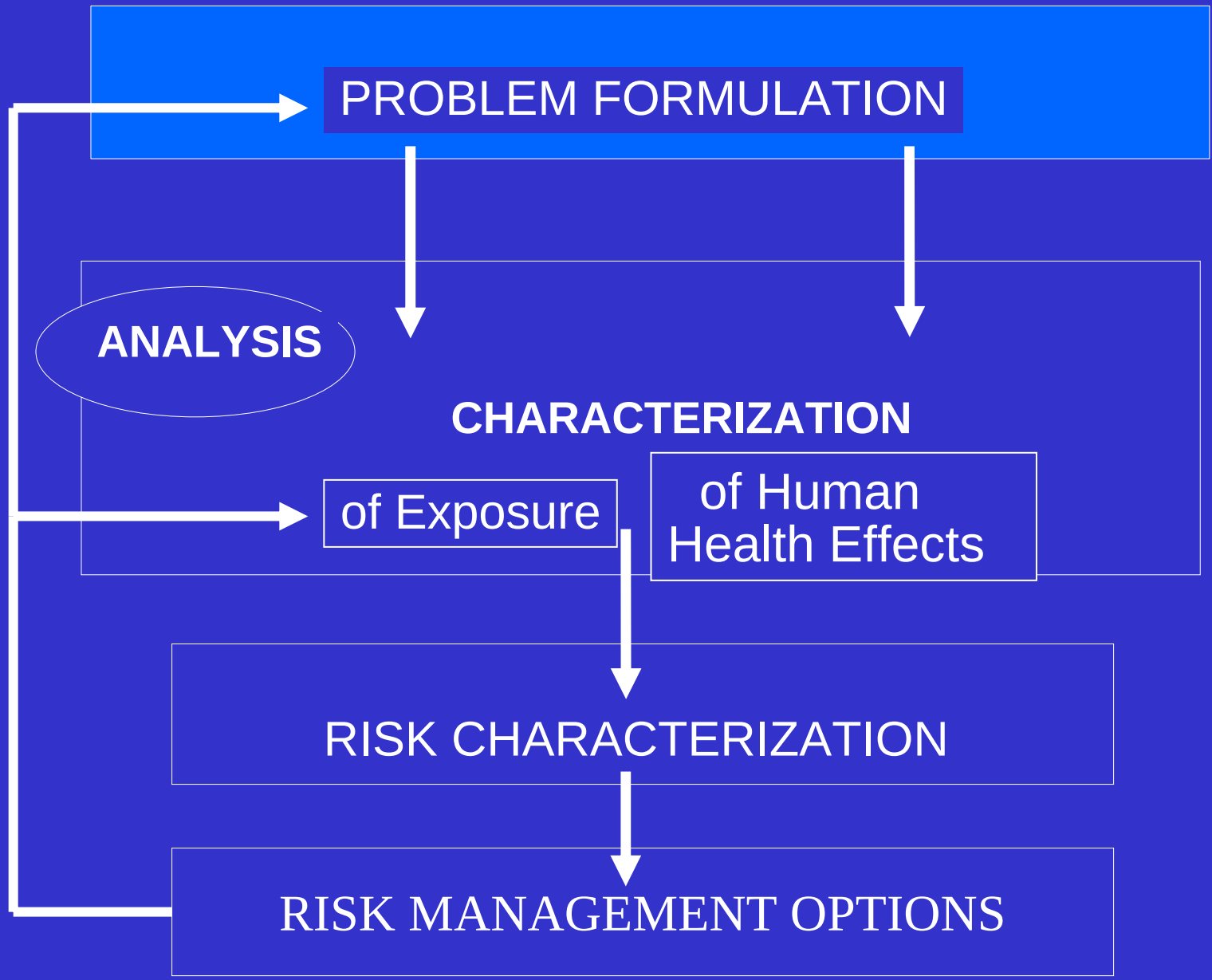
Dose-response for Giardia, viruses in Water.

1990

Adoption for food safety
WHO food and water consultations
Dynamic model applications
ILSI framework documents

2000's

Air and Home Land Security applications
Reg framework development
Population sensitivities


PROBLEM FORMULATION
ANALYSIS
CHARACTERIZATION
of Exposure
of Human Health Effects
RISK CHARACTERIZATION
RISK MANAGEMENT OPTIONS

ANALYSIS PHASE

Exposure Analysis

Health Effects

Disease

Severity

Secondary spread

Pathogen Occurrence (detection/survival and spread)

Dose-Response

Exposure Profile

Host Pathogen Profile

The Problem Formulation

Microbial Risks

PLAGUES

CONTAGION

EPIDEMICS

OUTBREAKS

1914

International Joint Commission Study

WATER QUALITY AGREEMENT

"Between 1912 and 1914 a massive bacteriological study of pollution in the boundary waters of the United States and Canada was conducted by the International Joint Commission: it was followed by another study of current and proposed sewage work. The findings of transboundary pollution from the bacteriological study led to a draft treaty on pollution in 1920. **The bacteriological work was flawless.**"

Durfee and Bagley 1997

1914 IJC Bacteriological Study

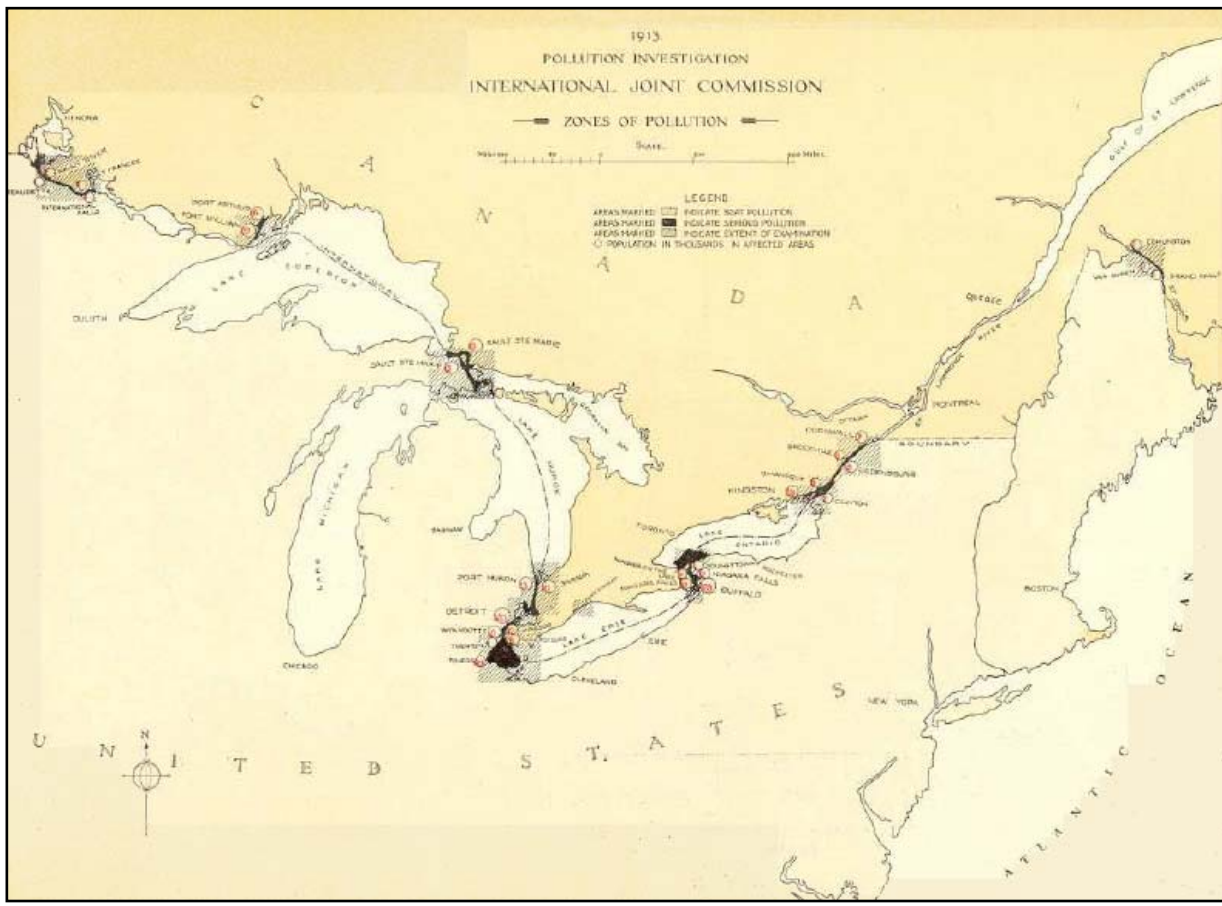
- Major Findings
  - **Municipal drinking water supplies were not safe – water intakes were located in highly polluted waters and water was not adequately treated**
  - **Current sewage/drinking water treatment technologies were limited and expensive to implement**

•Recommendations for remediation of polluted waters:

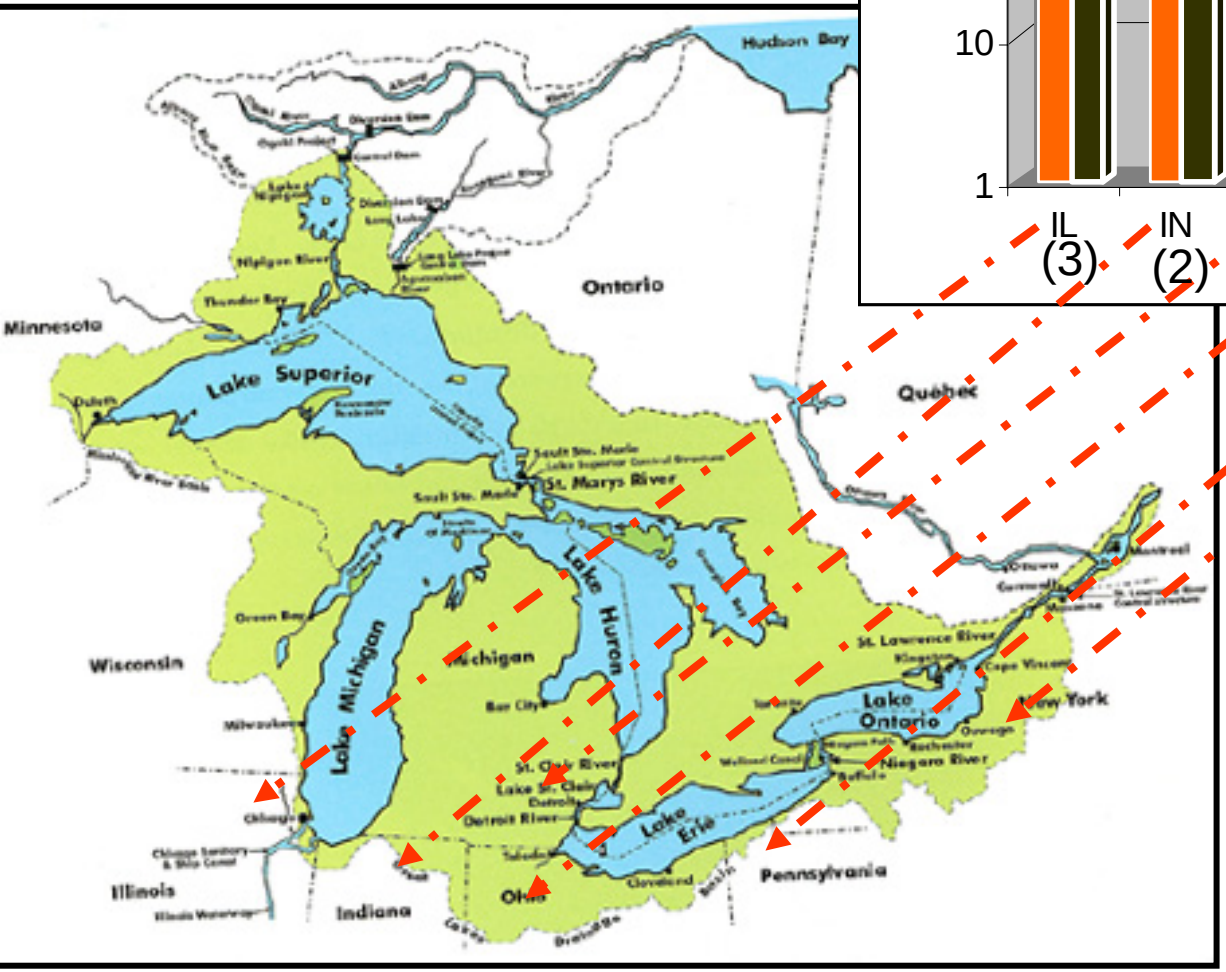
1. Prohibit discharge of untreated sewage/ship ballast into boundary waters

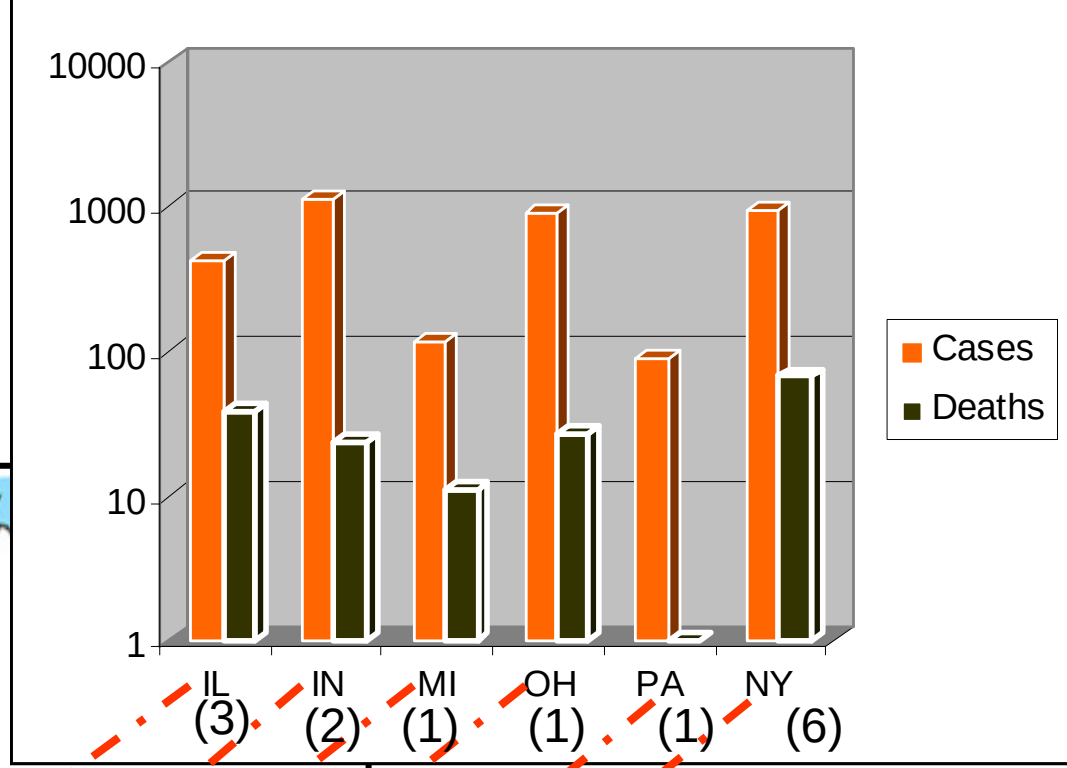
2. Discharge limit for *B. coli* (annual mean 500/100ml)

3. Prohibit/restrict discharge of garbage, sawmill and industrial wastes



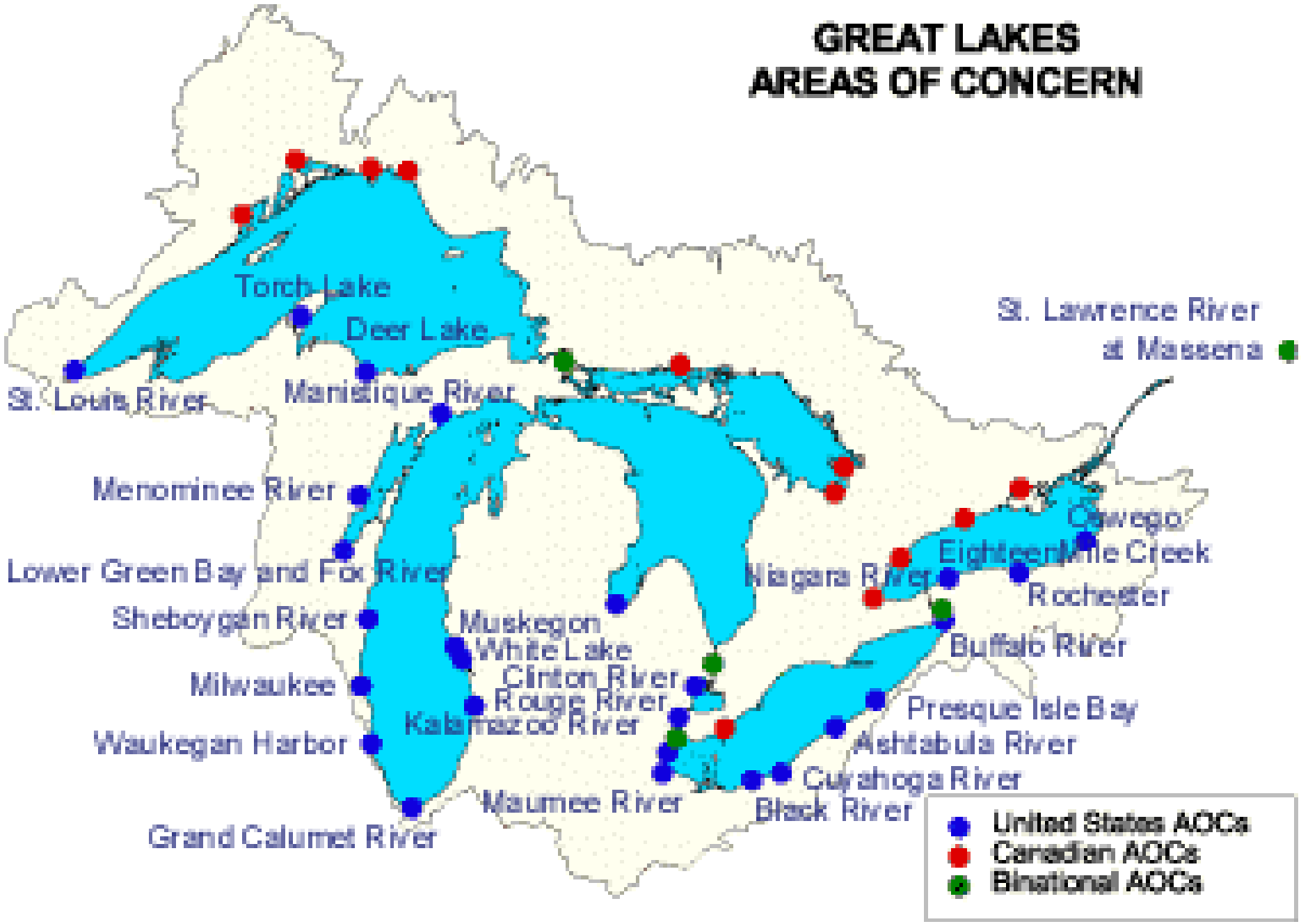
- **Largest Reported Typhoid Outbreaks in the US 1920-1929**





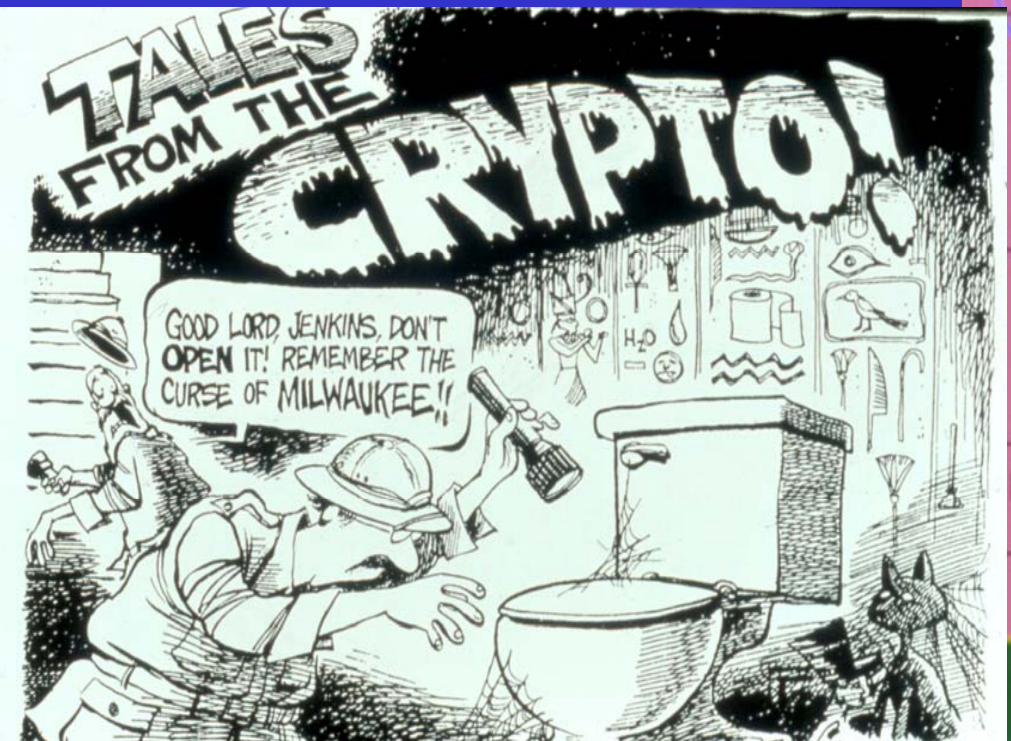
14 of top 25 outbreaks

(Wolman and Gorman, 1931)

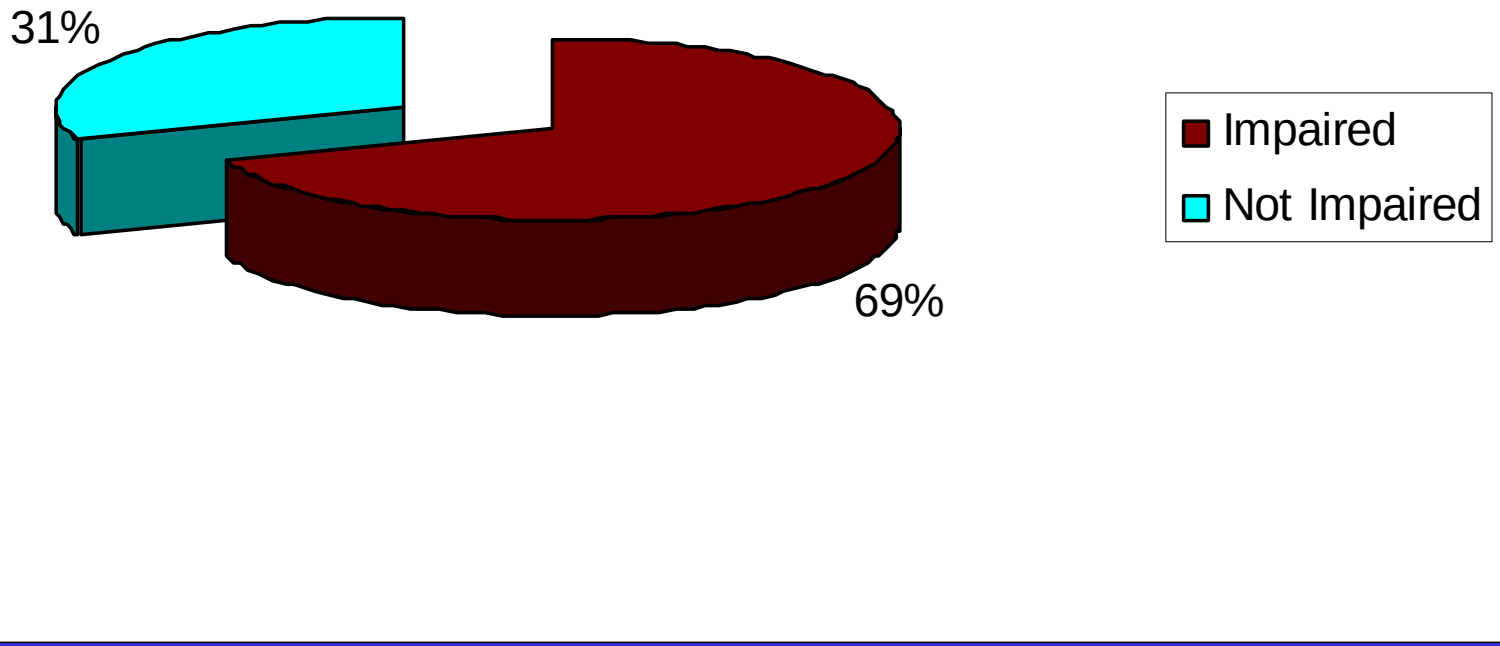

GREAT LAKES
AREAS OF CONCERN
Torch Lake
Deer Lake
St. Louis River
Manistique River
Menominee River
Lower Green Bay and Fox River
Sheboygan River
Muskegon
White Lake
Milwaukee
Clinton River
Rouge River
Kalamazoo River
Waukegan Harbor
Maumee River
Grand Calumet River
Black River
Cuyahoga River
Ashtabula River
Presque Isle Bay
Buffalo River
Niagara River
Eighteenmile Creek
Rochester
Oswego
St. Lawrence River
at Massena
United States AOCs
Canadian AOCs
Binational AOCs

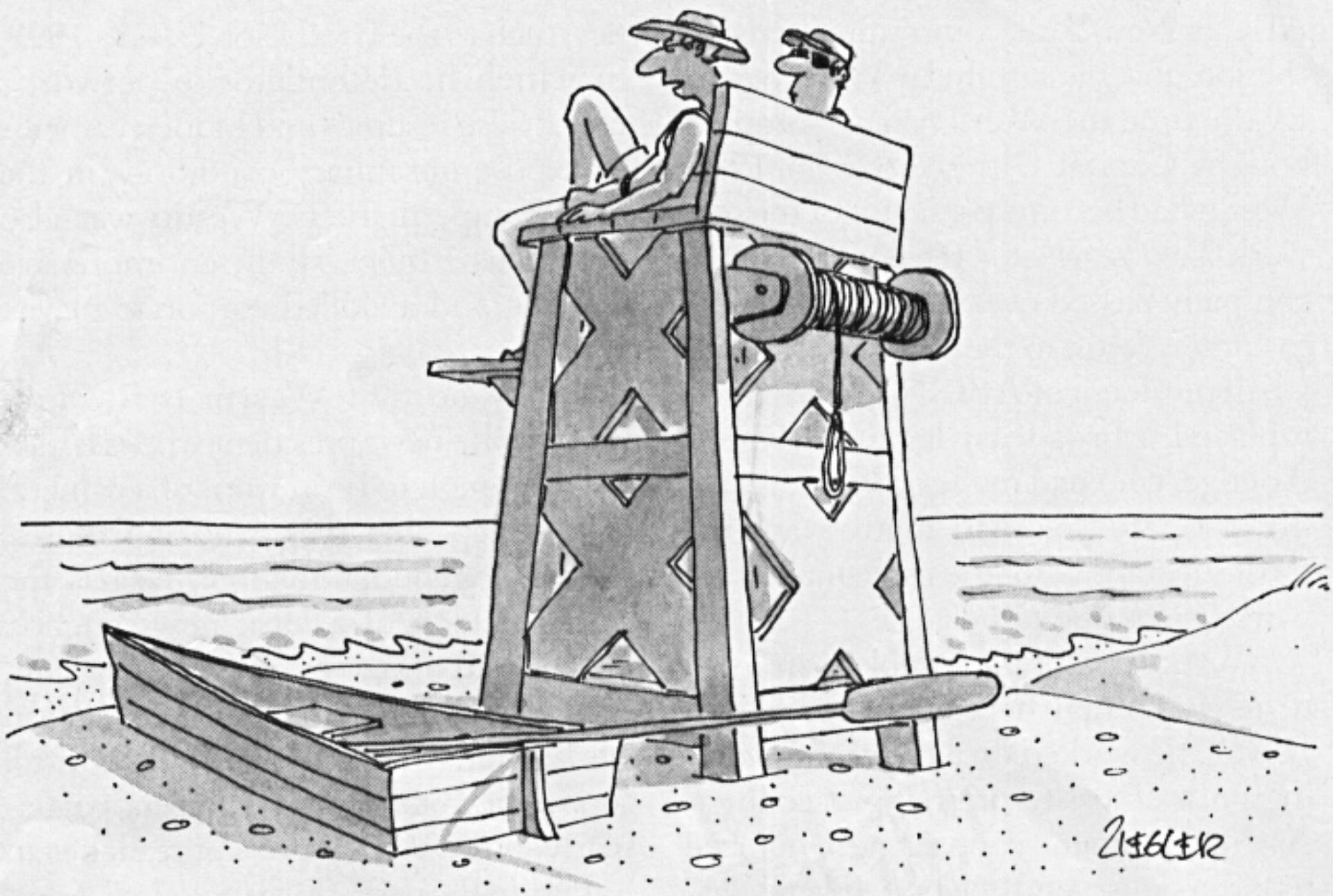
Emerging Waterborne Disease Of the 21st Century: Largest outbreak In the US 1993.

- 400,000 people ill (50% of the population) 100 died
- Cattle & Sewage blamed
- Water met all requirements Under the Safe Drinking Water Act

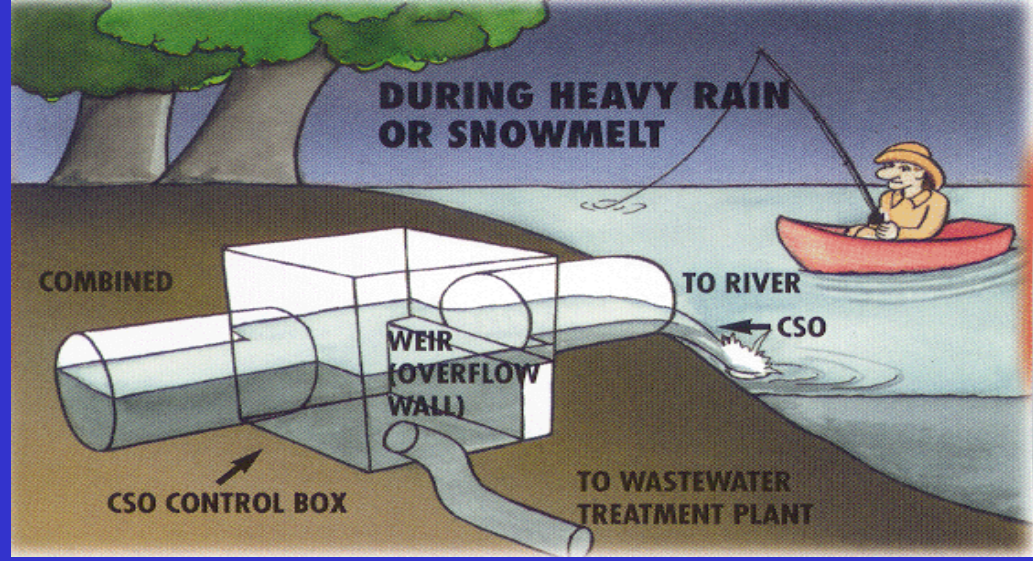


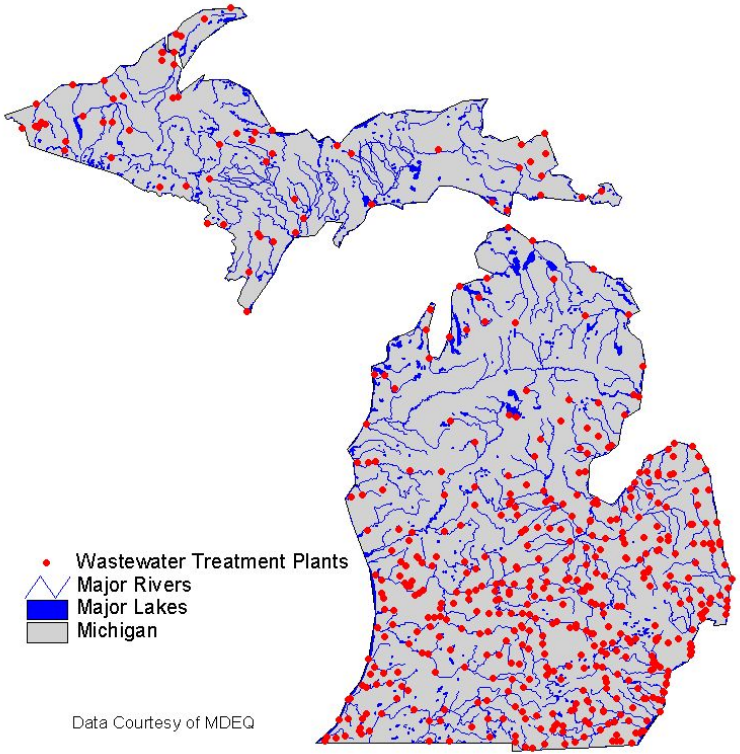
Recreational Water Impairment in the AOCs



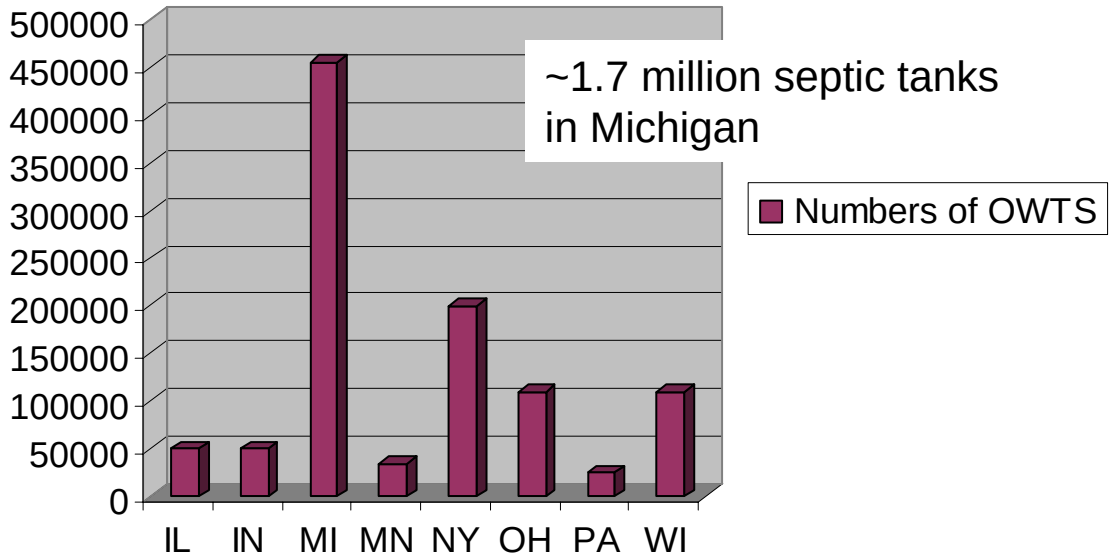


"I adore the beauty and tranquillity of these raw-sewage days."

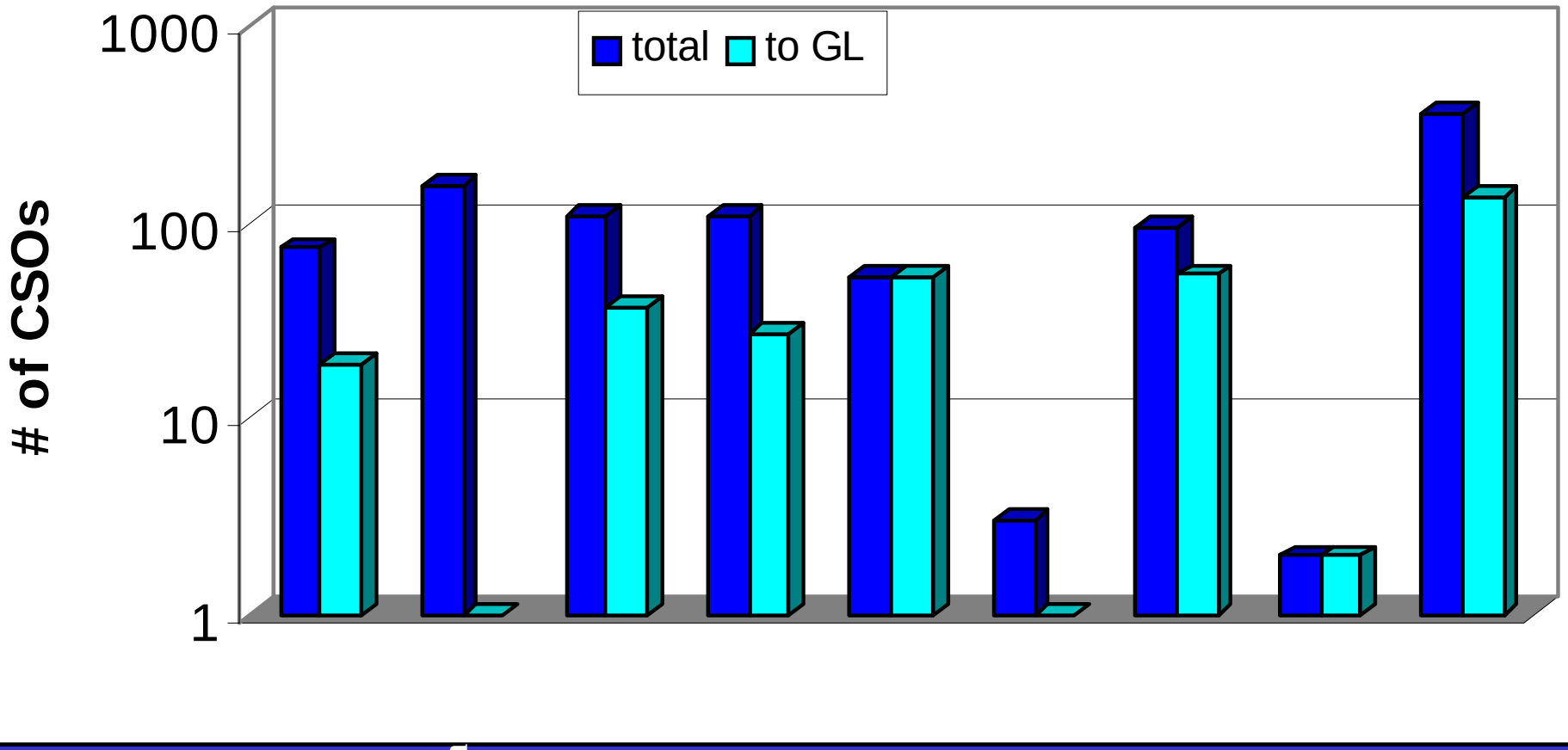




On site Wastewater Systems in the Great Lakes



CSOs in the Great Lakes Region

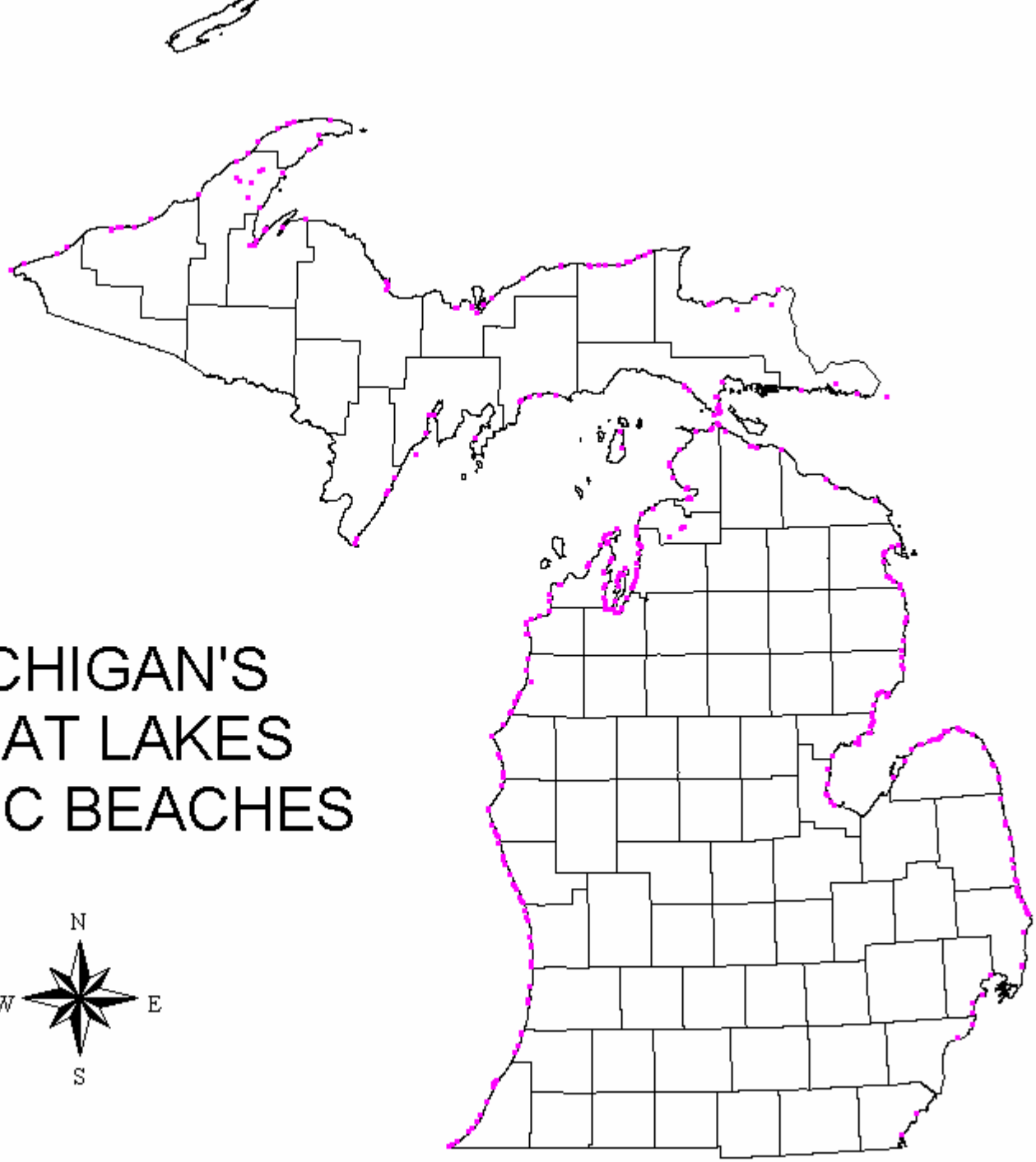


- > 18,000 days of closings and advisories at USA beaches in 2003
- ~20,000 days of closings in 2004
- Fecal pollution indicators, give no indication as to the source of fecal pollution.
- In Michigan in 2004, 27 billion gallons of a sewage-storm water mix was dumped into the Great Lakes
- 2005 Michigan communities

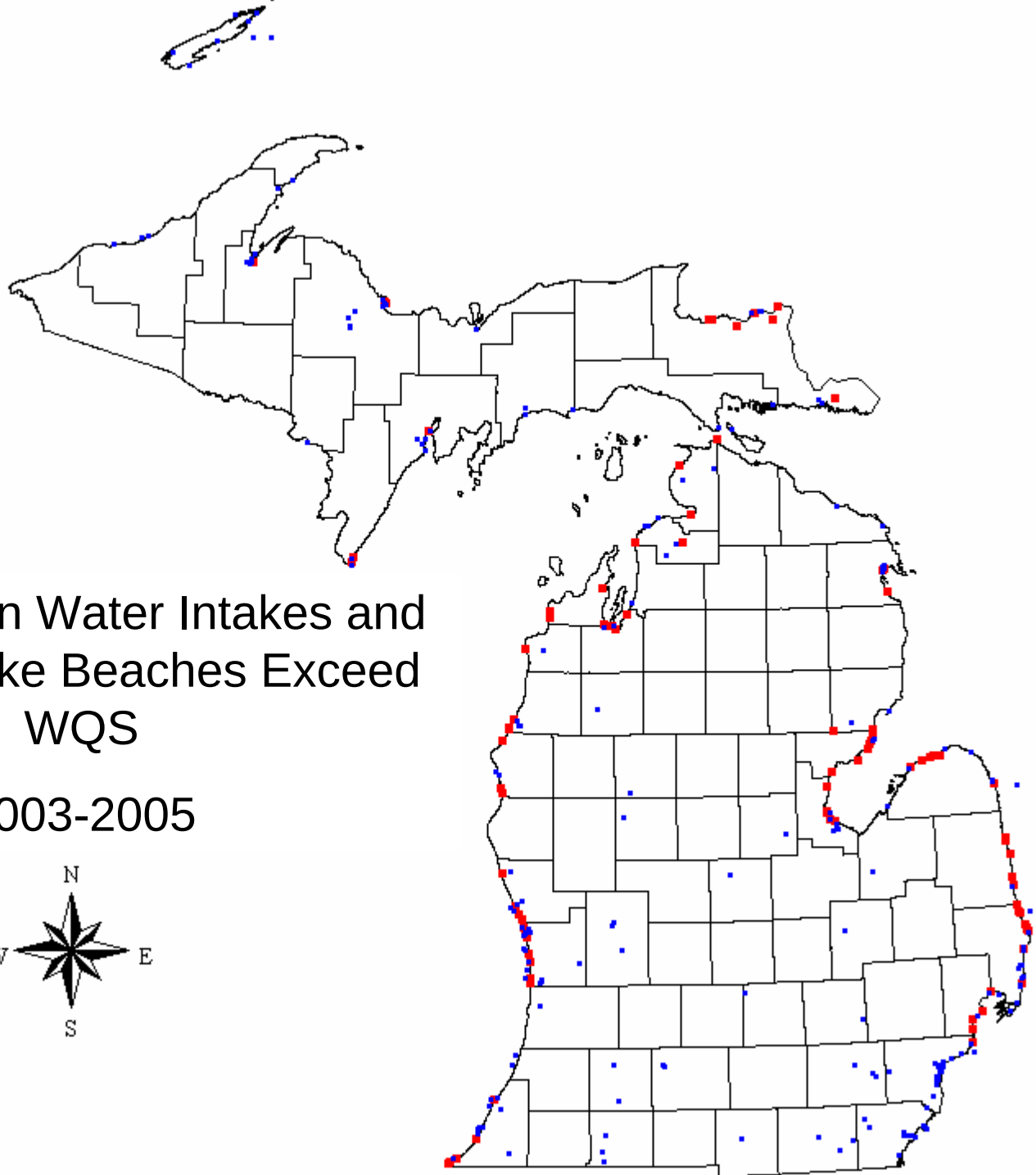
reported 338 sanitary sewer

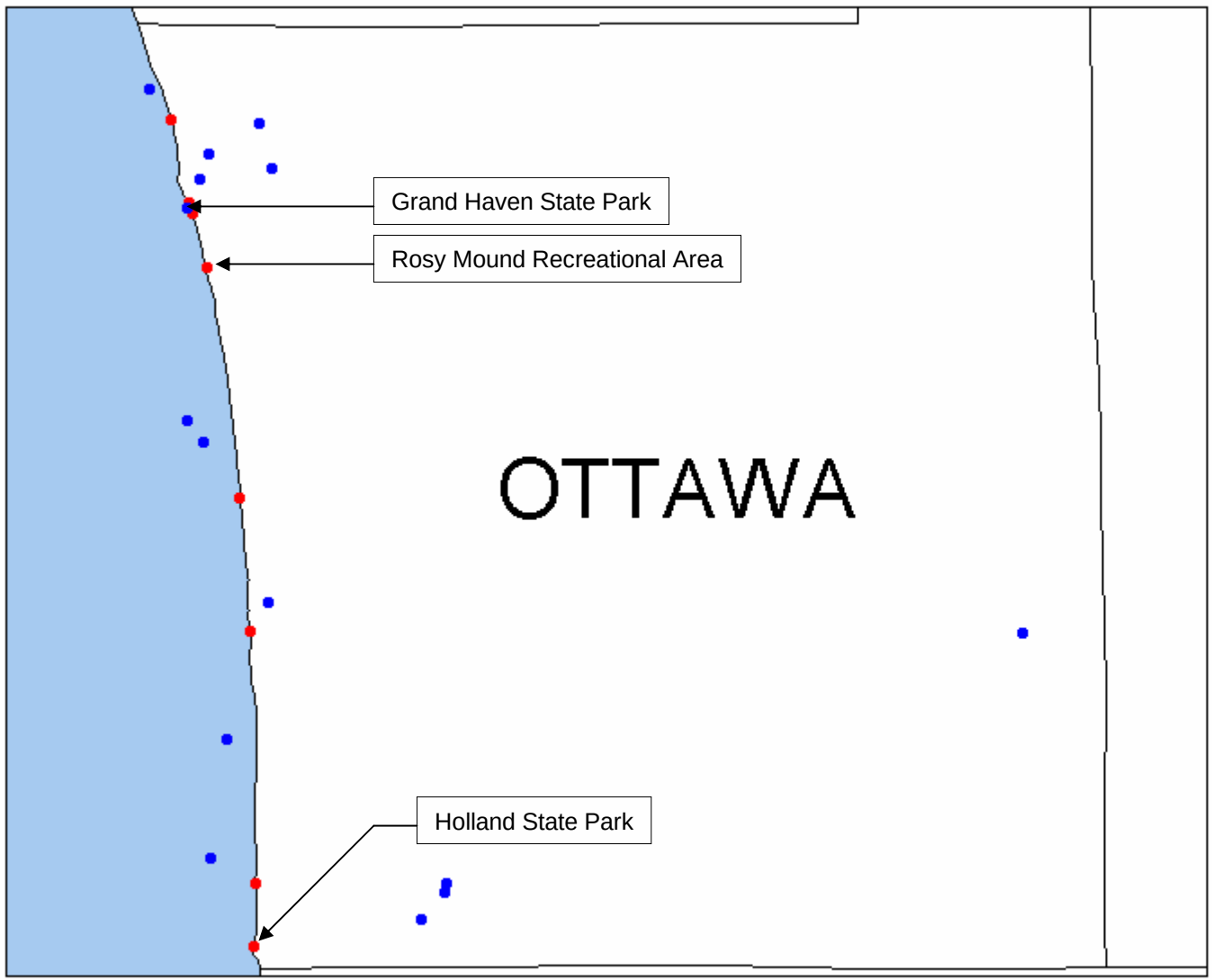
overflows 147 MG

raw sewage into the GL



N=412 Beaches

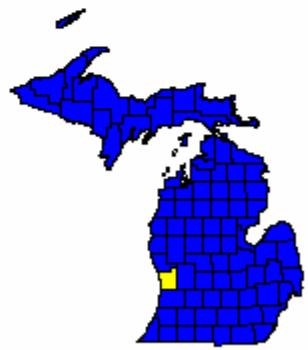

219 Michigan Water Intakes and
96 Great Lake Beaches Exceed
WQS
2003-2005
N
W
E
S



WATER INTAKE

BEACHES THAT EXCEEDED WQS

N
W
E
S



8 Exceedance sites

15 Water Intake sites

The HAZARDS

Emerging Biological Hazards

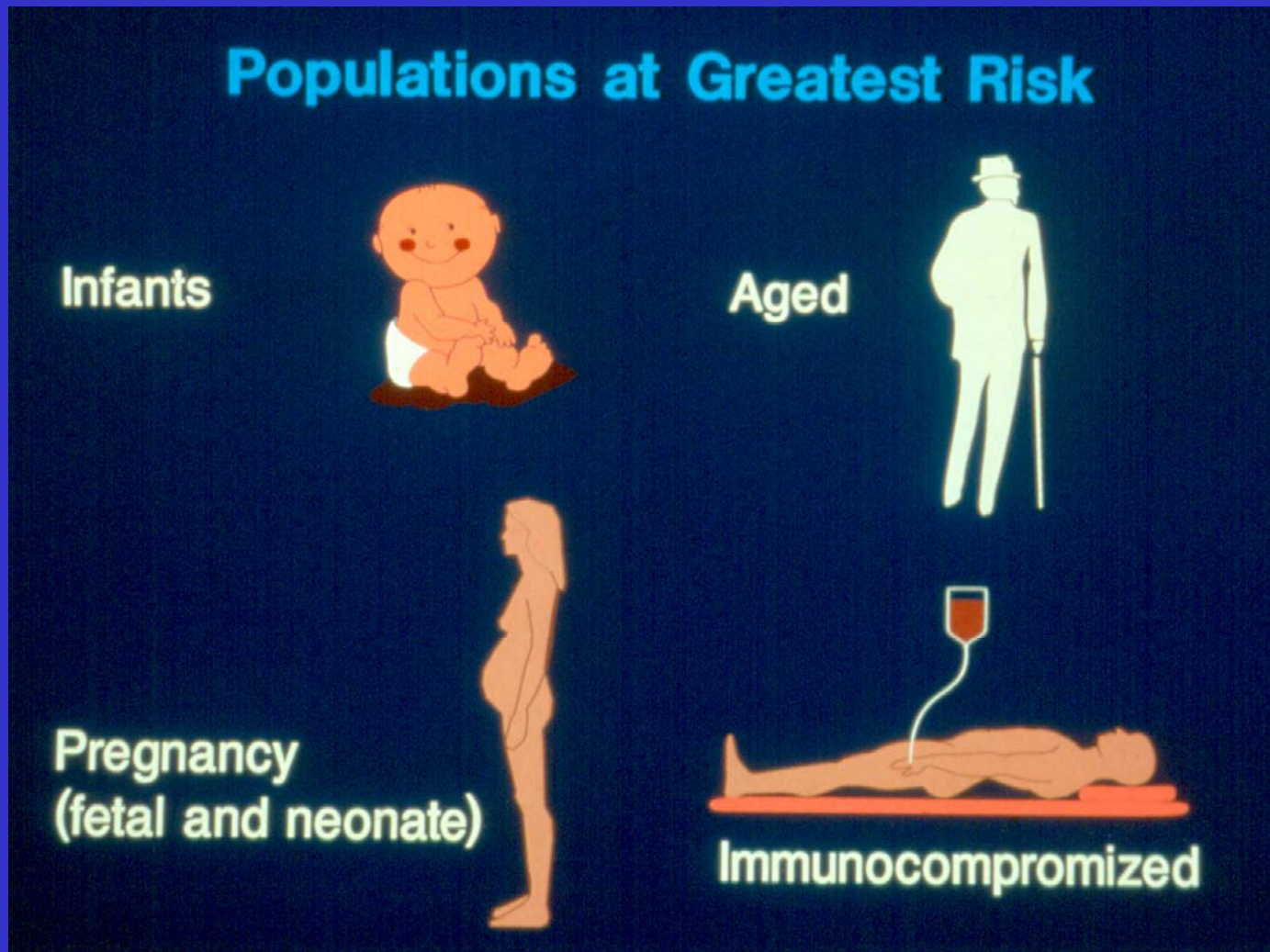
- Viruses, prions, bacteria, and protozoa are more likely than fungi or helminths to be associated with emerging infections.
- Zoonotic pathogens comprise 75% of emerging infectious diseases.
- Pathogens which are subject to relatively frequent mutation or genomic reassortment events (e.g. RNA viruses and viruses with segmented genomes) are more likely to emerge.
- Pathogens which infect multiple hosts or pathogens that infect species that can harbour multiply closely related agents providing an opportunity for reassortment or recombination (e.g. SARS in cats) are likely to emerge.
- Agents transmissible by more than one route or by indirect contact, e.g. water, food, environmental contamination, vectors, etc, are likely to emerge.

Acute and Chronic Outcome Associated with Microbial infections

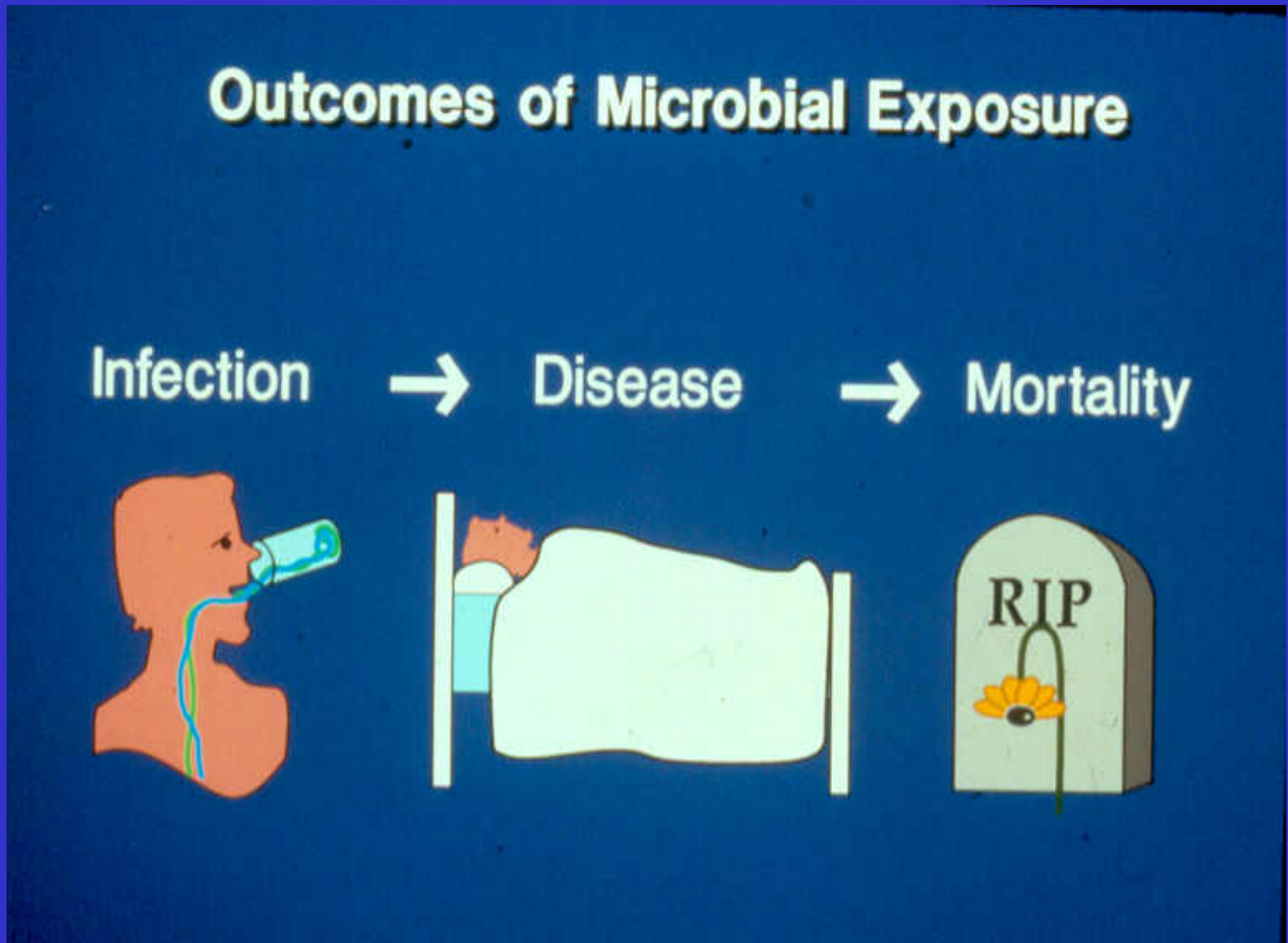
	Acute disease	**Chronic disease**
Microorganism	**Outcomes**	**Outcomes**
Campylobacter	Diarrhea	Gullain-Barre' syndrome
E. Coli 015H7	Diarrhea	Hemolytic uremic syndrome
Helicobacter	Gastritis	Ulcers and stomach cancer
Salmonella, Shigella, & Yersinia	Diarrhea	Reactive arthrititis
Coxsackievirus B *Adenoviruses*	Encephalitis, aseptic Meningitis, diarrhea, respiratory disease	Diabetes Myocarditis Obesity
Giardia	Diarrhea	Failure to thrive, lactose intolerance, chronic joint pain
Toxoplama	Newborn syndrome, hearing and visual loss	Mental retardation, dementia, seizures

Morbidity and Mortality greater in the Sensitive Populations
30% of our populations Fall into one of the Sensitive Populations at any one time.

ZOONOTIC
AGENTS
OPPORTUNISTIC
AGENTS
EFFECT
THIS
GROUP



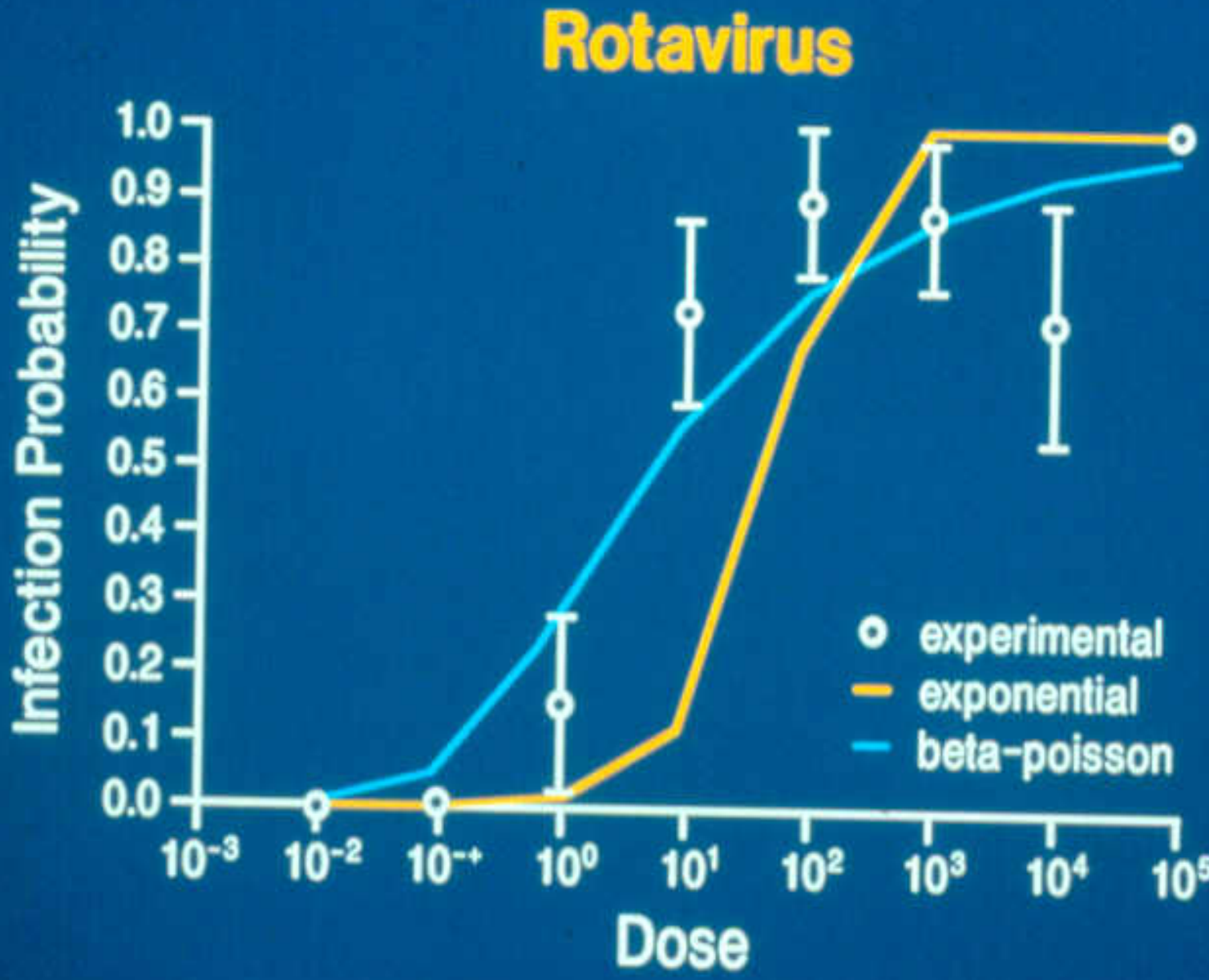
DOSE-RESPONSE



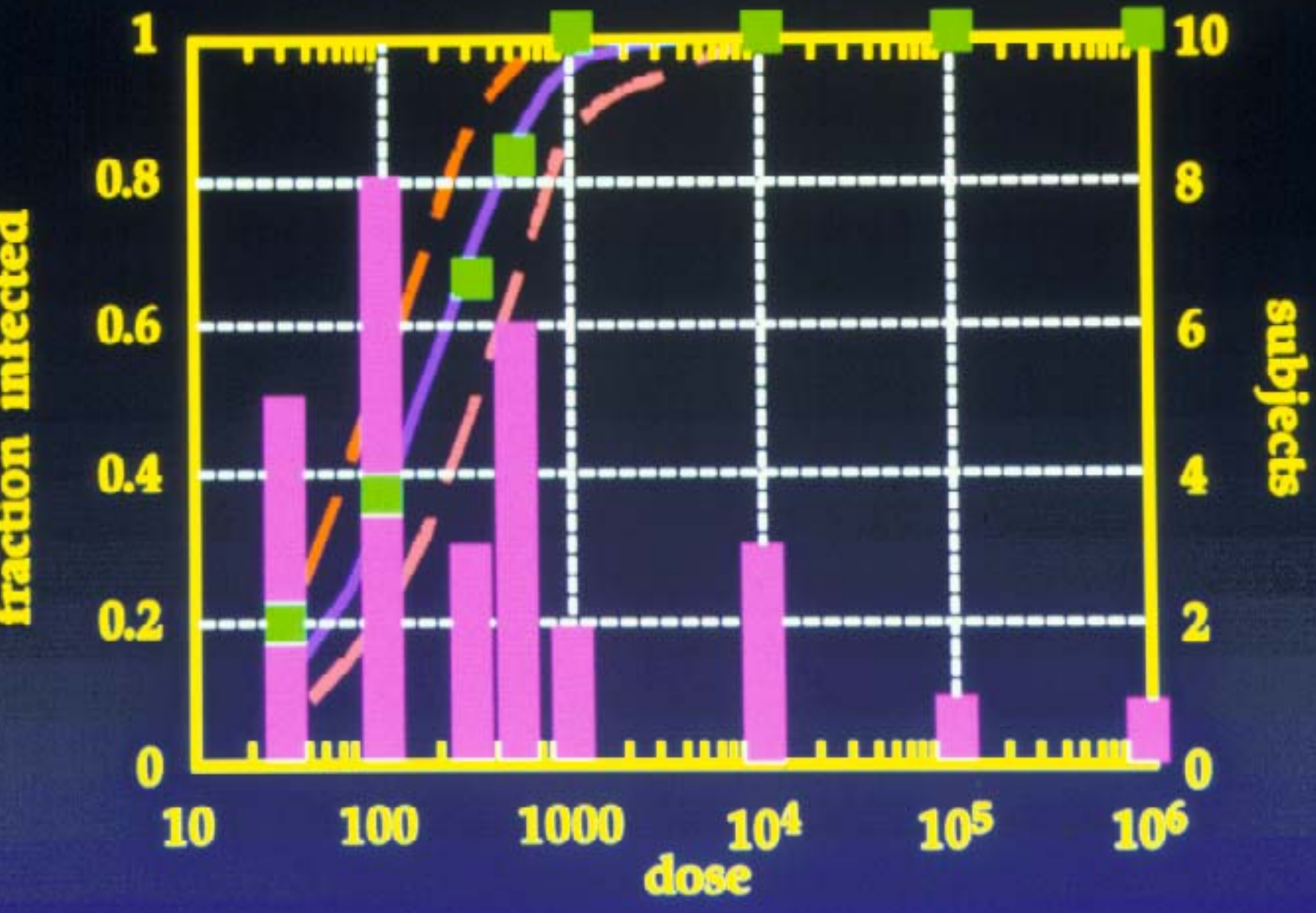
Dose~Response

Dose~response data sets have been developed in human feeding studies for

- Dose measurements were by PFU/or by infectious titer, CFU or cysts or oocysts.
- End points of measurements were excretion of the pathogen and/or antibody response, rarely disease.
- Mathematically address the shape of the ratio of those affected/exposed.
- Need minimum of three doses. Must have doses which elicit effects different from 0% and 100%


Rotavirus
Infection Probability
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
experimental
exponential
beta-poisson
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}
10^{5}
Dose

Dose - Response Information (DuPont)



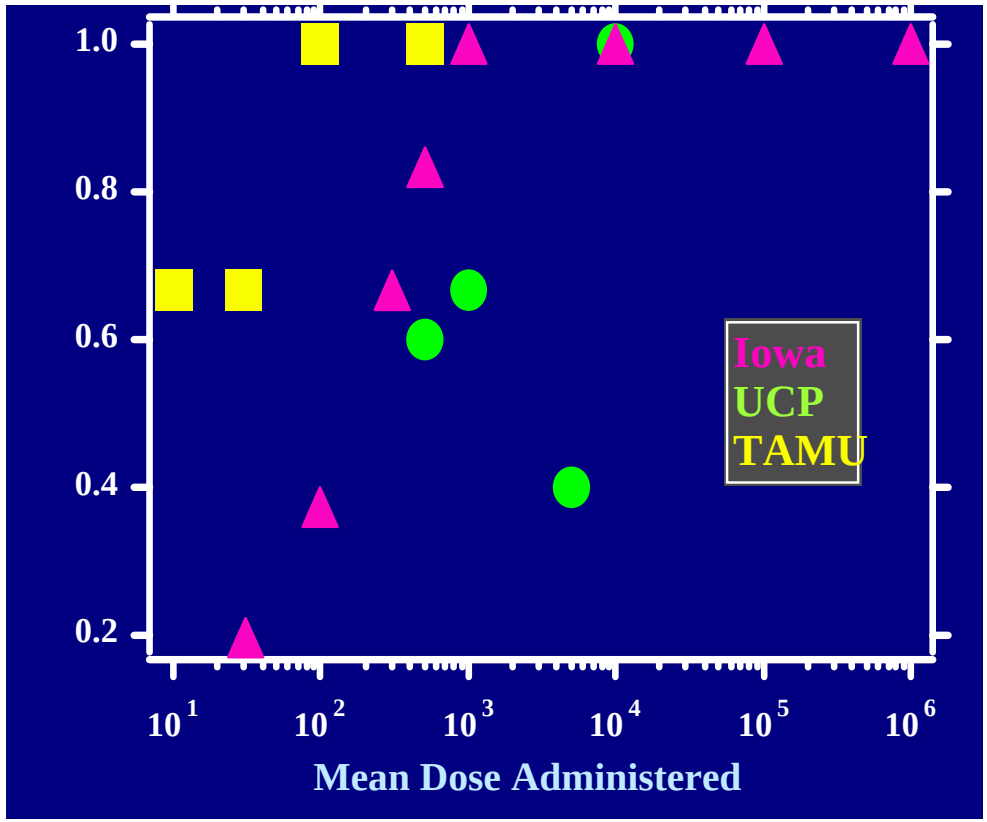
Strain Differences

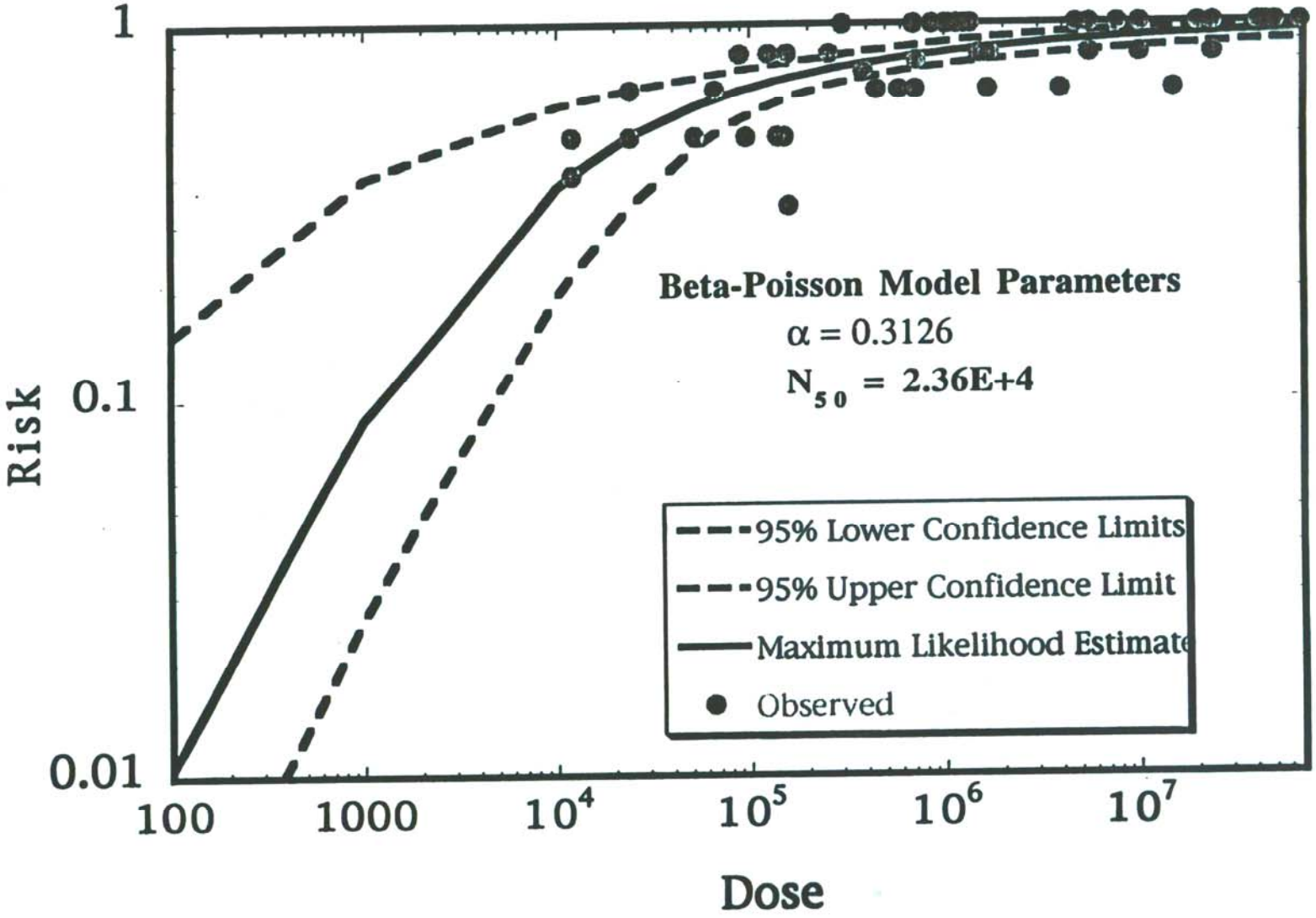
Human volunteers, *C. parvum*,

DuPont et al. (1995)

Okhuysen et al. (1999)

Potential for probabilistic modeling of inter-strain variability (Teunis and colleagues)




1
0.1
0.01
Risk
100
1000
10^4
10^5
10^6
10^7
Dose
Beta-Poisson Model Parameters
$\alpha = 0.3126$
$N_{50} = 2.36E+4$
95% Lower Confidence Limits
95% Upper Confidence Limit
Maximum Likelihood Estimate
Observed

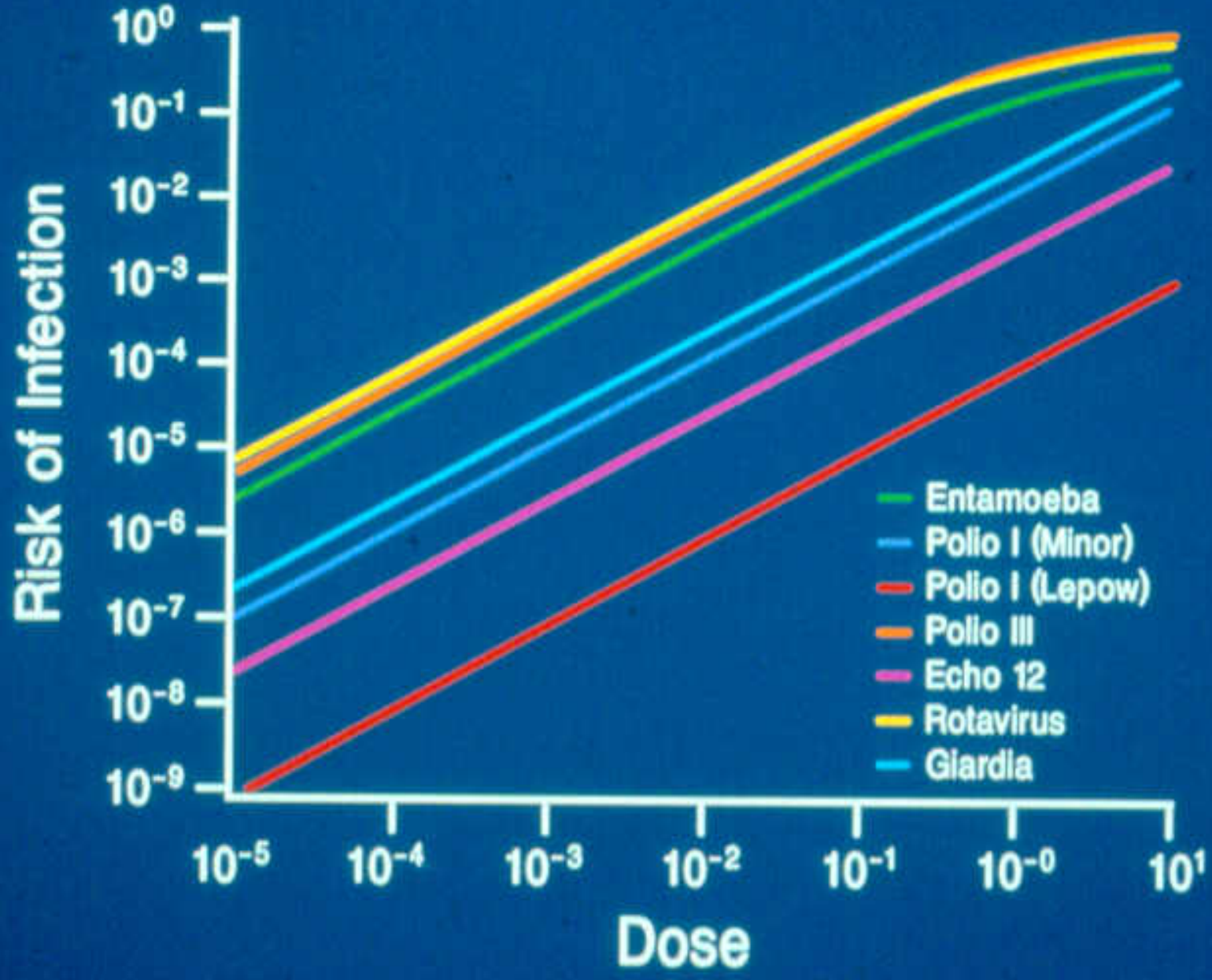
Probability of Infection

Organism	Best Model	Model Parameters
Echovirus	beta-poisson	$\alpha = 0.374$
		$\beta = 186.69$
Rotavirus	beta-poisson	$\alpha = 0.26$
		$\beta = 0.421$
Adenovirus	exponential	$r = 0.4172$
Polio1	beta-poisson	$\alpha = 0.1097$
		$\beta = 1524$
Polio3	beta-poisson	$\alpha = 0.409$
		$\beta = 0.788$

Models: $P_i = 1 - (1 + N/\beta)^{-\alpha}$ (beta-poisson model)

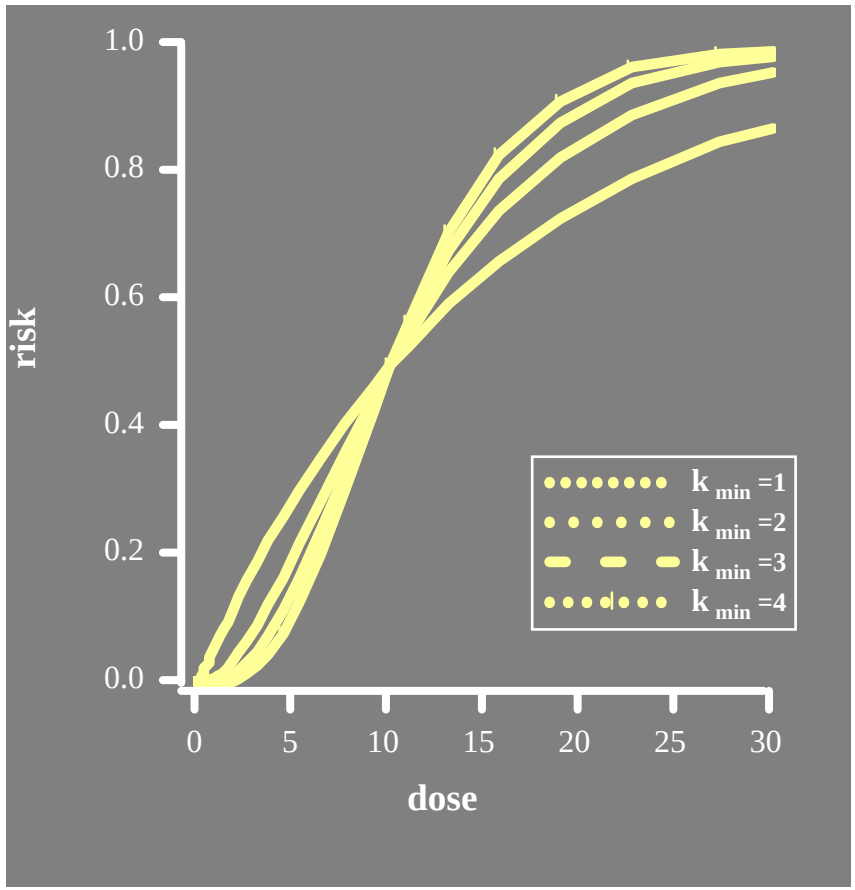
$P_i = 1 - \exp(-rN)$ (exponential)

N=exposure


Risk of Infection
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{-0}
10^{1}
Dose
Entamoeba
Polio I (Minor)
Polio I (Lepow)
Polio III
Echo 12
Rotavirus
Giardia

“Threshold (>1)” Models

- threshold models ($k_{min}>1$) yield steeper slopes and non-linear low dose models
- no human data sets yet examined justify these models



Validation - Water, *Cryptosporidium*

- **1993 Milwaukee outbreak (drinking water)**
- **400,000 cases; (21 % attack rate)**
- **21 day duration**

- **estimated daily risk=1.12 %**
- **from dose-response (infections), estimate daily intake=2.4 oocysts/day**
- **from water consumption==> 1.2 oocysts/L**

- **best estimate(?) from ice measurements, corrected for freezing = 0.79/L**

EXPOSURE ASSESSMENT

- Route of Exposure
- Duration of exposure
  - Seconds, hours, minutes
- Number of exposures
  - How many times in a day, month, year
- Degree of exposure
  - Liters of water ingested
  - Liters of air inhaled
  - Grams of food ingested

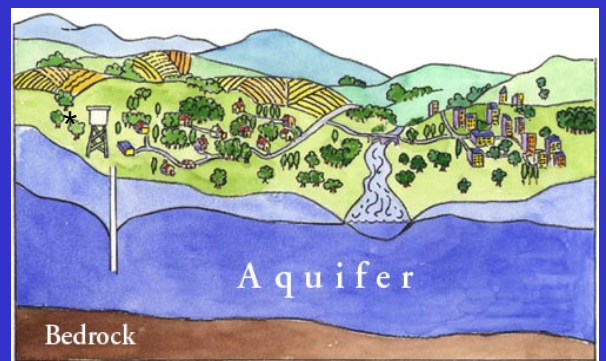
Watershed assessment, Flow, Transport, Integration with water quality and thus exposure.

Overland

In-Stream

Near-Shore

Sub-Surface



Microbial Source Tracking

- **Tools are now available to determine the molecular fingerprint of the fecal pollution.**
- **Health risks**
- **Remediation**
- **Prioritization**
- **Responsibility**

Host Specific Markers are Key to Source Tracking Future

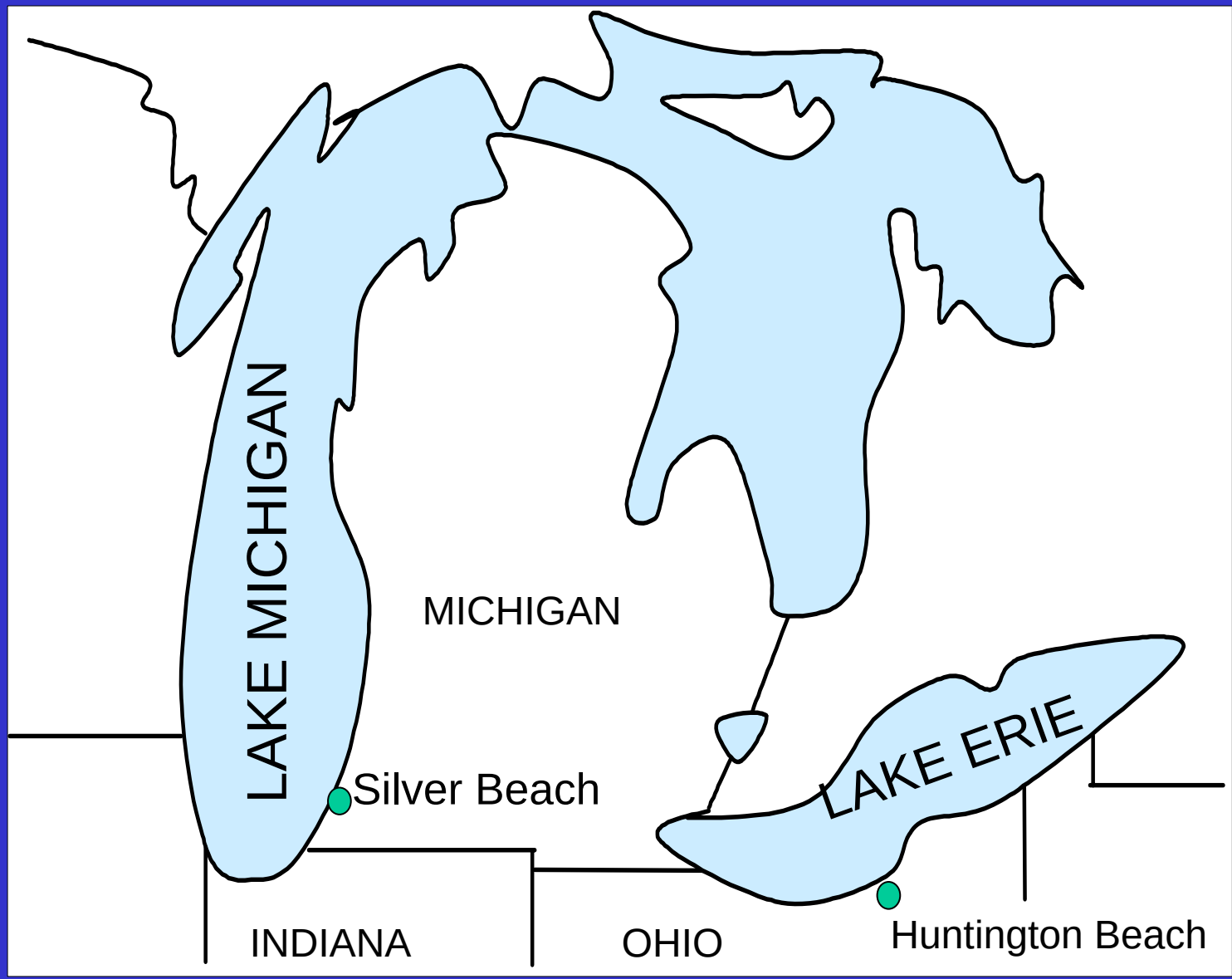
- Bacteroides (genetic approaches PCR)
- 4/4 sewage; 4/4 human; 4/5 cow (lowest concentration missed) 4/4 dogs however no marker for Birds: Missed 2 samples with dog and 2 with cow that were mixed.

- E.coli Toxin genes able to detect sewage (4/4).

- Enteroviruses and Adenoviruses found in 3 of 4 sewage samples.

- Enterococci ESP marker found in 107/109 human sewage water samples and zero of 80 animal samples.

USGS blind samples 0/10 animals; 6/8 Human


LAKE MICHIGAN
MICHIGAN
LAKE ERIE
Silver Beach
Huntington Beach
INDIANA
OHIO

Location of sampling sites (1-3) at Silver Beach, St Joseph, Michigan (Lake Michigan).

Photo: US Army Corps of Engineers.

esp human marker in Great Lakes recreational beach waters

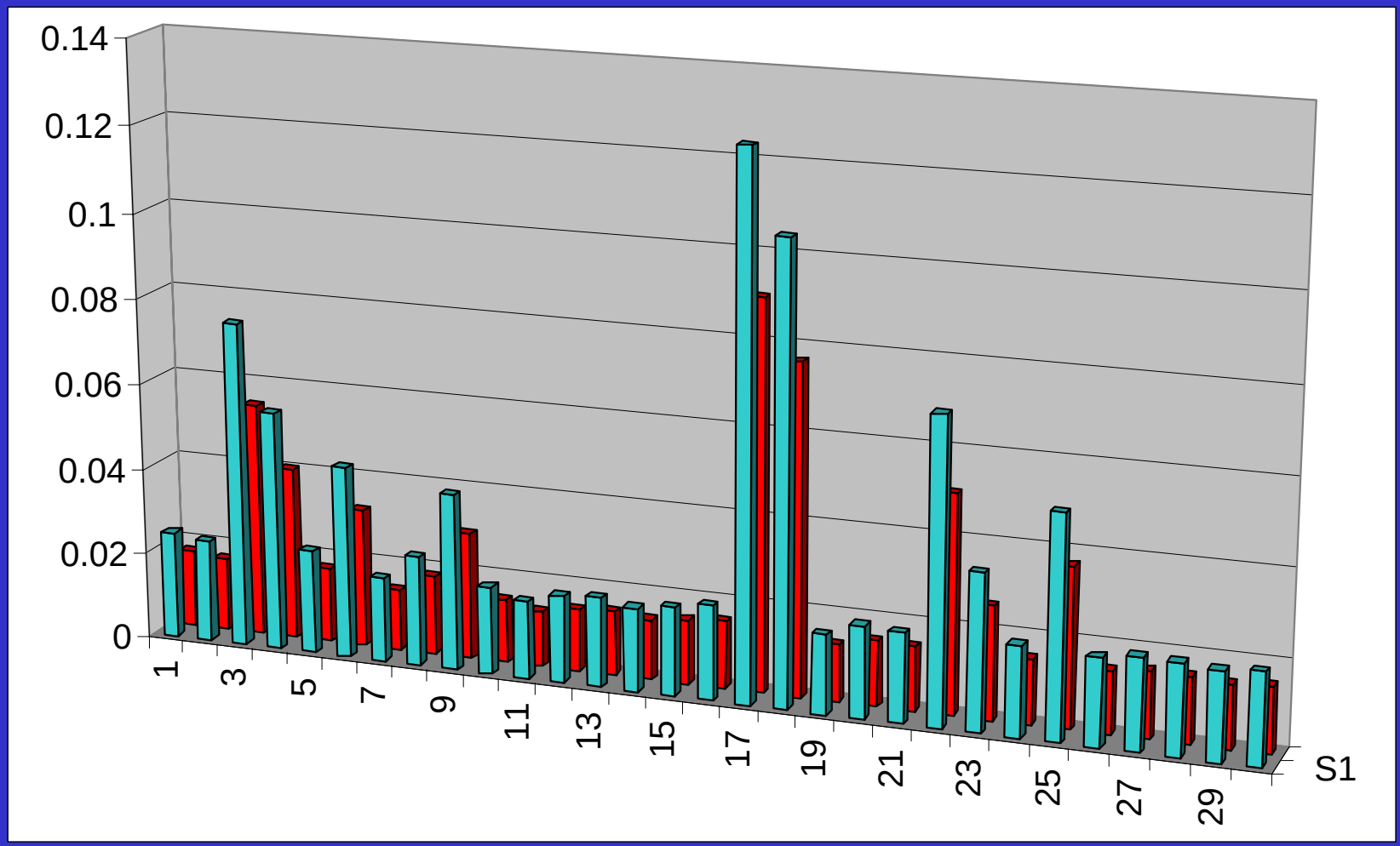
	Silver Beach, MI		
Sampling time	**Number of swimmers**	**Mean turbidity (NTU) [SD]**	**positive for *esp* marker**
Morning	17	3.2 [3.8]	5/168 3% (n=276)
Afternoon	805	3.7 [3.7]	4/88 4.5% (n=138)
Total	**822**		**9/256**

Presence of Enteric Viruses

	Silver Beach, MI			
Sampling time	cell culture +/n	Id by PCR/RT-PCR		
		Ad	EV	RV
Morning	8/15	10/11	0/11	1/11
Afternoon	8/15	6/9	0/9	2/9
Total	16/30	16/20	0/20	3/20

- ***esp*** **marker detected in**
  ~5-9% Lake Michigan samples
- **enteric viruses detected in 16/30 samples from Silver Beach via cell culture**
- **adenovirus and rotavirus identified in samples from these beaches by PCR**
- **EPA found that between 1 and 10% of all swimmers became ill after swimming at GL beaches.**

Daily Risk of Viral Infections Based on Rota and Adeno virus models



30 day risk is 7.5 and 14/1000 (0.7 to 1.4%)

Ohio blames groundwater for Lake Erie island outbreak

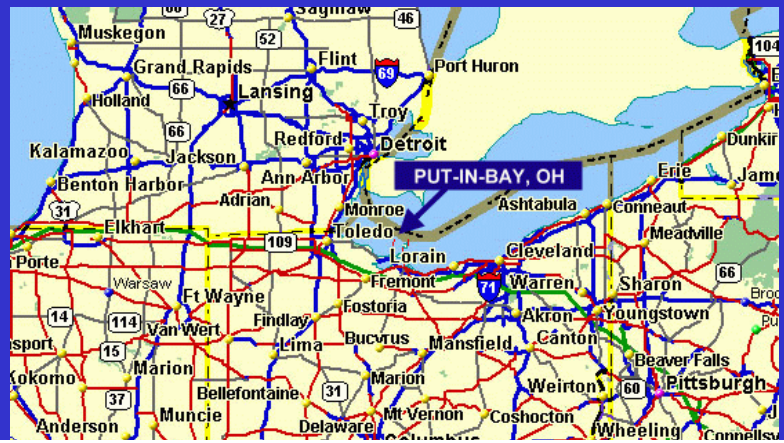
Tuesday, February 22, 2005

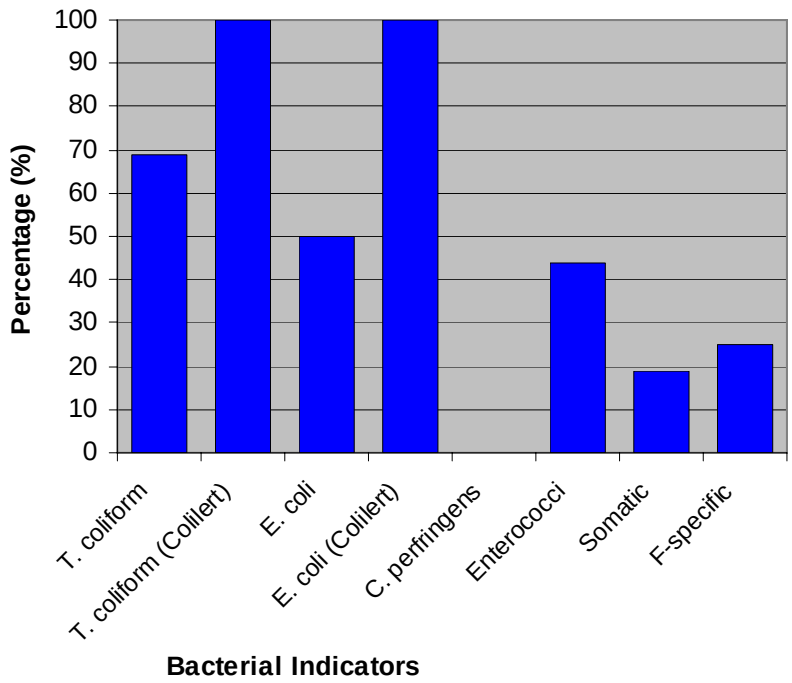
ASSOCIATED PRESS

TOLEDO, Ohio -- Widespread groundwater contamination on a Lake Erie resort island was the likely source of illnesses that sickened hundreds last summer, the Ohio health department said Tuesday.

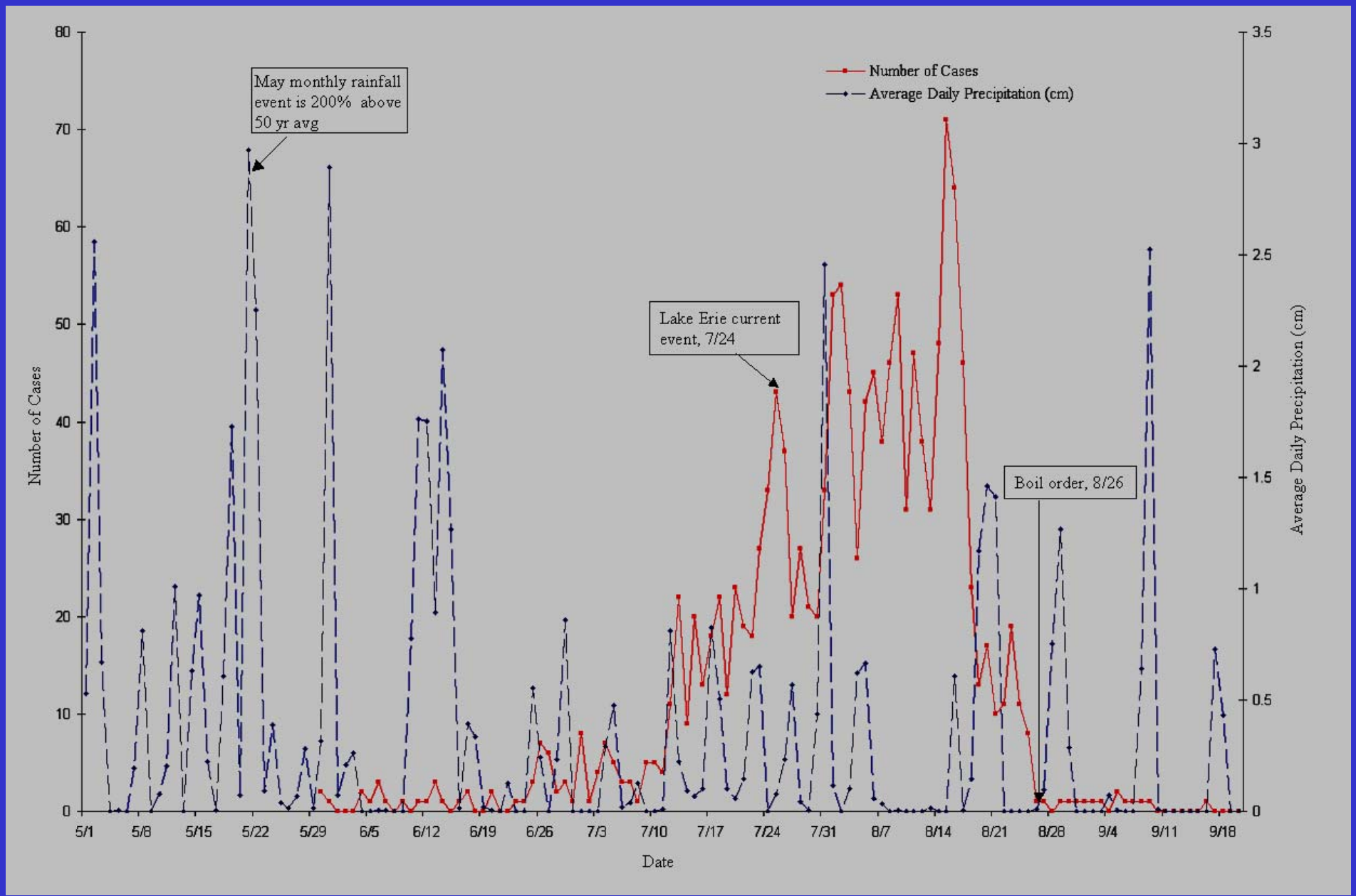
Several sources, including septic tanks, have tainted the South Bass Island's groundwater over a long period, and the contamination may have been worsened last summer because of a season of heavy rains, a health department report said.

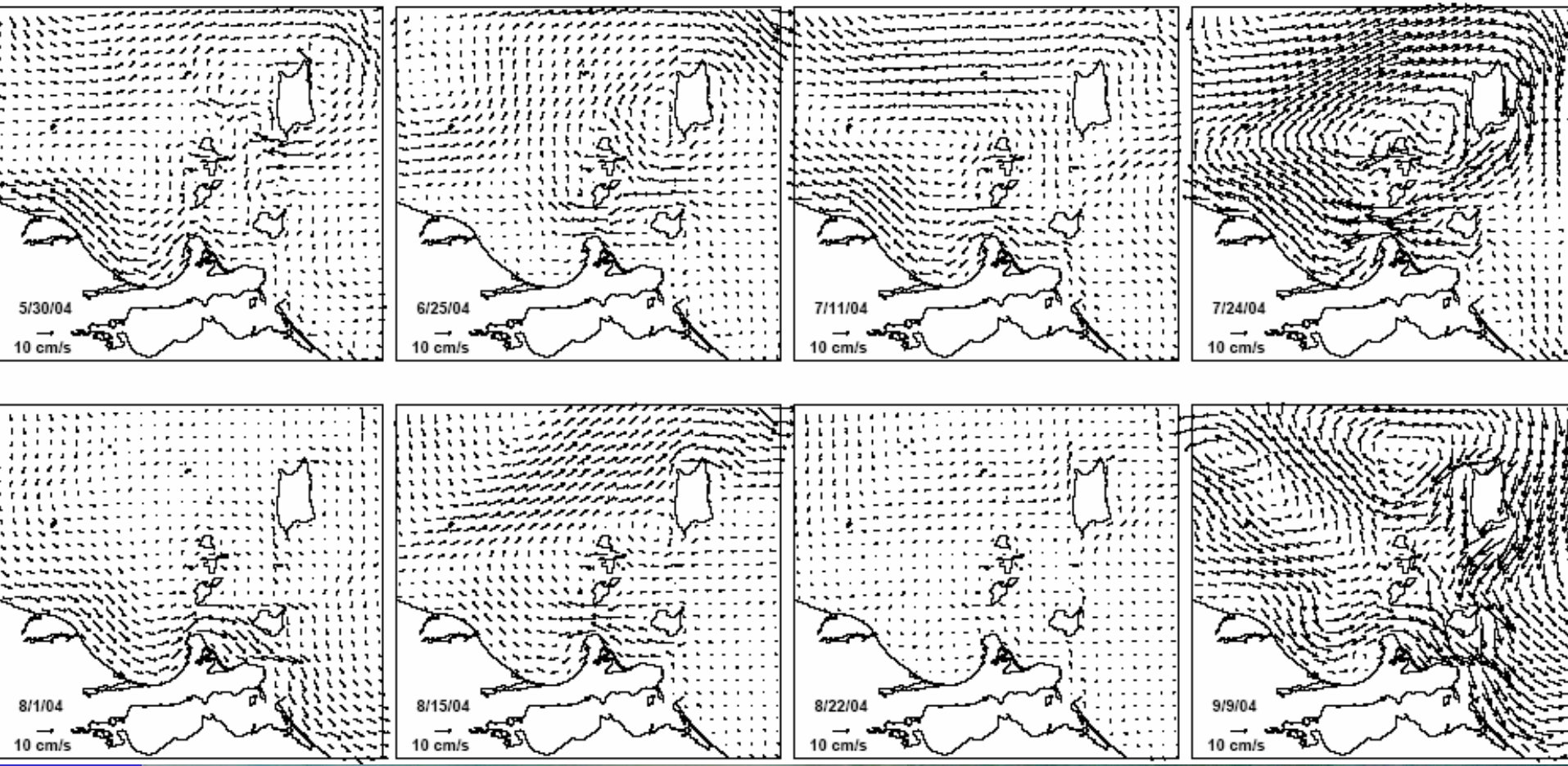
The outbreak of gastrointestinal illness sickened about 1,400 tourists and residents, ending the tourist season early for many businesses.



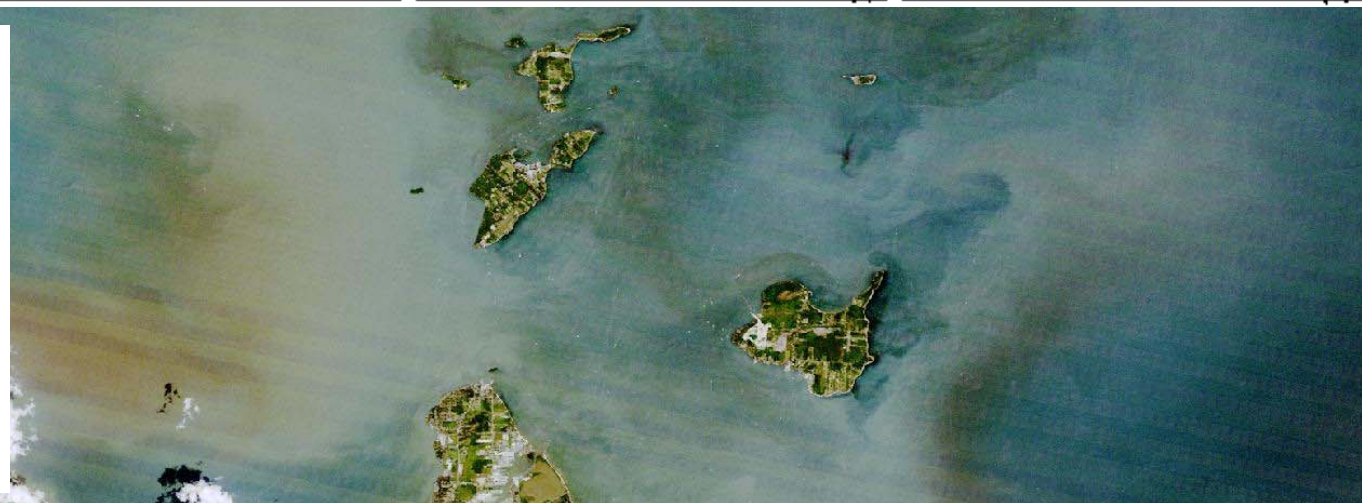


MSU assisted with the investigation
Identified virus contamination and potentially a new and emerging bacteria


May monthly rainfall event is 200% above 50 yr avg
Lake Erie current event, 7/24
Boil order, 8/26
Number of Cases
Average Daily Precipitation (cm)
Number of Cases
Average Daily Precipitation (cm)
Date
0
10
20
30
40
50
60
70
80
0
0.5
1
1.5
2
2.5
3
3.5
5/1
5/8
5/15
5/22
5/29
6/5
6/12
6/19
6/26
7/3
7/10
7/17
7/24
7/31
8/7
8/14
8/21
8/28
9/4
9/11
9/18



South Bass Island
Lake Erie
Sources septic Tanks
& sewage discharges
Massive Ground Water
and Surface Water
Contamination



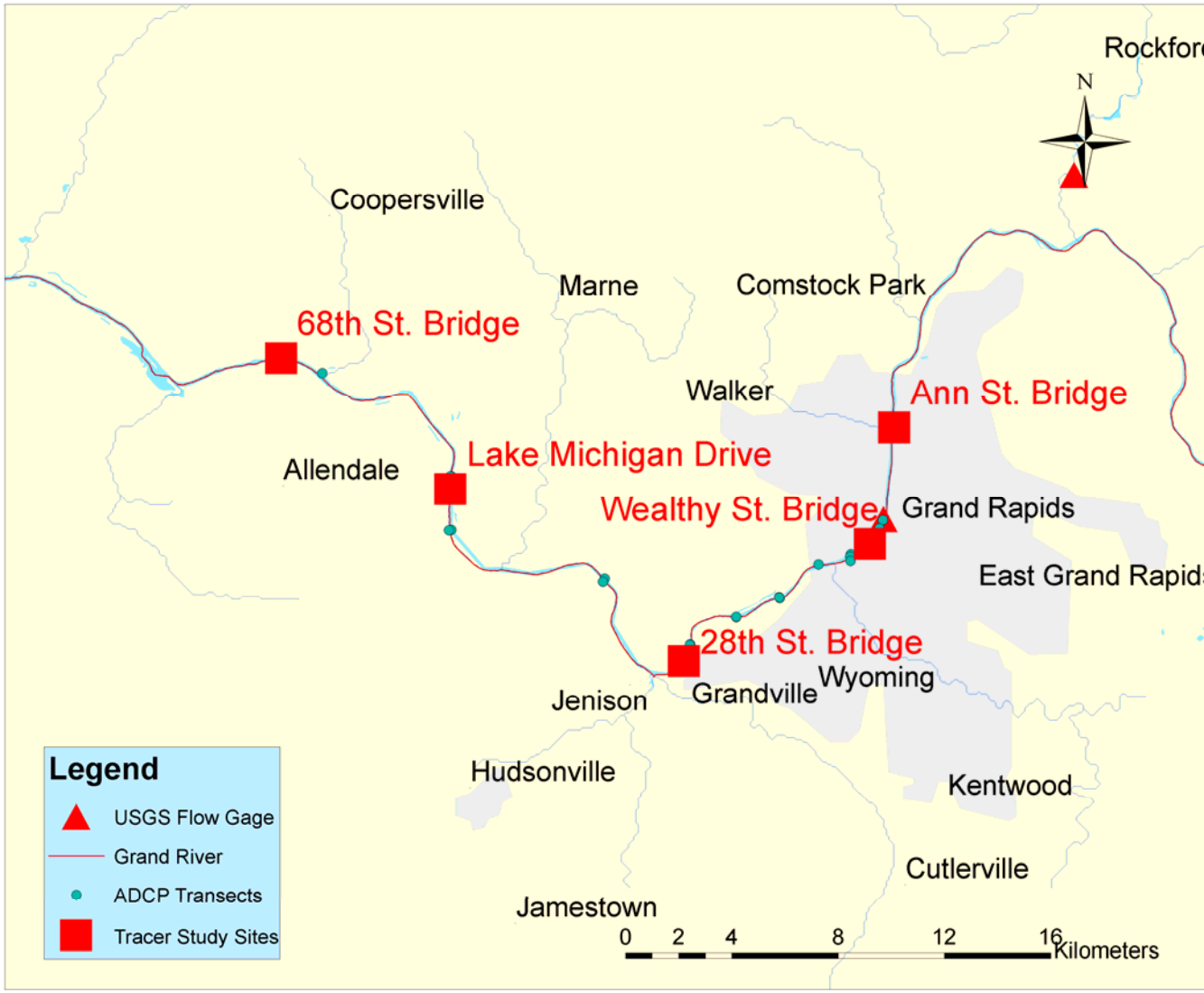
Study Reach

Examine Fecal Indicators

Examine Sediments

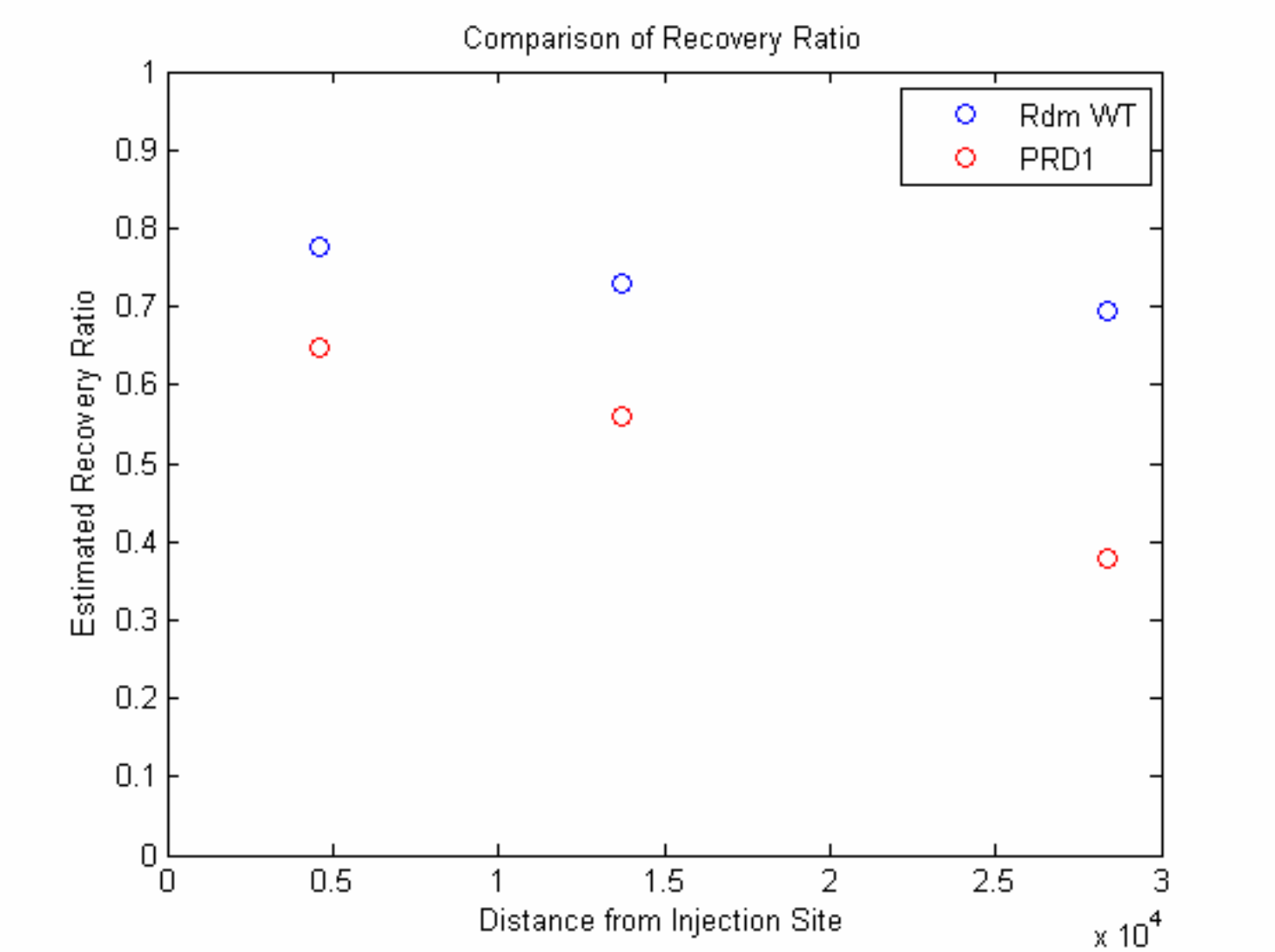
Examine Transport from River to Beach

Monitoring & Tracer Studies

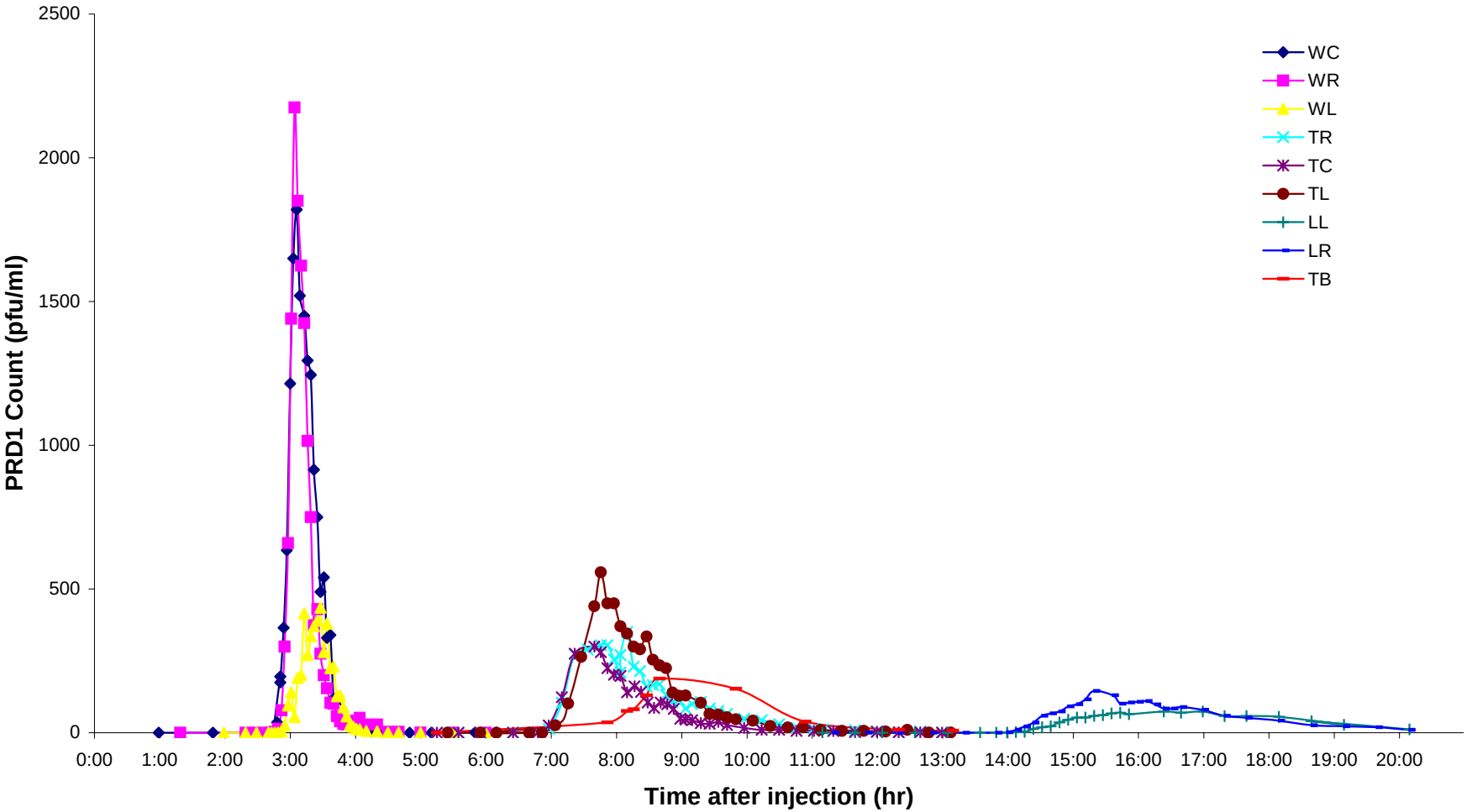


Rhodamine vs PRD1

- Recovery Ratio (Estimated from Average Breakthrough Curve)



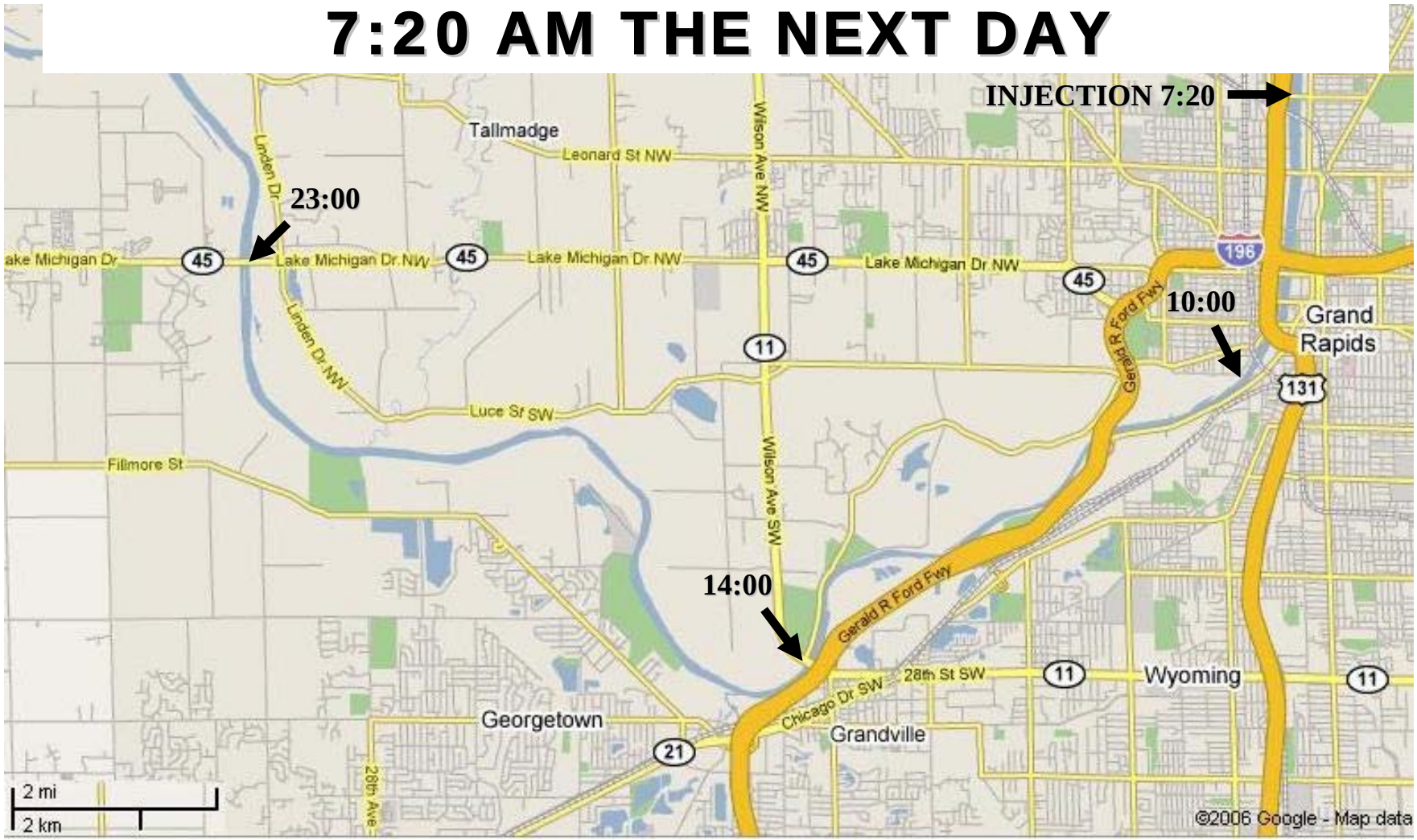
PRD-1


PRD1 Count (pfu/ml)
2500
2000
1500
1000
500
0
0:00
1:00
2:00
3:00
4:00
5:00
6:00
7:00
8:00
9:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
Time after injection (hr)
WC
WR
WL
TR
TC
TL
LL
LR
TB

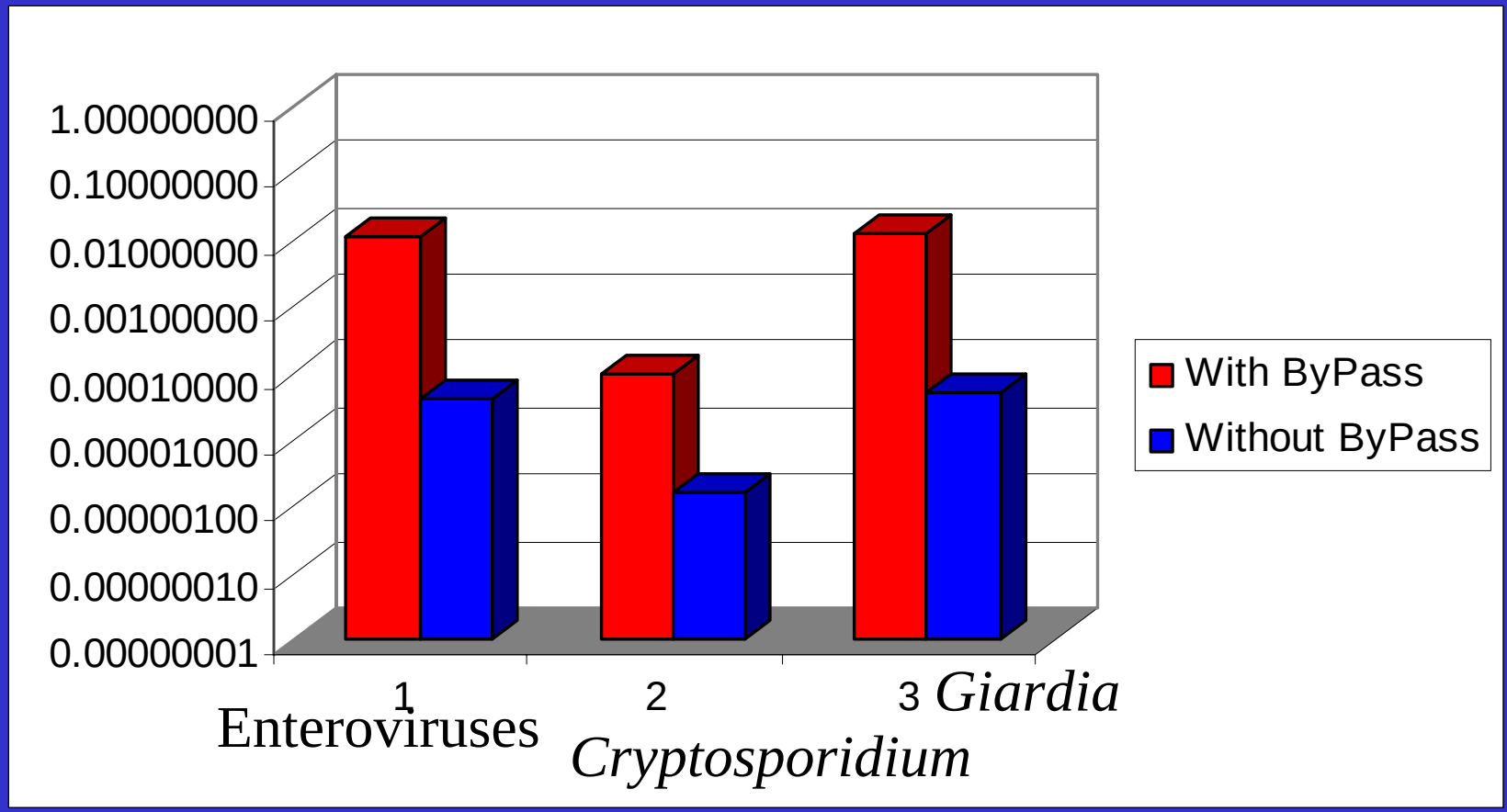
Arrival Time at Each Site

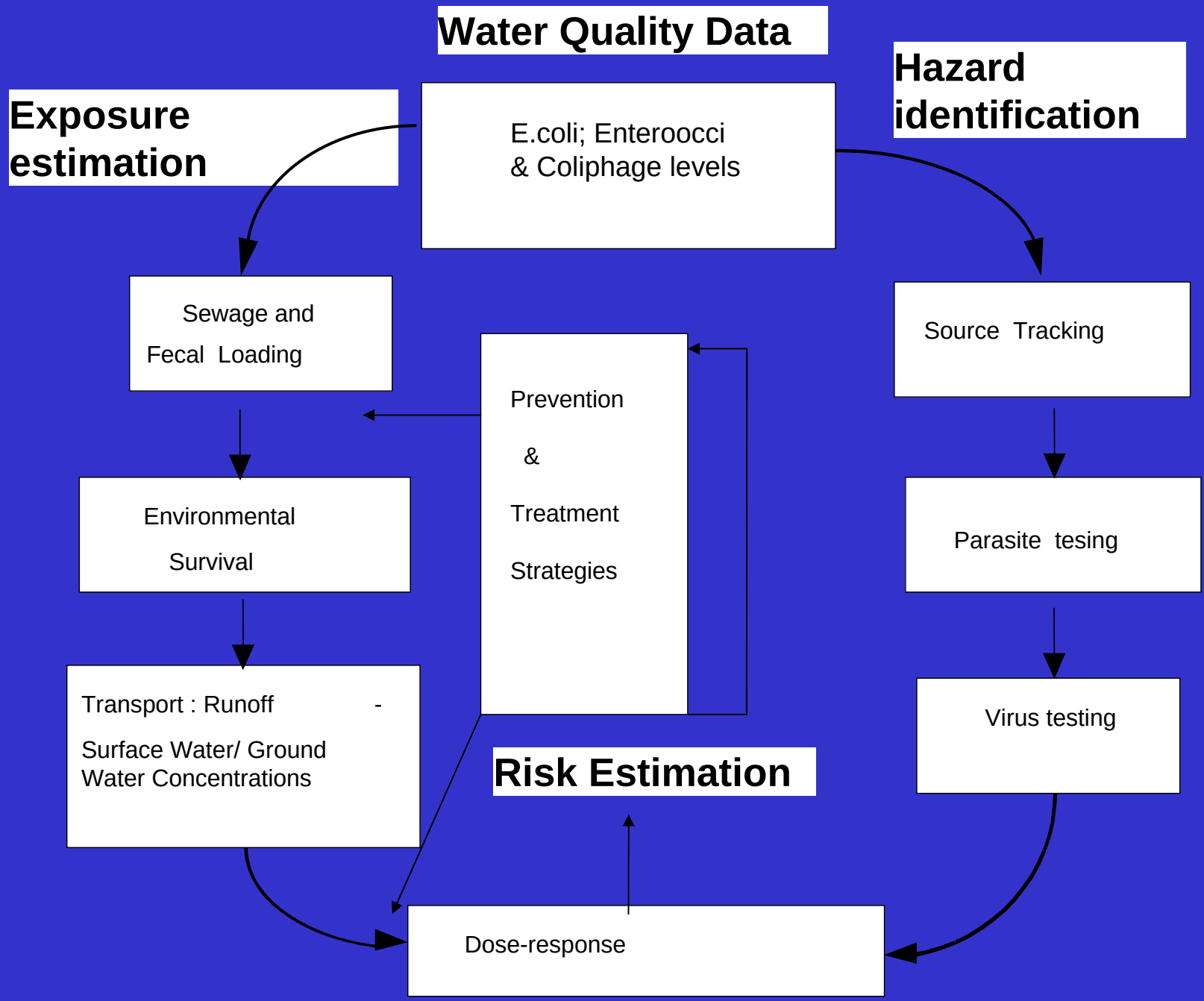
ESTIMATED ARRIVAL AT LK MICHIGAN

7:20 AM THE NEXT DAY



Risk Estimates

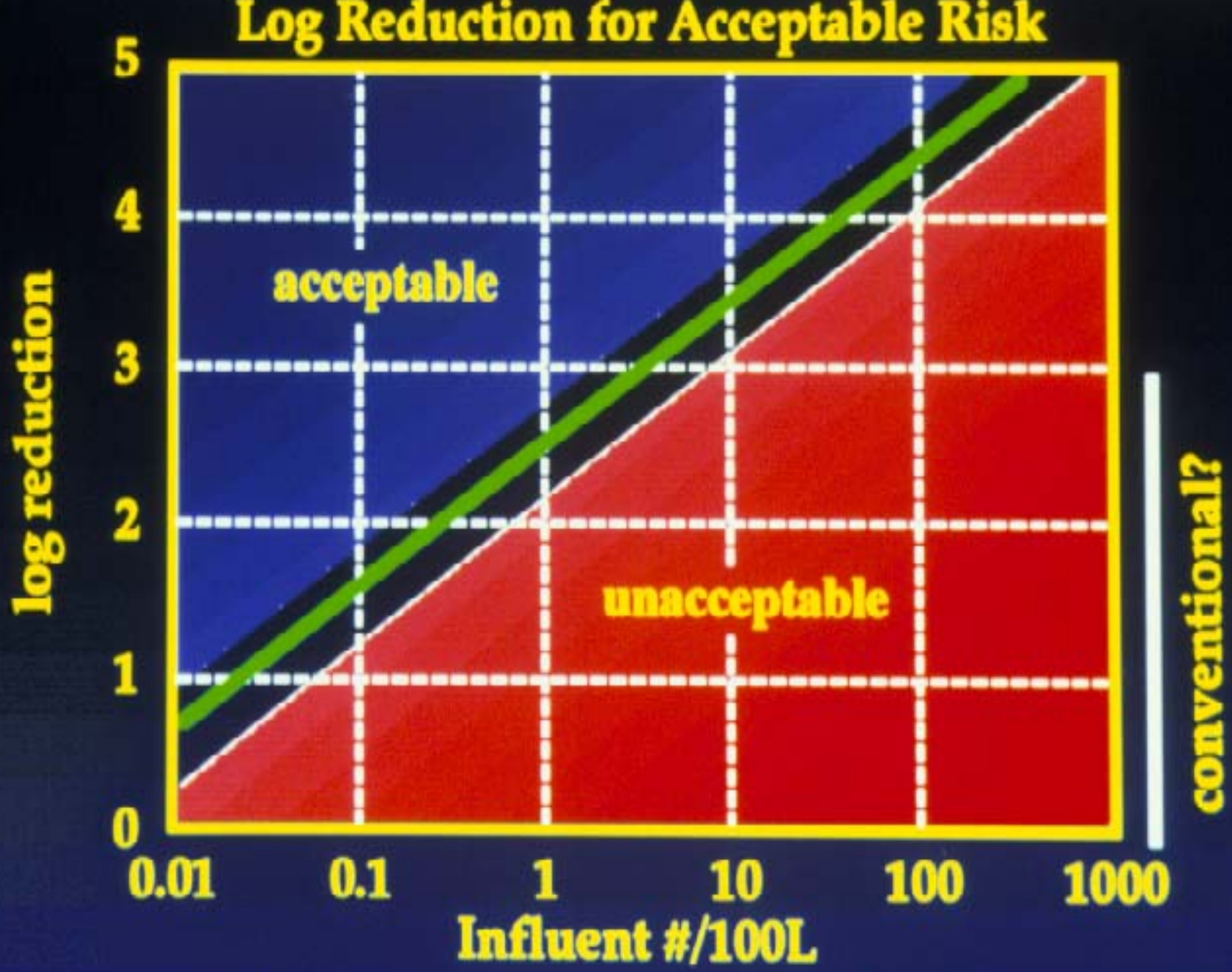



Water Quality Data
Hazard identification
Exposure estimation
E.coli; Enteroocci
& Coliphage levels
Sewage and
Fecal Loading
Source Tracking
Prevention
&
Treatment
Strategies
Environmental
Survival
Parasite tesing
Transport : Runoff -
Surface Water/ Ground
Water Concentrations
Virus testing
Risk Estimation
Dose-response

Applications for Microbial Risk Assessment

- Establish policies for protection of health using standards or performance based criteria
- Compare risks
- Evaluate alternative solutions
- Prioritize risks
- Identify scientific data gaps
- Develop protocols for monitoring

Treatment vs. Influent: Endemic Risk



CAMRA

Center for Advancing Microbial Risk Assessment

Carnegie Mellon

NORTHERN ARIZONA UNIVERSITY

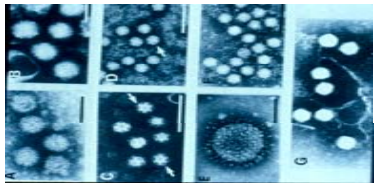
Drexel UNIVERSITY

to build a national network for microbial risk knowledge management, learning and transfer, for the community of scientists, and students via educational programs and community of professionals in the field and in our communities.

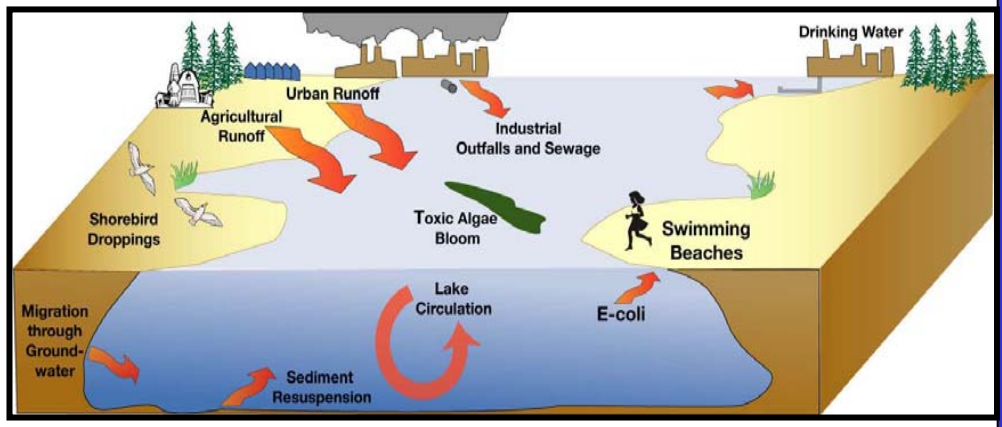
to develop models, tools and information that will be used in a credible risk assessment framework to reduce or eliminate health impacts from deliberate use of biological agents of concern in the indoor and outdoor environment.

ADVANCING MICROBIAL RISK ASSESSMENT

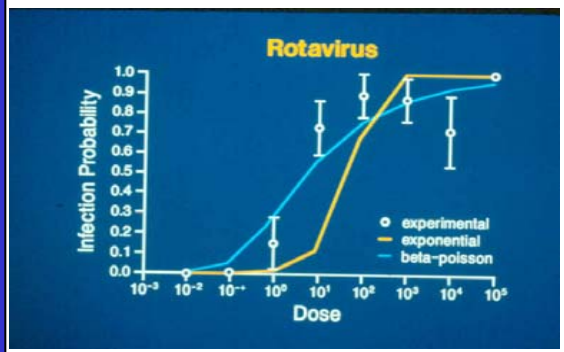
Hazards



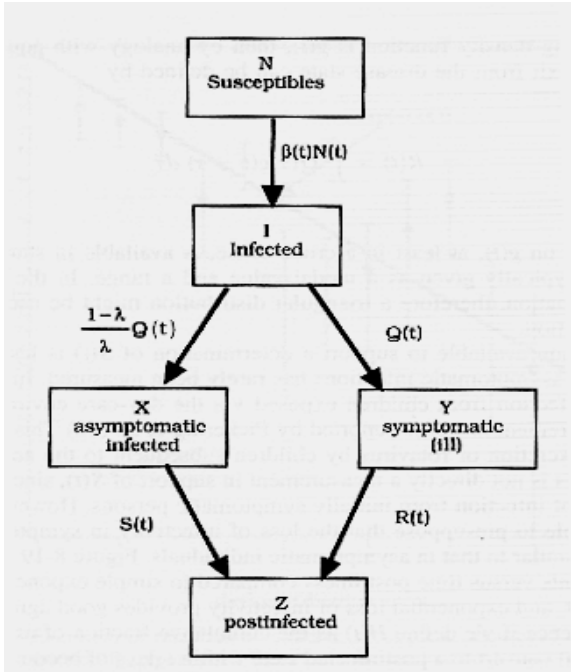
Exposure



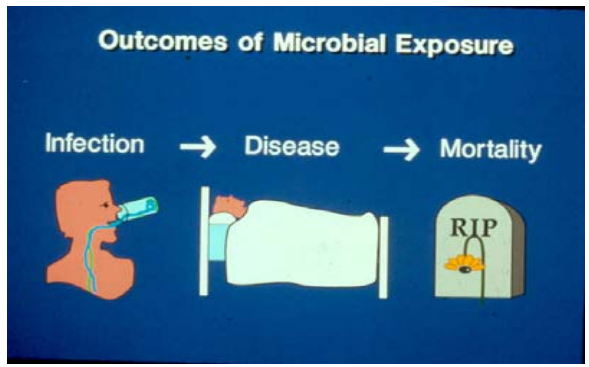
Dose-response



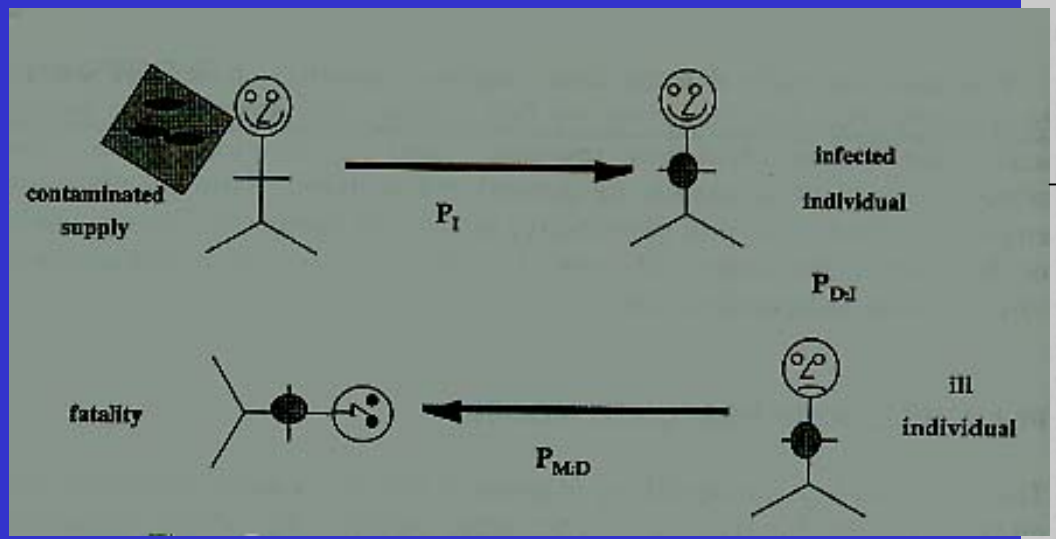
Disease Dynamics

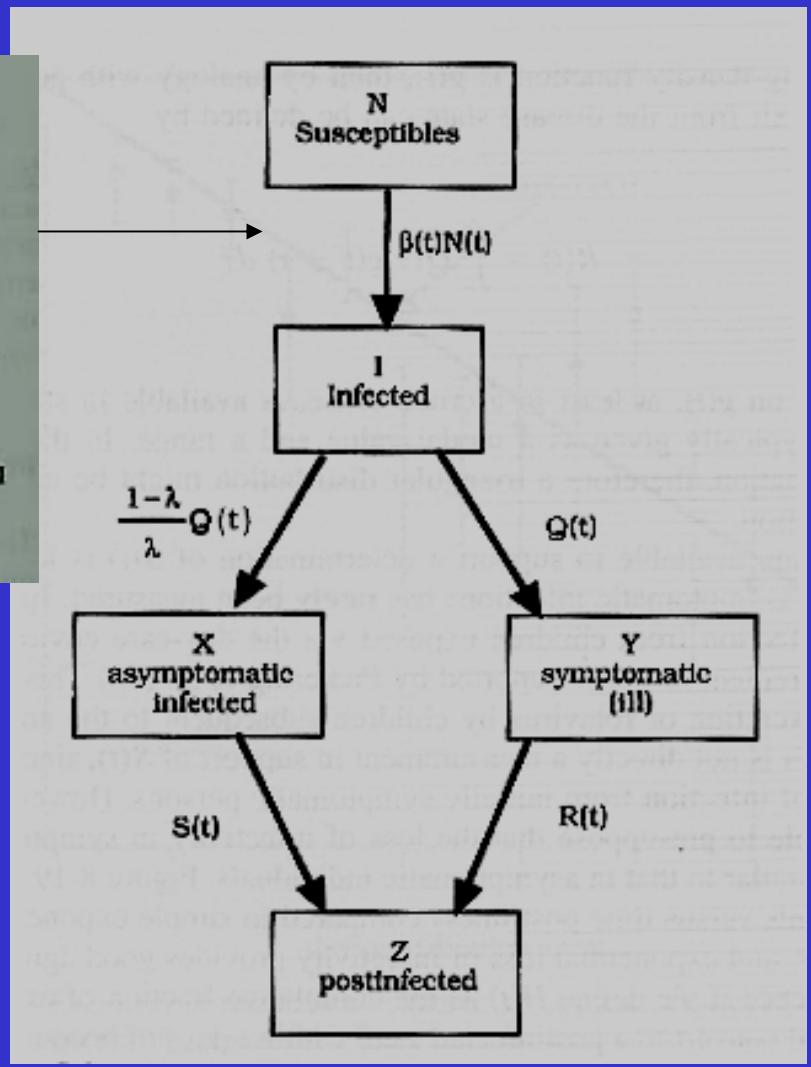


Risk Characterization

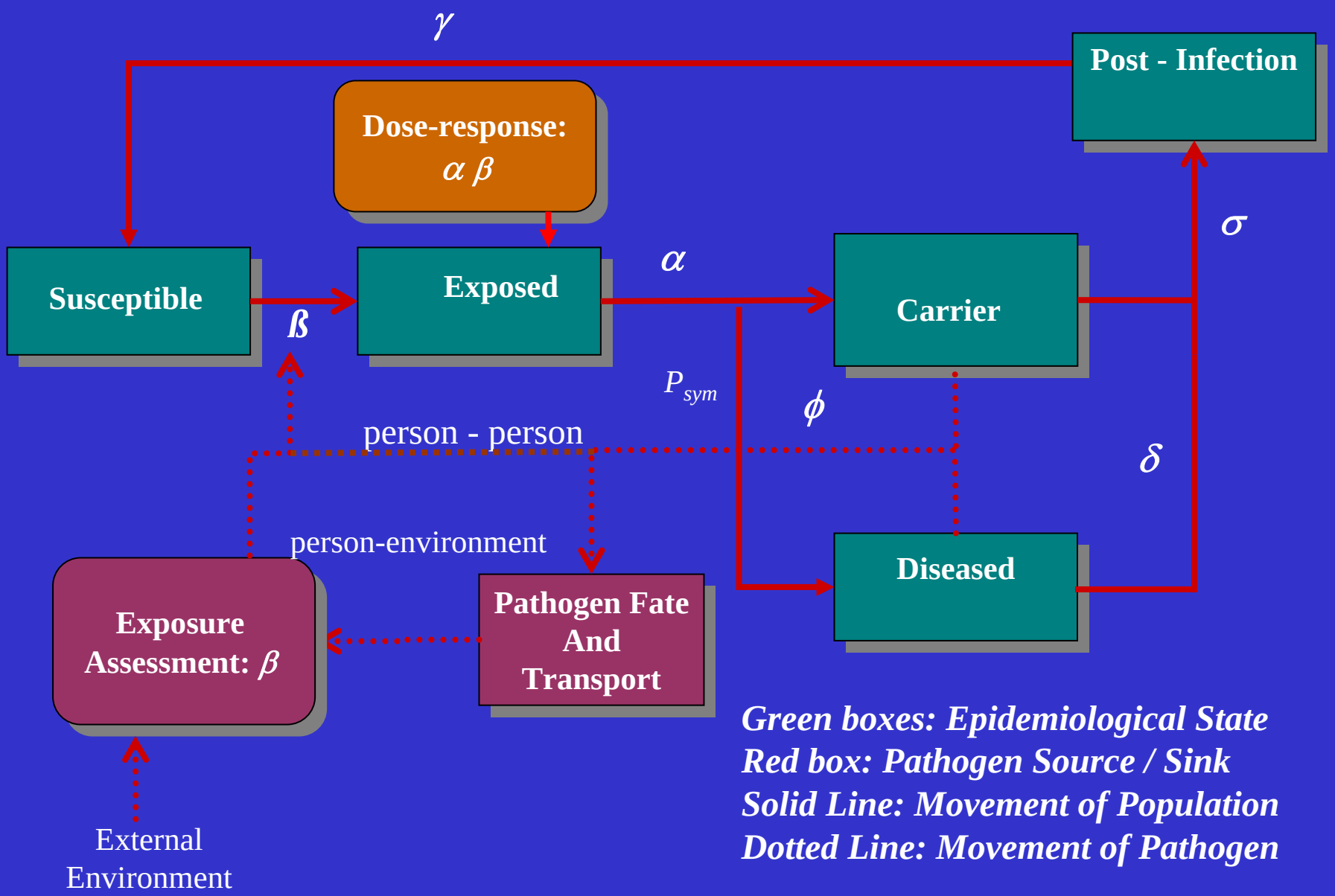


Must Link probability of infection to population models & address the environmental exposure

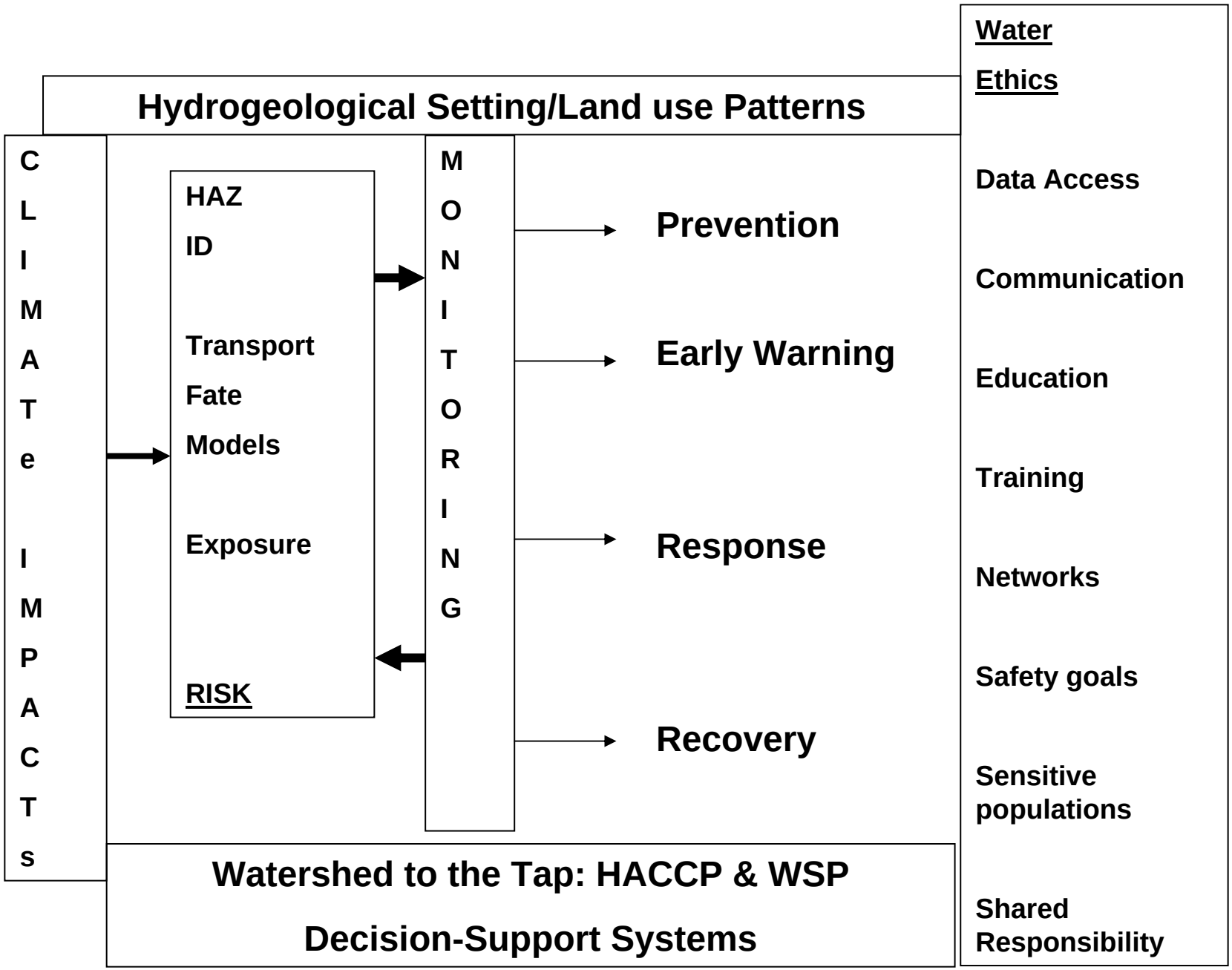




Interaction between Disease Transmission and the Environment



Green boxes: Epidemiological State
Red box: Pathogen Source / Sink
Solid Line: Movement of Population
Dotted Line: Movement of Pathogen


Hydrogeological Setting/Land use Patterns
CLIMATe IMPACTs
HAZ ID
Transport
Fate
Models
Exposure
RISK
MONITORING
Prevention
Early Warning
Response
Recovery
Water
Ethics
Data Access
Communication
Education
Training
Networks
Safety goals
Sensitive populations
Shared Responsibility
Watershed to the Tap: HACCP & WSP
Decision-Support Systems

THE NATION'S NEWSPAPER

Special Reprint Edition

USA TODAY

NO. 1 IN THE USA . . . FIRST IN DAILY READERS

October 21, 199

SPECIAL REPORT

How safe is your water?

A USA TODAY investigation finds:

- 58 million people got water last year th violated testing and purity standards.
- 25 million people got water that had 'significant' violations posing 'serious threats to public health.'

SPECIAL REPORT: DRINKING WATER'S HIDDEN DANGERS

Lax oversight raises ta

THANK YOU

AEESP &

Univ. MN

Science for

Societal Benefits.