Protecting Our Water Environment

Metropolitan Water Reclamation District of Greater Chicago

"RISK ASSESSMENT OF HUMAN HEALTH IMPACTS OF DISINFECTION VS. NO DISINFECTION OF THE CHICAGO AREA WATERWAYS SYSTEM"

by

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The GeoSyntec Team

BACKGROUND

- IEPA is conducting a Use Attainability Analysis (UAA) on the Chicago Area Waterways
- IEPA will determine the need for bacterial water quality standards
- This District study is done to assist IEPA in making its determination

STUDY OBJECTIVES

Conduct a comparative risk assessment of the human health impact of not disinfecting versus disinfecting the effluents from the Calumet, North Side and Stickney Water Reclamation Plans (WRPs):

1. ***Quantify the decrease if any in the incidence of disease to a representative recreational user of the CWS if effluent disinfection is initiated***

2. ***Quantify the decrease if any in the incidence of disease that could be predicted for the entire number of estimated recreational users of the CWS if effluent disinfection is initiated***

PATHOGEN SOURCES IN THE CWS

Sources that contribute to the presence of pathogens in the waterways include:

1. Faulty sewage disposal systems
2. Combined sewer overflows (CSOs)
3. Wild and domestic animal waste
4. Illegal discharges to drains and sewers
5. Storm water runoff
6. Treated, but non-disinfected wastewater effluent

Source: http://www.ChicagoAreaWaterways.org

WATERWAY USE

Designated uses of the CWS include:

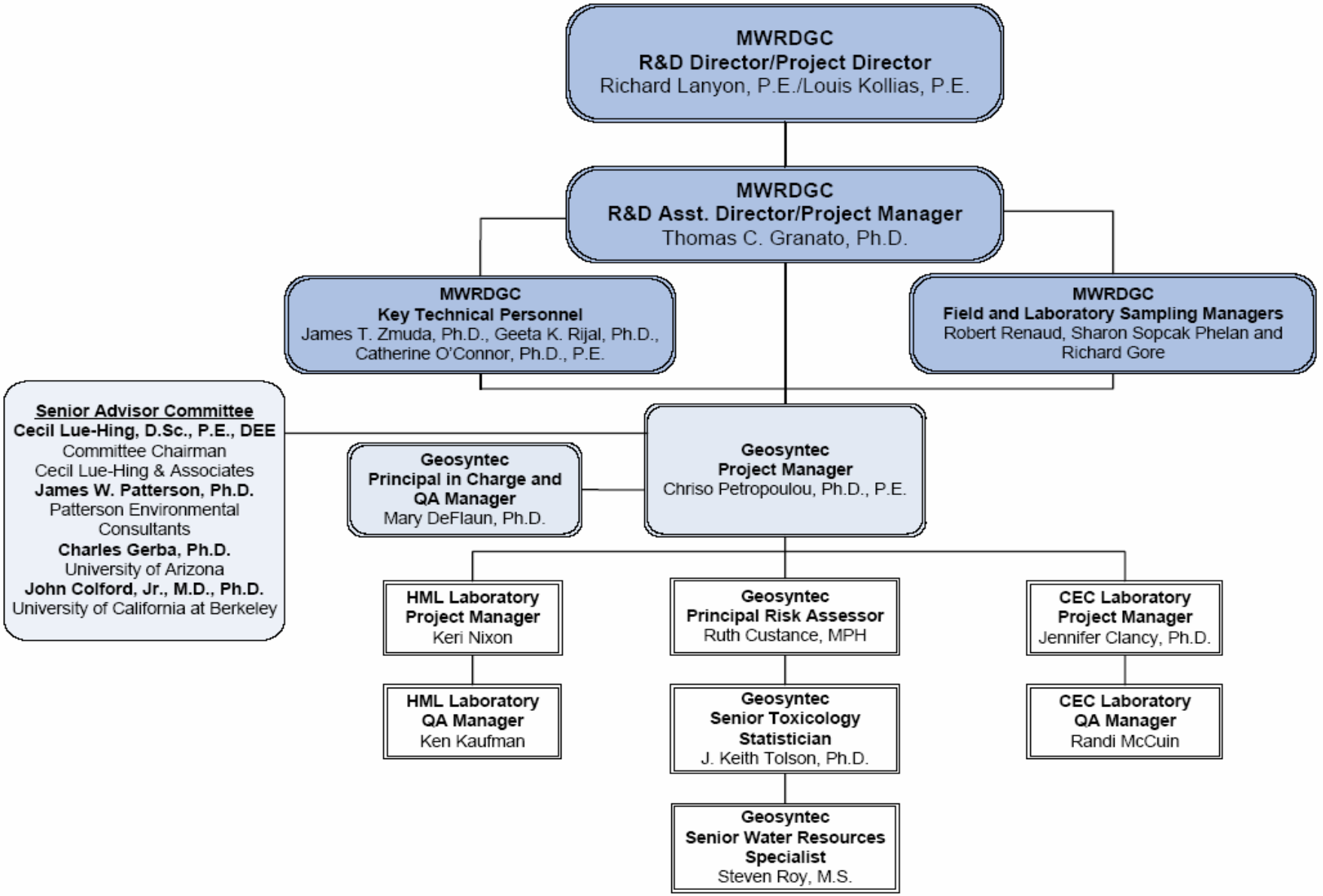
1. Recreational boating
2. Canoeing
3. Fishing
4. Other streamside recreational activities
5. Aquatic habitat for wildlife

Swimming and other primary contact recreation is not a designated use of the CWS

PROJECT STRATEGY

1. Dry/wet weather effects
2. Barge and boat traffic effects (such as sediment re-suspension)
3. Use UAA recreational user survey data
4. Compile disinfection technology performance data for pathogens
5. Obtain the minimal infectious dose results from the peer reviewed literature

PROJECT TEAM



PROJECT TEAM DISCIPLINES

- Risk assessment
- Statistical analysis of analytical results
- Environmental microbiology
- Virology
- Epidemiology
- Development of sampling, analysis and quality assurance plans
- Microbial water sampling
- Water resources
- Disinfection
- Environmental engineering
- Environmental laws and regulations

OVERVIEW

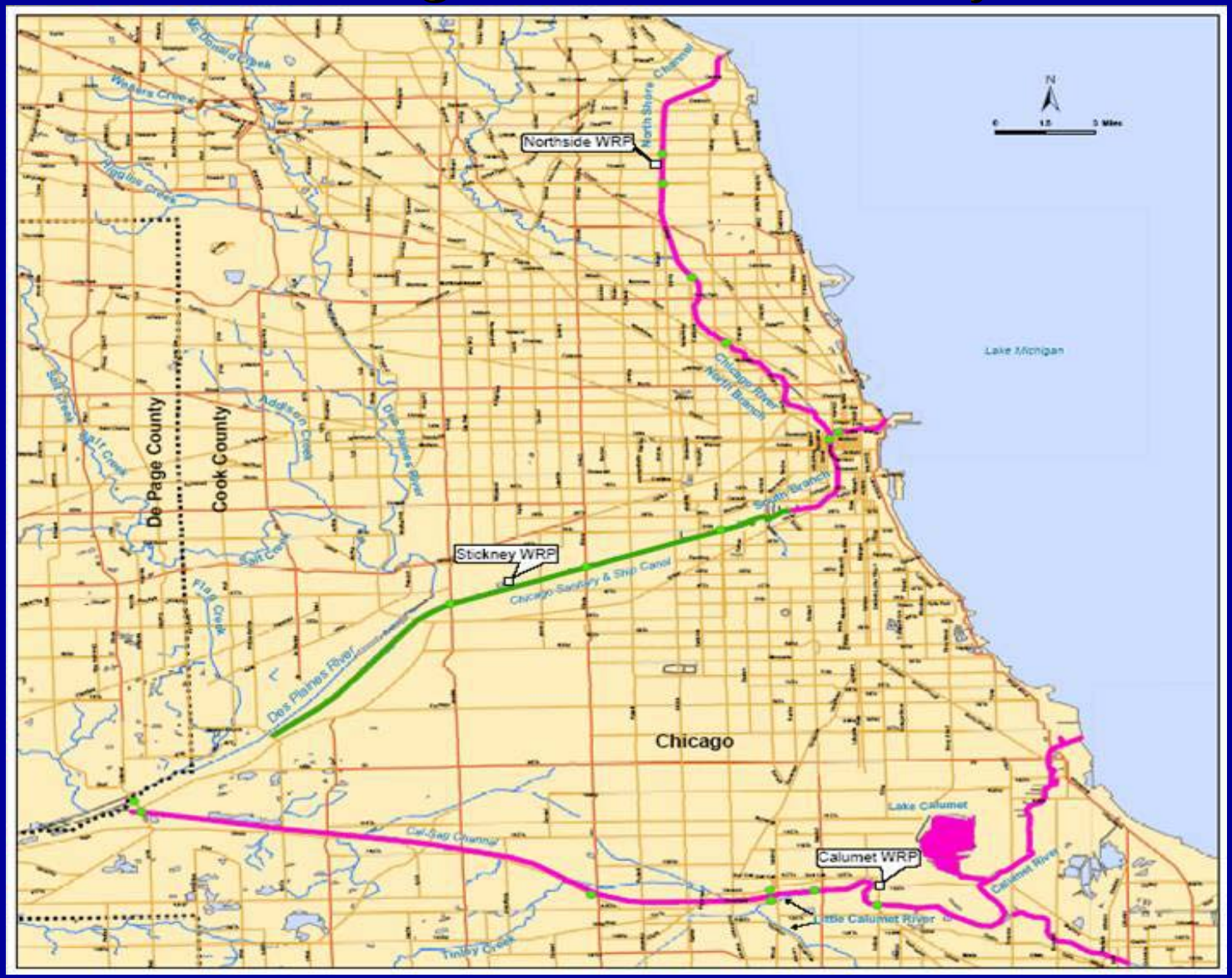
- Dry/Wet Weather Microbial Sampling
- Microbial Characterization/Analysis
- Risk Assessment
  1. Exposure Assessment Overview
  2. Dose Response Overview
  3. Risk Characterization Approach
  4. Risk Assessment Results

DRY WEATHER SAMPLING

- Five weekly sampling events **(July-September 2005)**
- Each event included sampling at North Side, Stickney, and Calumet
- Five samples were collected at each WRP :
  - Two upstream (surface and 1-meter depth) **(composites from the left side, center and right side)**
  - Two downstream (surface and 1-meter depth) **(composites from the left side, center and right side)**
  - One at the outfall **(six hour composites)**
- Seventy five samples were collected (five events x 15 samples per event)

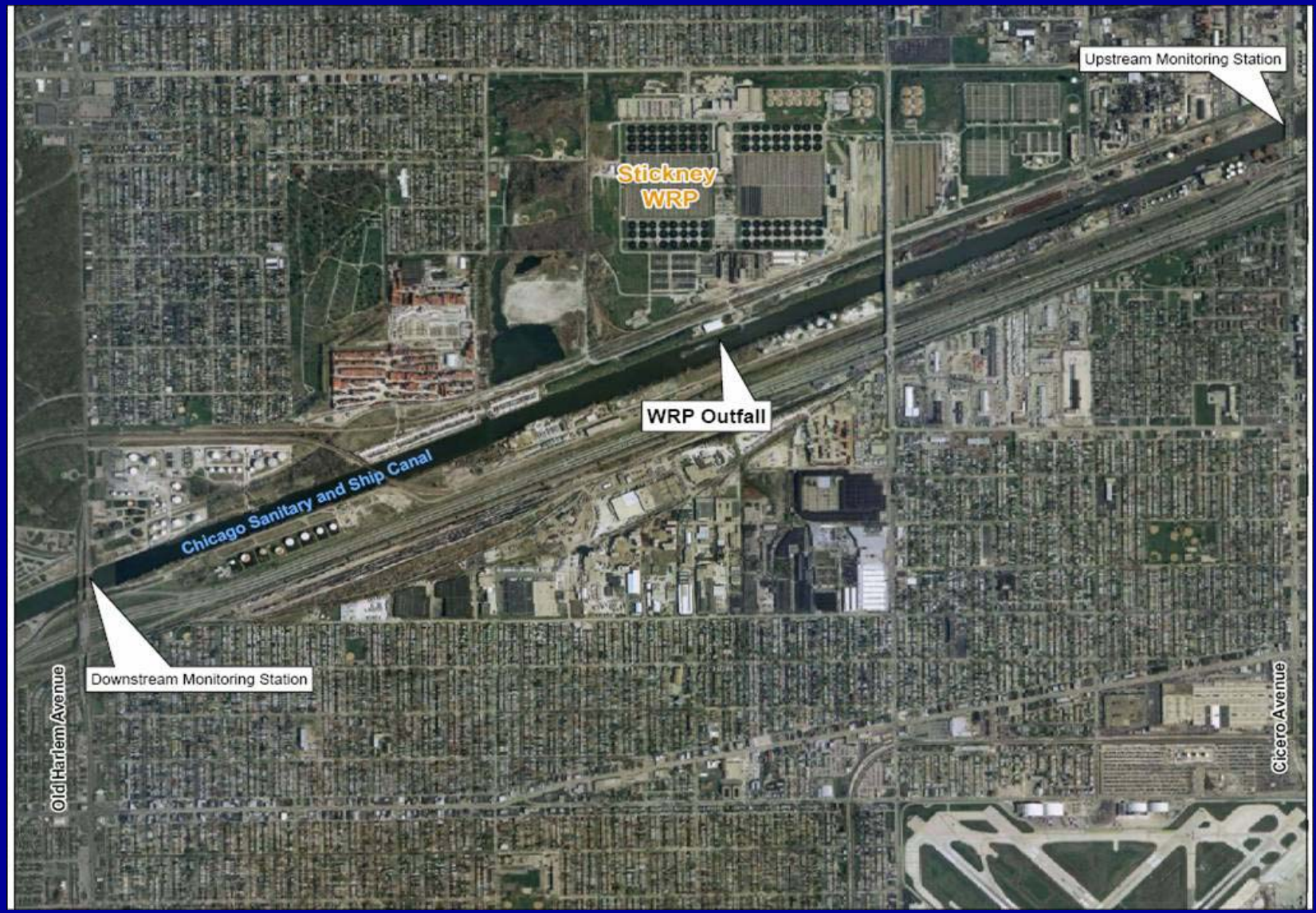
Sampling Crew Training by Dr. Gerba (University of Arizona)

Chicago Area Waterways



North Side WRP

Stickney WRP



Calumet WRP


Calumet WRP
WRP Outfall
Downstream Monitoring Station
Little Calumet River
Indiana Aveune
Halsted Street
Upstream Monitoring Station

MICROBIAL TEST RESULTS

- Enteric viruses: i) total culturable viruses, (ii) adenovirus; and (iii) *calicivirus*
- *Cryptosporidium parvum* and *Giardia lamblia*
- *Salmonella*
- *Pseudomonas aeruginosa*
- Fecal coliforms
- *Escherichia coli*
- *Enterococci*

Summary of Protozoa Results

- No infectious *Cryptosporidium* oocysts were detected in the samples analyzed
- Most *Giardia* cysts found in the samples at all sites were non-viable
- Outfall samples at the Stickney and North Side WRPs contained the highest level of viable cysts
- Viable cysts were also found in upstream samples at North Side and Stickney
- Not all viable *Giardia* cysts are capable of causing infection

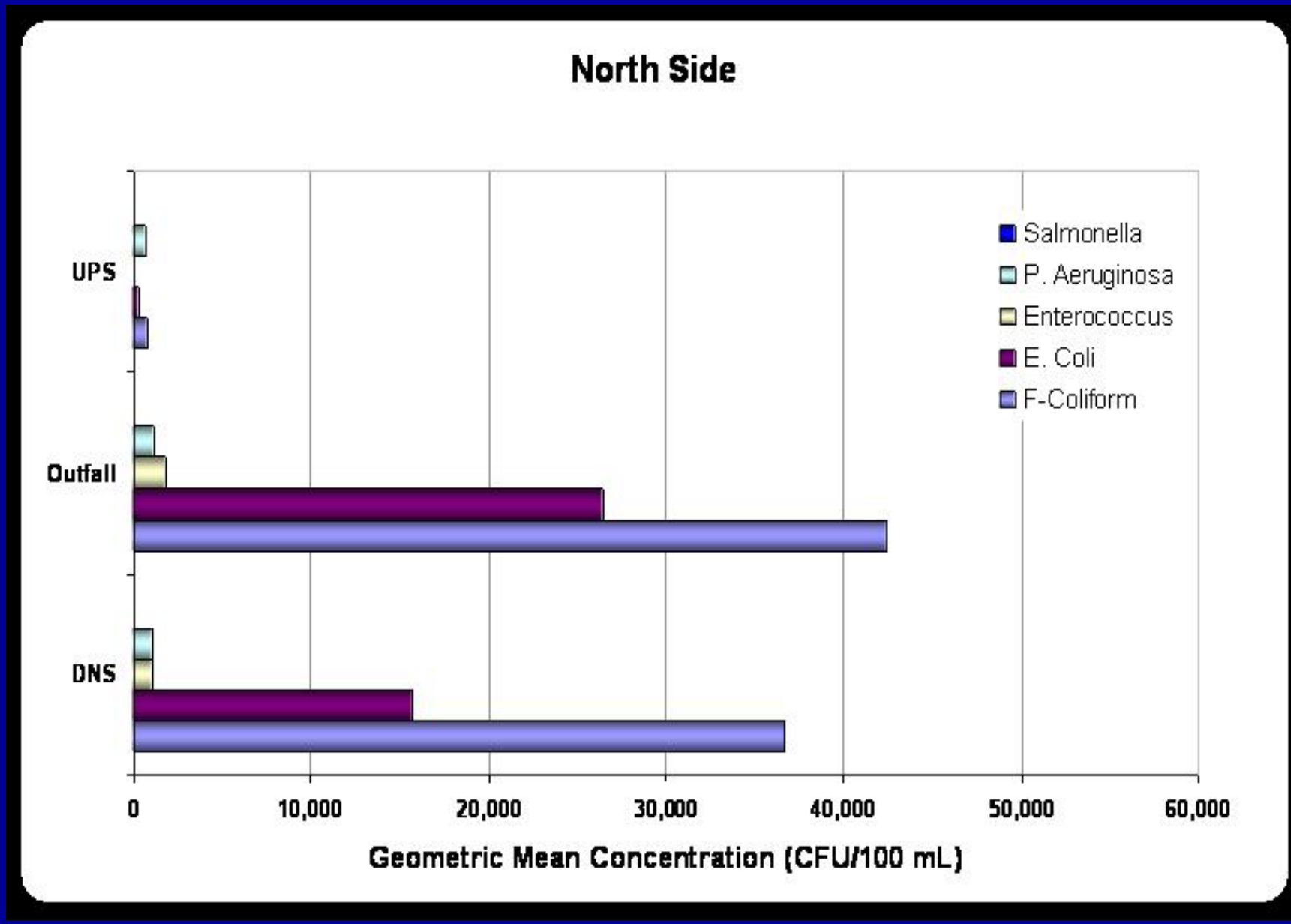
Virus Results

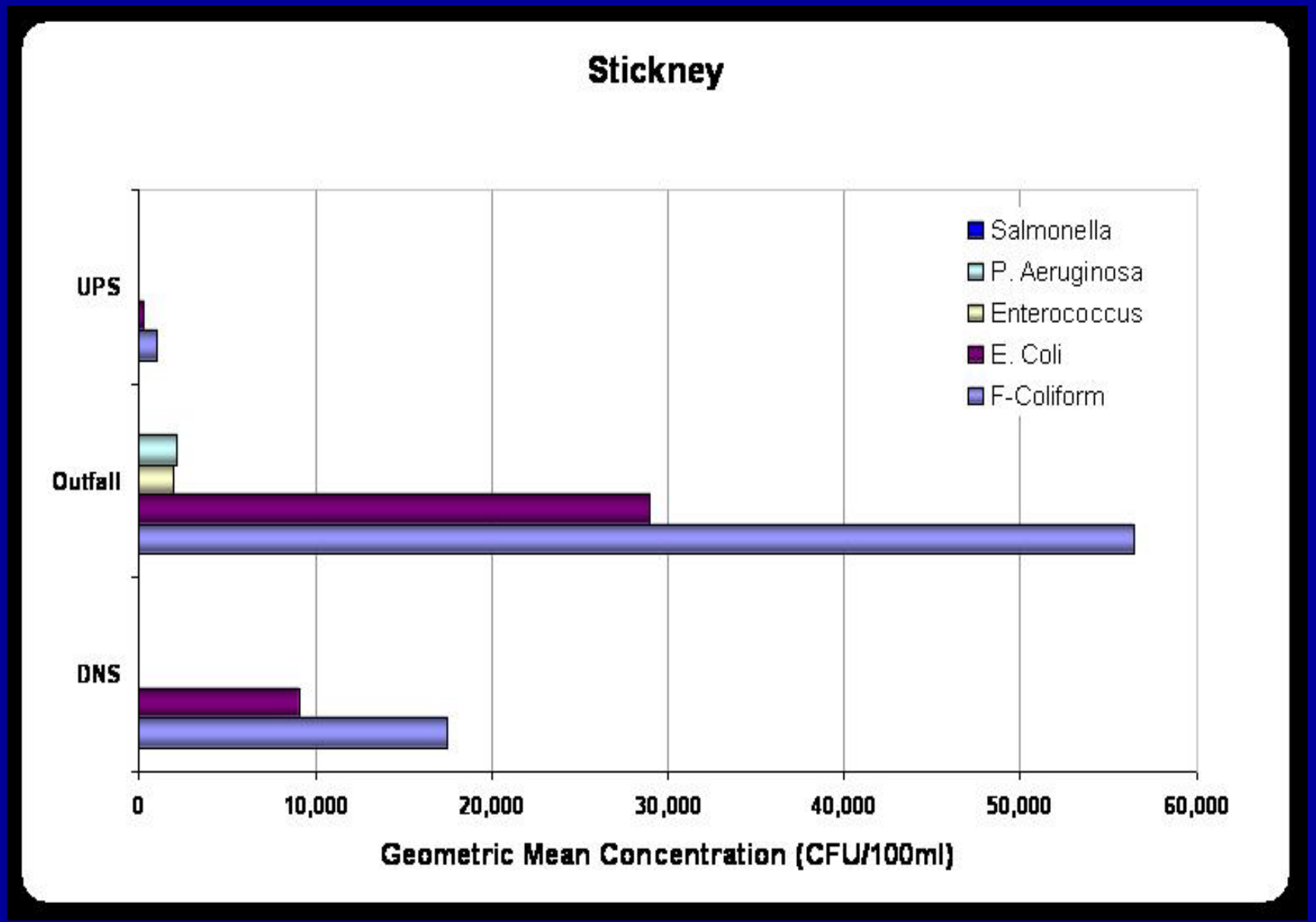
Positive (%)	Cell Line	Virus
23	BGM	Enteric viruses
56	PLC/PRF5	Total Culturable
41	*[PCR confirmation]*	Adenovirus
7	PCR	*Calicivirus*

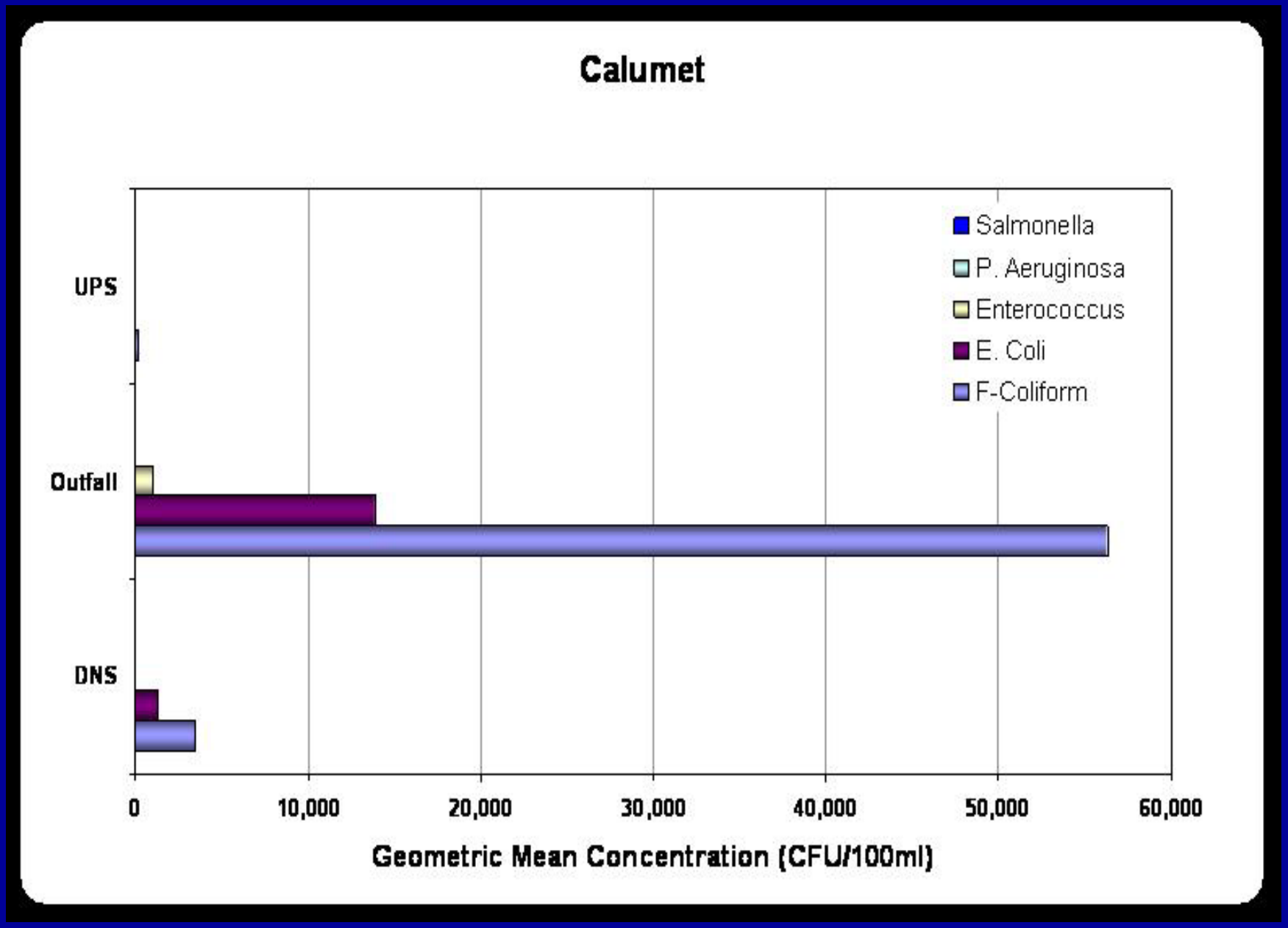
Virus	North Side	Stickney	Calumet
Enteric Upstream Downstream Outfall	8/25 (29%) 1.04-3.25MPN/100L 2.12 -16.07MPN/100L 1.33MPN/77.14L-21MPN/84.9L	6/25 (24%) 1.03-3.25 MPN/100L 1.02-1.03MPN/100L <1MPN/100L	3/25 (12%) 1.04MPN/100L 1.04MPN/100L 1.02MPN/100L
Adenovirus Upstream Downstream Outfall	12/25 (48%) 1.5-2.94MPN/100L 5.03-27.6MPN/100L 45.1-256MPN/100L	13/25 (52%) 11-117MPN/100L 1.39-112MPN/100L 8.39-36.9MPN/100L	6/25 (24%) <1MPN/100L 1.31-3.05MPN/100L 7.52-15.5MPN/100L
Calicivirus Upstream Downstream Outfall	1/25 (4%) ND ND 35,000 PCRMPN/100L	3/25(12%) 181-511PCRMPN/100L 176 PCRMPN/100L ND	1/25 (4%) ND ND 781 PCRMPN/100L

BACTERIA RESULTS OVERVIEW

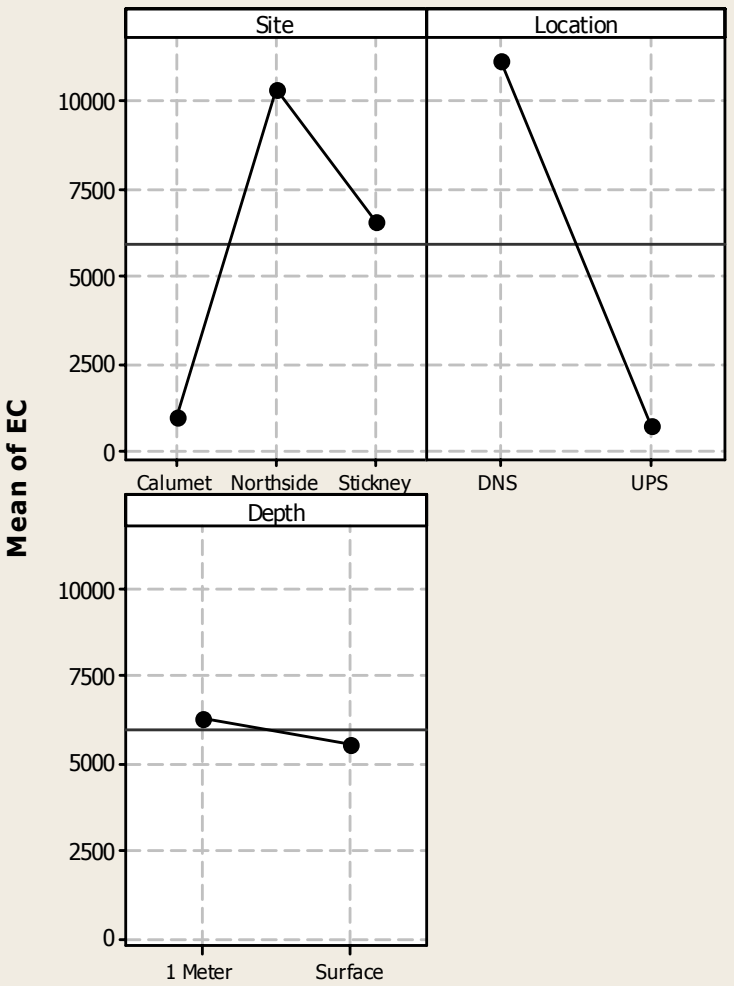
- Geometric Means
- Analysis of Variance (ANOVA)
  - Site: North Side, Stickney, Calumet
  - Location: Upstream, Downstream
  - Depth: Surface, 1 meter
- Pathogen/Indicator Correlations

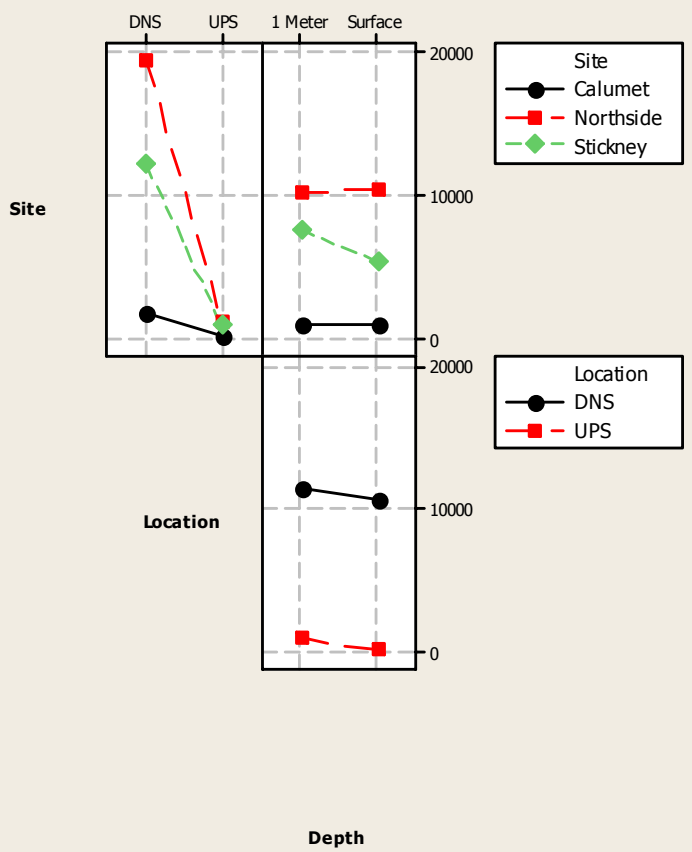

North Side
UPS
Outfall
DNS
Salmonella
P. Aeruginosa
Enterococcus
E. Coli
F-Coliform
0
10,000
20,000
30,000
40,000
50,000
60,000
Geometric Mean Concentration (CFU/100 mL)


Stickney
UPS
Outfall
DNS
Salmonella
P. Aeruginosa
Enterococcus
E. Coli
F-Coliform
0
10,000
20,000
30,000
40,000
50,000
60,000
Geometric Mean Concentration (CFU/100ml)

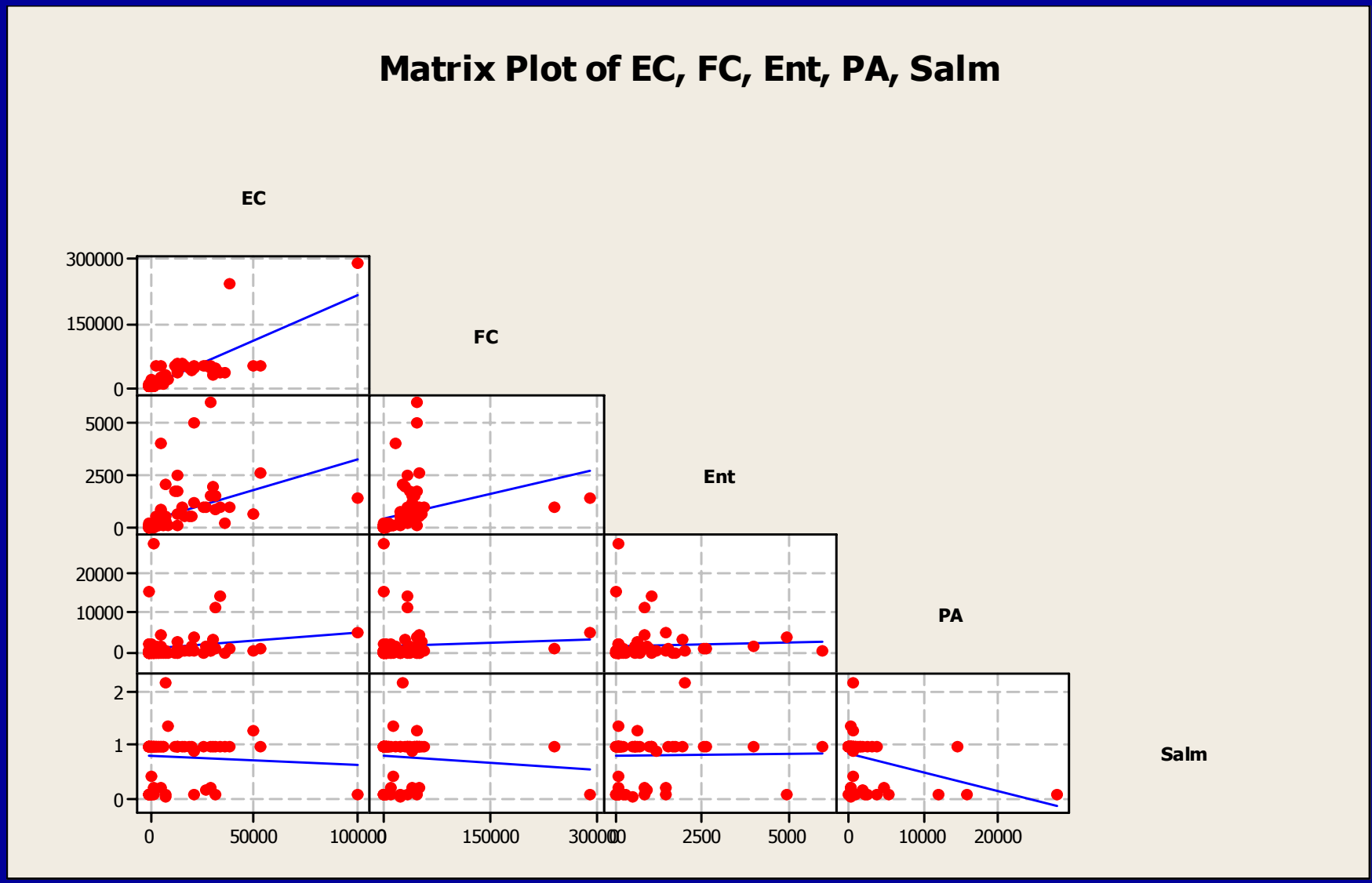

Calumet
UPS
Outfall
DNS
Salmonella
P. Aeruginosa
Enterococcus
E. Coli
F-Coliform
0
10,000
20,000
30,000
40,000
50,000
60,000
Geometric Mean Concentration (CFU/100ml)

ANOVA : *E. coli* versus Site, Location, Depth





Correlations Of In-Stream Bacteria Correlations



SUMMARY OF BACTERIA RESULTS

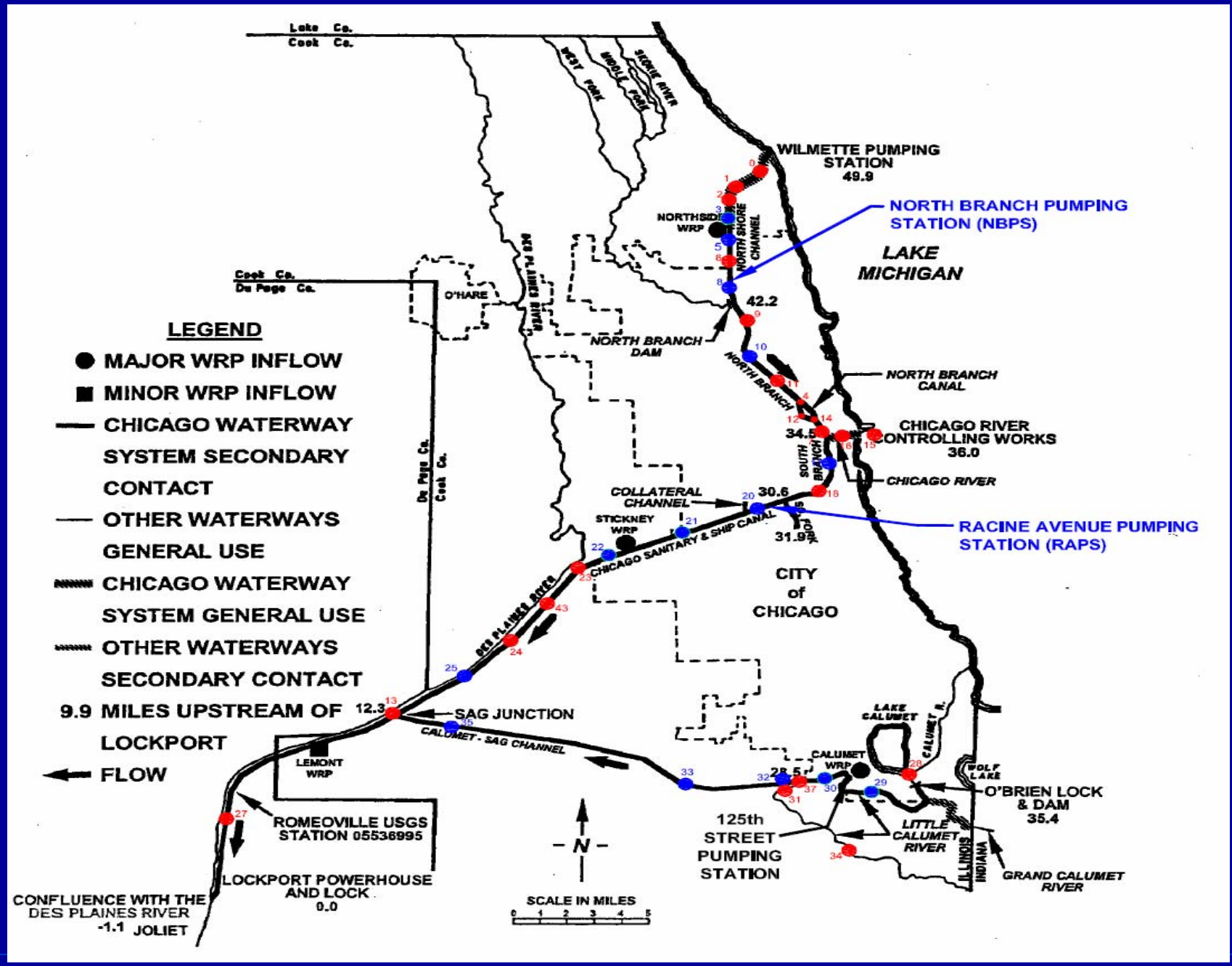
- The concentrations at North Side, Stickney, and Calumet are statistically different
- The concentrations upstream are statistically different (lower) than the concentrations downstream
- There is no statistical difference in bacteria concentrations by depth (1-meter and surface)
- There is a good correlation between *E. coli* and fecal coliform concentrations

WET WEATHER SAMPLING OBJECTIVES

- Evaluate the impact of Pumping Station CSOs and other wet weather impacts on the microbial quality of the CWS
- Estimate pathogen risk to recreational users of the CWS due to wet weather conditions

WET WEATHER SAMPLING

- Nine sampling events **(June-October)**
- Five waterway sampling locations and outfall
- Analyze for the same microorganisms as for dry weather
- Criteria for wet weather sampling


Lake Co.
Cook Co.
WEST FORK
MIDDLE FORK
SKOKIE RIVER
WILMETTE PUMPING STATION
49.9
NORTH BRANCH PUMPING STATION (NBPS)
NORTHSIDE WRP
NORTH SHORE CHANNEL
LAKE MICHIGAN
Cook Co.
Du Page Co.
O'HARE
DES PLAINES RIVER
42.2
NORTH BRANCH DAM
NORTH BRANCH
NORTH BRANCH CANAL
CHICAGO RIVER CONTROLLING WORKS
36.0
34.5
SOUTH BRANCH
CHICAGO RIVER
COLLATERAL CHANNEL
30.6
STICKNEY WRP
RACINE AVENUE PUMPING STATION (RAPS)
31.9
CHICAGO SANITARY & SHIP CANAL
CITY of CHICAGO
DES PLAINES RIVER
LEGEND
MAJOR WRP INFLOW
MINOR WRP INFLOW
CHICAGO WATERWAY SYSTEM SECONDARY CONTACT
OTHER WATERWAYS GENERAL USE
CHICAGO WATERWAY SYSTEM GENERAL USE
OTHER WATERWAYS SECONDARY CONTACT
9.9 MILES UPSTREAM OF LOCKPORT
FLOW
12.3
SAG JUNCTION
CALUMET - SAG CHANNEL
LEMONT WRP
LAKE CALUMET
CALUMET R.
CALUMET WRP
WOLF LAKE
O'BRIEN LOCK & DAM
35.4
125th STREET PUMPING STATION
LITTLE CALUMET RIVER
ILLINOIS
INDIANA
GRAND CALUMET RIVER
ROMEOVILLE USGS STATION 05536995
LOCKPORT POWERHOUSE AND LOCK
0.0
CONFLUENCE WITH THE DES PLAINES RIVER
-1.1
JOLIET
N
SCALE IN MILES
0 1 2 3 4 5

WET WEATHER SAMPLING LOCATIONS

Upstream of Stickney WRP at the CSSC

- CSSC-Damen Avenue
- CSSC-Cicero Avenue
- RAPS outfall

Downstream of Stickney WRP at the CSSC

- CSSC- Harlem Avenue
- CSSC-Route 83

Upstream of the Calumet WRP at the Little Calumet

- Little Calumet-Indiana Avenue

Downstream of the Calumet WRP at the Little Calumet CSC

- Little Calumet-Halsted Street
- CSC-Ashland Avenue
- CSC-Cicero Avenue
- CSC-Route 83

Upstream of the North Side WRP at the NSC

- NSC-Oakton Avenue

Downstream of the North Side WRP at the NSC and Chicago River

- NSC-Touhy Avenue
- NBPS or North Branch-Wilson Avenue
- North Branch-Diversey Parkway
- South Branch-Madison Street

Wet Weather Sampling Summary

WRP	UPS (per event)	DNS (per event)	PS (per event)	No. of Events	Outfall	Total No.
Stickney	2	2	1	3	1	16
Calumet	1	4	0	3	3	18
North Side	1	3	1	3	1	16
Total						50

WET WEATHER SAMPLING PROTOCOL

- Track storm front
- Wet weather sampling criteria
  1. Following dry period (72-hour)
  2. Rainfall depth/duration -At least 1” of precipitation in a six hour period
- Alert sampling crew
- Alert laboratory
- Trigger monitoring

Historical Rainfall Depth

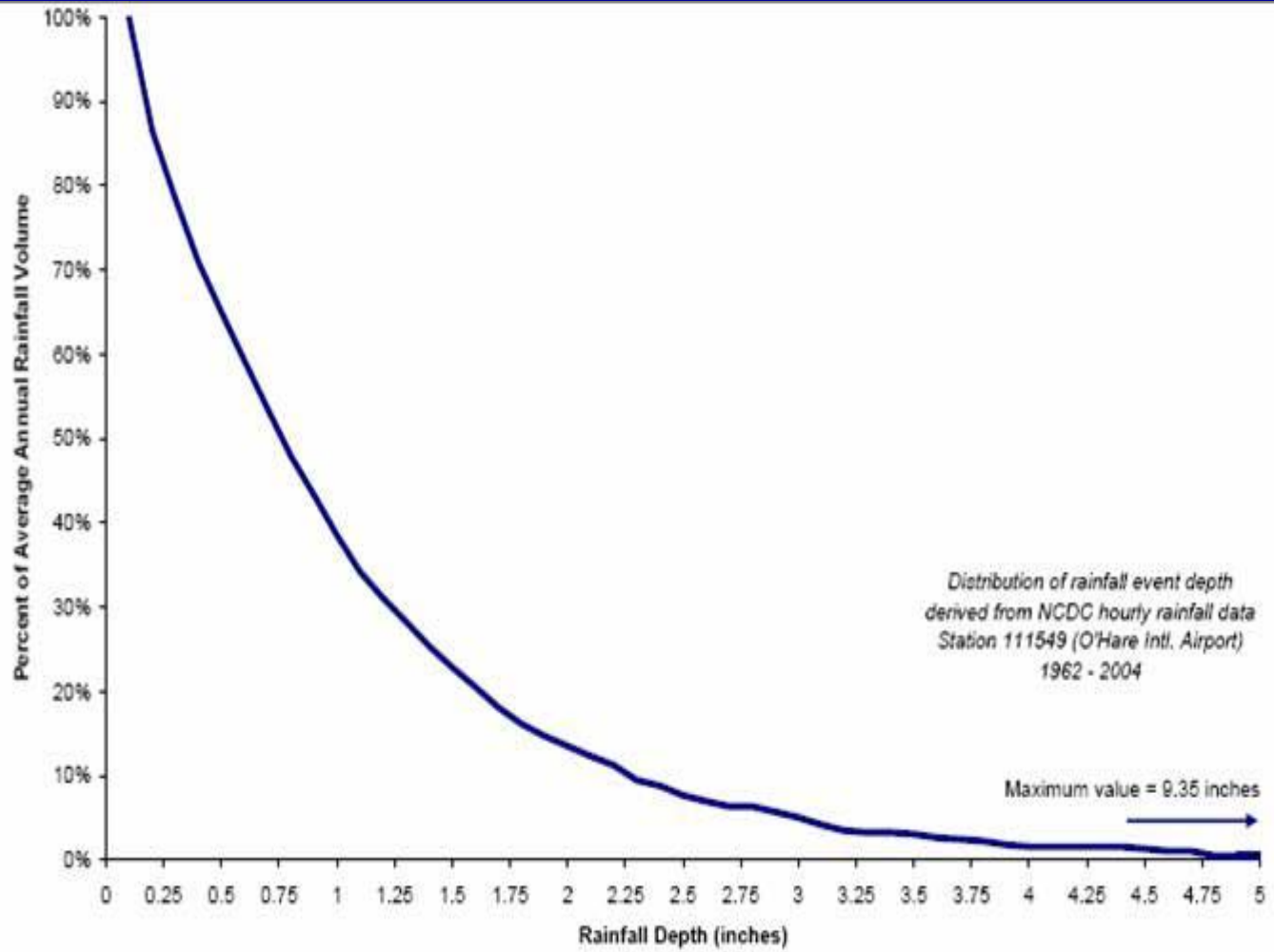


Figure 1. Frequency distribution for rainfall event depth
NCDC Station 11549 (O'Hare Intl. Airport) 1962-2004

Historical Rainfall Event Intensity

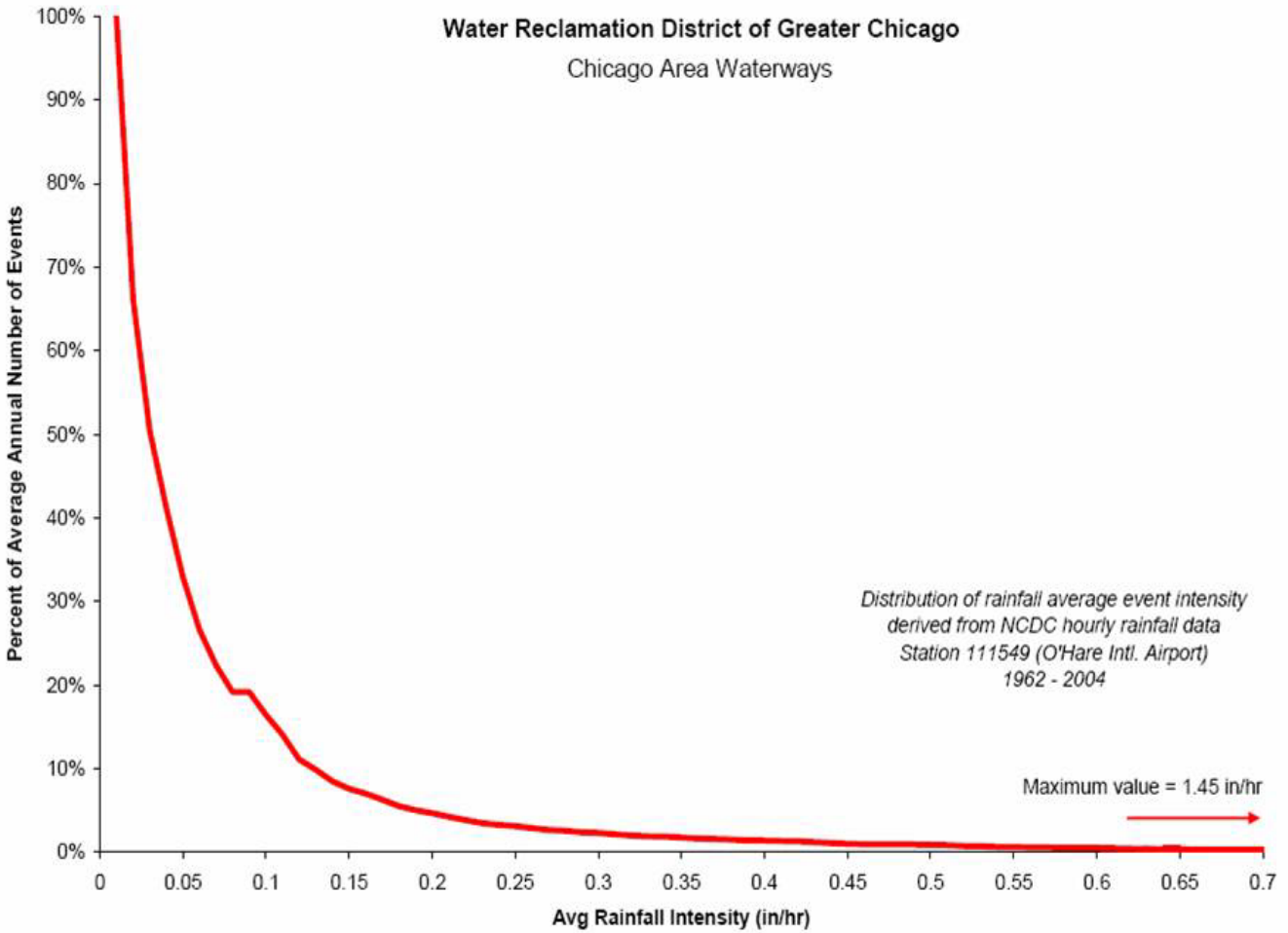
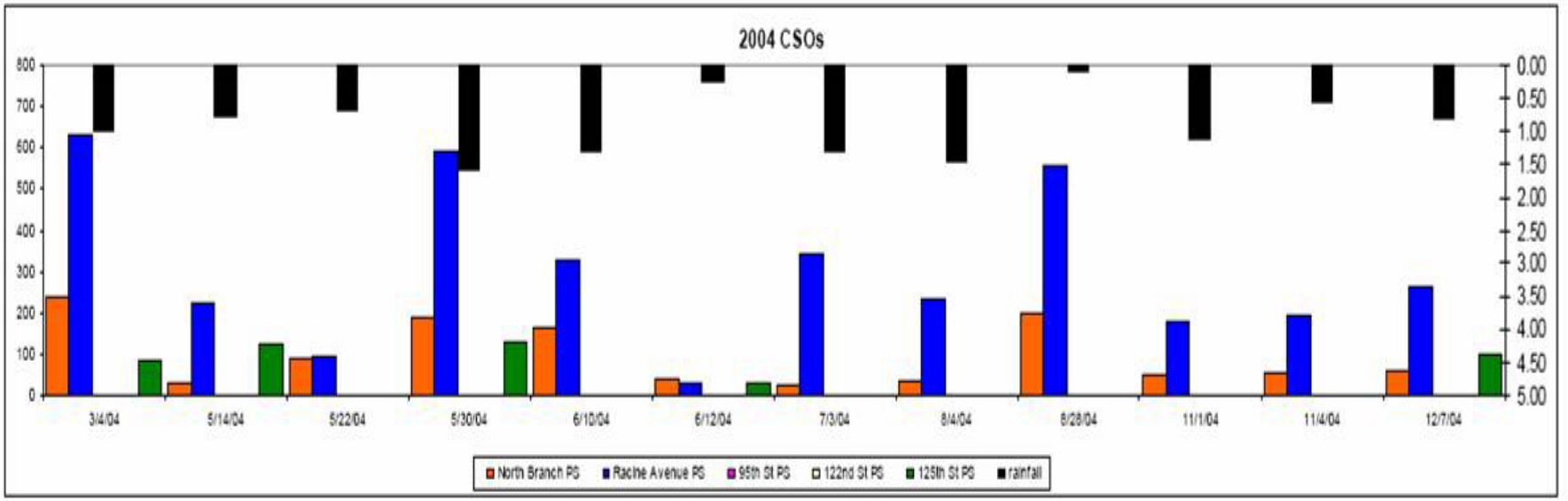


Figure 2. Frequency distribution for rainfall event average intensity
NCDC Station 11549 (O'Hare Intl. Airport) 1962-2004

CSO Volumes and Rainfall Depths



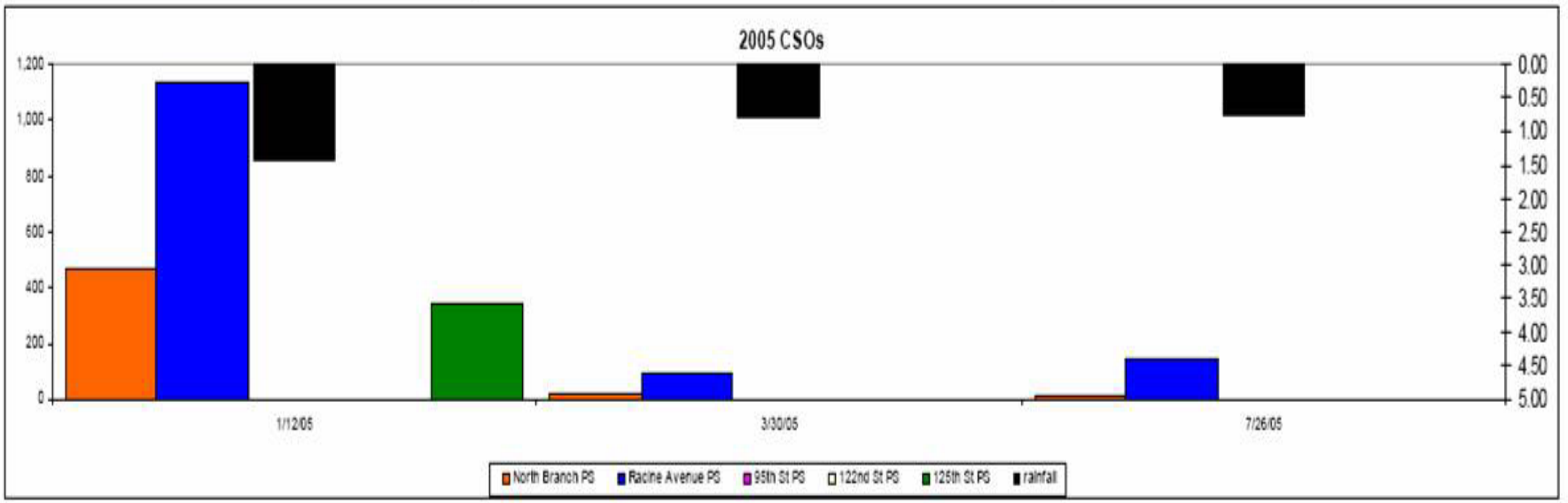


Figure 6. CSO discharges (millions of gallons) and associated rainfall event depths (inches)

Dry Weather Risk Assessment

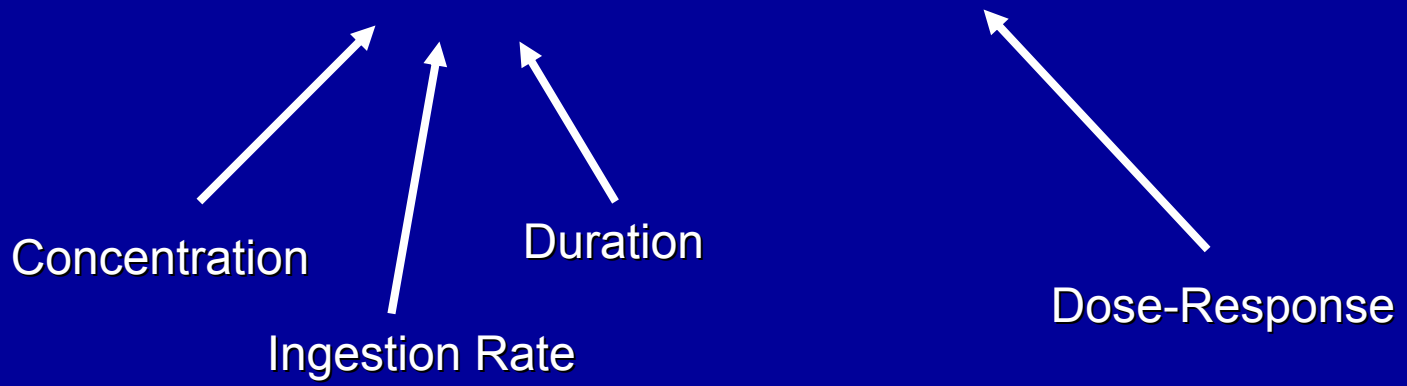
Risk Components

- **Concentration Term**
  - What are the Levels of Pathogens in the Waterway?
    - Spatial distribution (location of exposure)
    - Temporal distribution (CSO, wet weather, dry weather)
- **Exposure Parameters**
  - What is the Dose?
    - Type of recreation
    - Exposure location (launch point)
    - Ingestion rate
    - Exposure duration
- **Dose Response**
  - What is the Relationship Between Dose and Risk?
    - Primary infection
    - Risk of illness given infection
    - Secondary transmission

Risk Calculations

The probability of illness can be calculated by developing simple average exposure inputs – Deterministic Analysis.

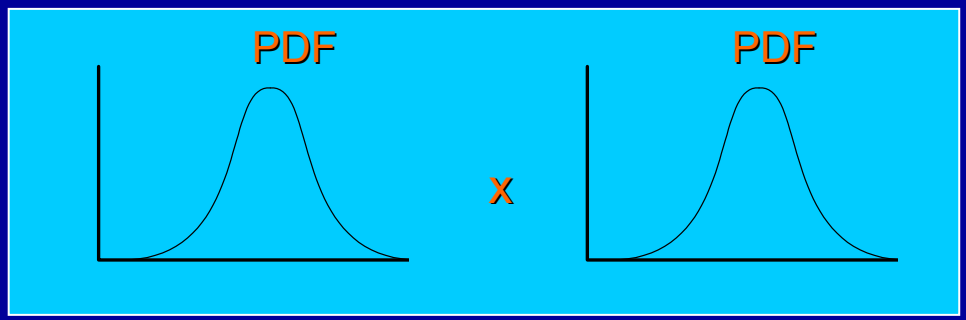
Risk = Exposure x Potency



Use of averages for exposure inputs loses information on the range of exposures possible.

Probabilistic Risk Calculation

Input values in the Risk Assessment are represented by a distribution rather than a single number.



= Distribution of Risks

Monte Carlo analysis (simulations) used to estimate solutions for mathematical problems with difficult or impossible closed form analytical solutions.

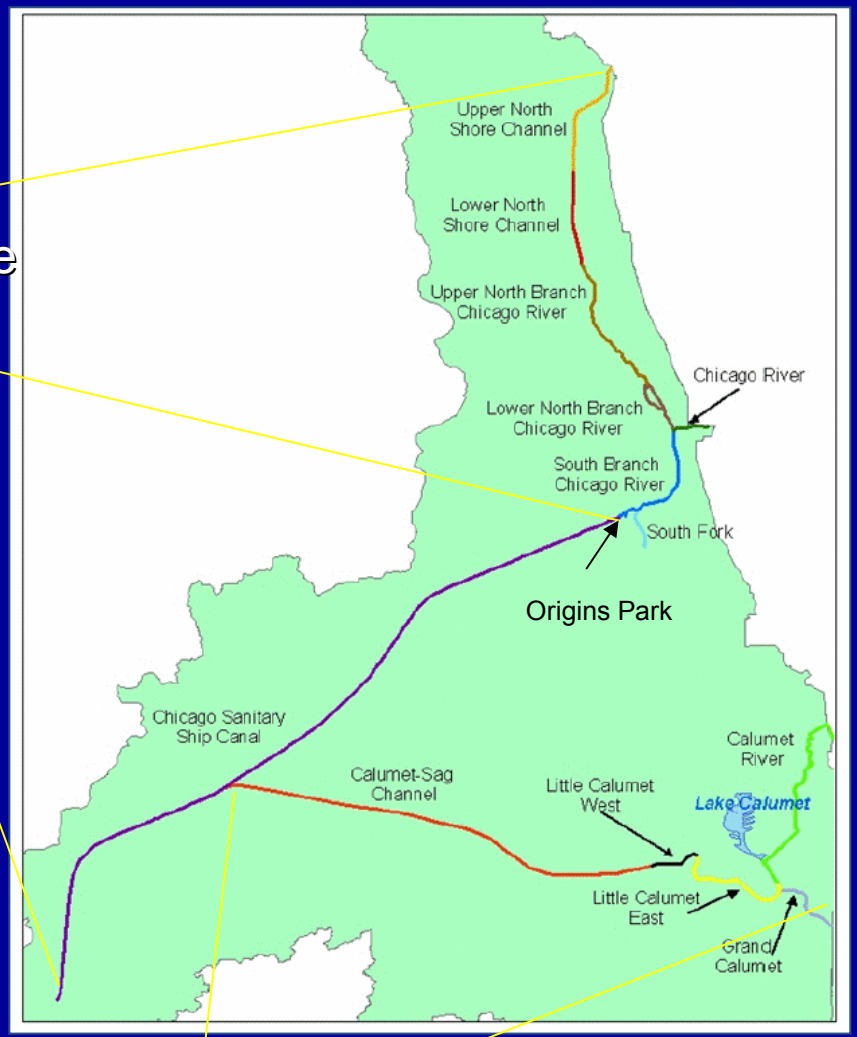
Waterway Divisions

Waterway is divided in three sections and designated according to the WRP.

North Side

Stickney

Calumet

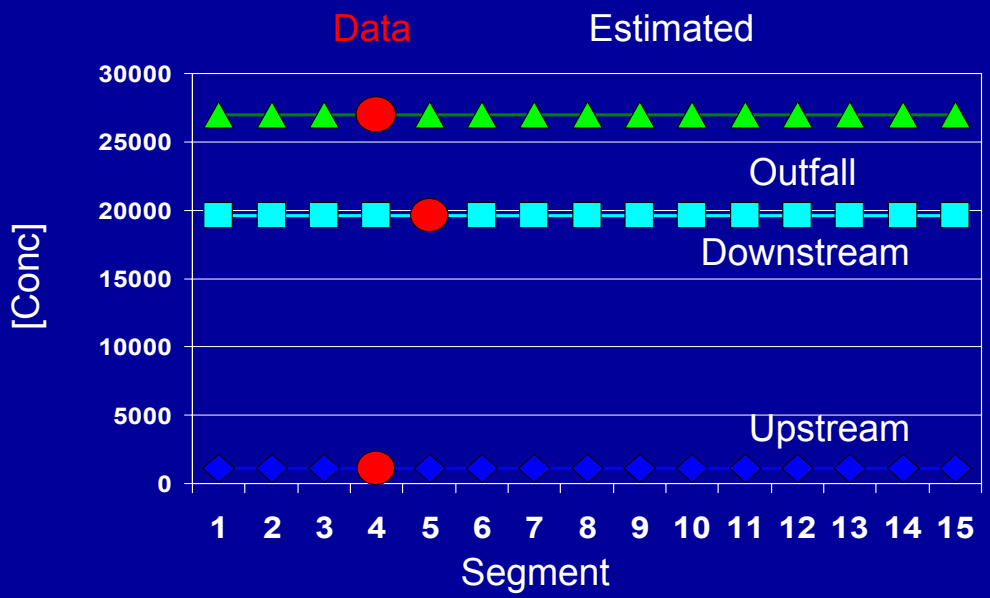


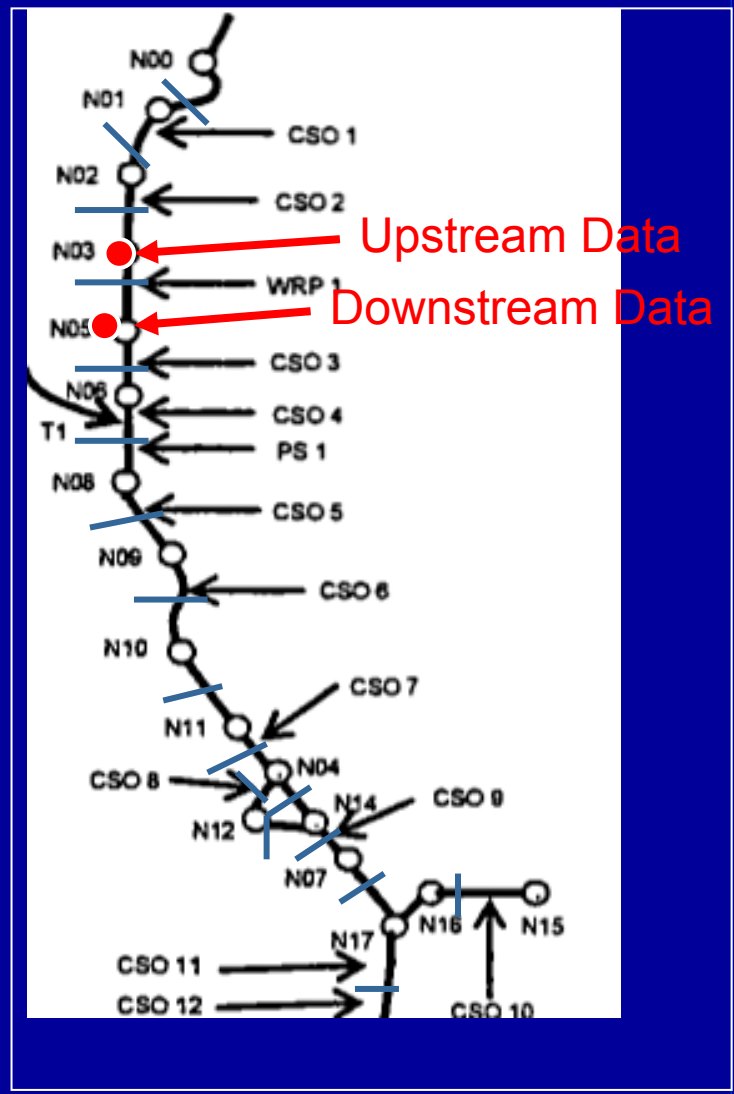
This division scheme works well with the UAA data and intended use designations.

Pathogen Concentrations

The risk assessment requires a concentration term for each segment

In the dry weather assessment, the results were assumed to represent the entire waterway segment. This is a conservative assumption.





Concentration Data Inputs

- The entire pathogen sampling dataset was used as input for the simulations.
- For each simulation the data from a single sampling event was selected to represent that particular recreational users exposure concentration.
- The process was repeated a number of times with a different randomly selected concentration term used in each simulation.
- This data re-sampling technique is commonly used in probabilistic risk assessment and accounts for variation in the input pathogen concentration data.

Concentration Data Simulations

Simulation #1

Randomly Select Waterway Pathogen Levels From Dry Weather Dataset

[Pathogen Level A]

Compute Outcome 1

Simulation #2

Randomly Select Waterway Pathogen Levels From Dry Weather Dataset

[Pathogen Level B]

Compute Outcome 2

Repeat Process Many Times

Simulation #n

Randomly Select Waterway Pathogen Levels From Dry Weather Dataset

[Pathogen Level C]

Compute Outcome n

Compile Results

Exposure Assessment

Canoeist – canoe, scull

- Frequent contact with wet items (paddles, boat deck, equipment)
- Close proximity to water surface
- Occasional direct contact with water (hand immersion)

Fishing – shoreline, powerboat, rowboat

- Occasional contact with wet items (tackle, boat deck, equipment)
- Infrequent direct contact with water

Pleasure Boating – sailboat, powerboat, tour boats

- Infrequent contact with wet items (boat deck, equipment)
- No direct water contact

Ingestion Rate

Swimming – Pool

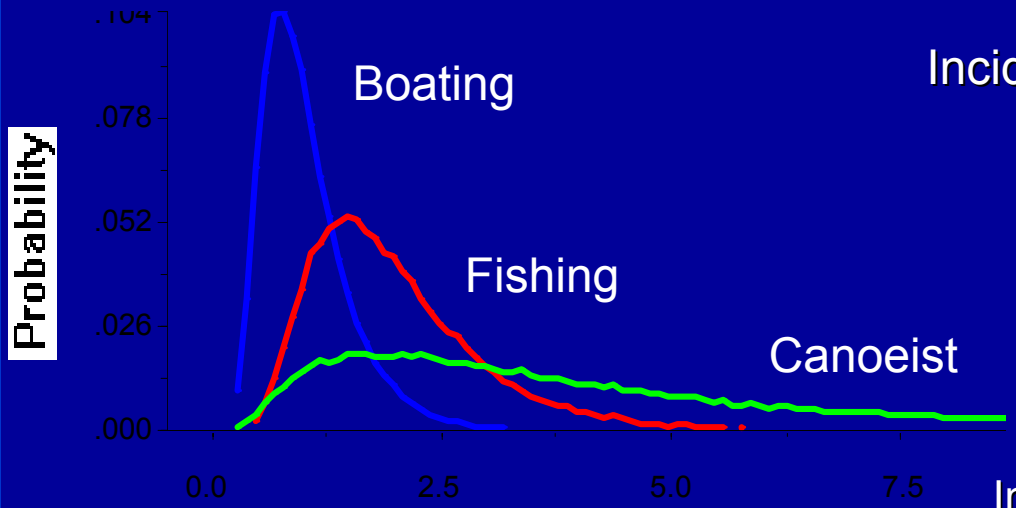
50 mL/hr; USEPA. (1989). Exposure Factors Handbook.

Swimming - Recreational Water

30mL/event; Crabtree, K.D., Gerba, C.P., Rose, J.B. and Haas, C.N. (1997). Waterborne adenoviruses: a risk assessment. Water Science Technology, 35, 1–6.

30mL/event; Van Heerden, M.M. Ehlers, J.C. Vivier AND W.O.K. Grabow. (2005). Risk assessment of adenoviruses detected in treated drinking water and recreational water. Journal of Applied Microbiology, 99, 926–933.

Ingestion Rate



Incidental ingestion of water developed using a lognormal distribution.

Samples were drawn from each input distribution.

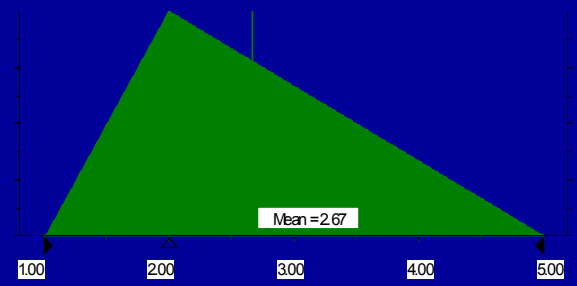
Ingestion Results from Simulations (mL/hr)

Percentiles	Boating	Fishing	Canoeing
10%	0.49	0.98	1.21
25%	0.65	1.30	2.02
50%	**0.90**	**1.79**	**3.52**
75%	1.23	2.47	6.15
90%	1.64	3.28	10.16
95%	1.95	3.89	13.84
97.5%	2.26	4.51	17.99
100%	6.43	20.13	30.00

Exposure Duration

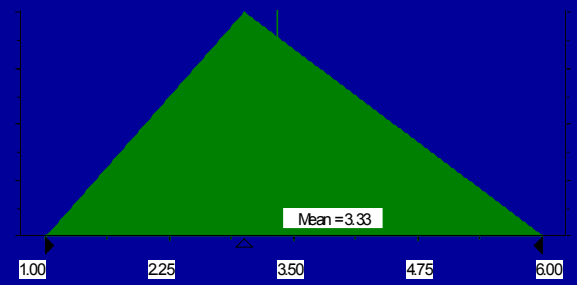
Canoeing - Triangular Distribution

- Minimum 1 hour
- Mode 2 hours
- Maximum 5 hours



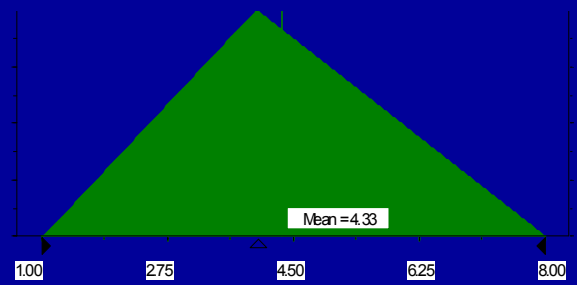
Fishing - Triangular Distribution

- Minimum 1 hour
- Mode 3 hours
- Maximum 6 hours



Pleasure Boating - Triangular Distribution

- Minimum 1 hour
- Mode 4 hours
- Maximum 8 hours



Exposure Data - UAA Survey

Proportion of Recreational Use

	Northside	Stickney	Calumet
Canoeing	20.2%	1.2%	0.5%
Fishing	72.2%	28.4%	47%
Pleasure Boating[1]	7.6%	70.4%	52.5%

[1]Based on assumptions of 2.5 users per boat

Dose Response Models

Exponential Model

$$P(D) = 1 - \exp(-D/k)$$

Where: D = dose (# organisms)
k = exponential parameter

Beta Poisson Model

$$P(D) = 1 - \left[1 + \frac{D}{N_{50}}\left(2^{1/\alpha} - 1\right)\right]^{-\alpha}$$

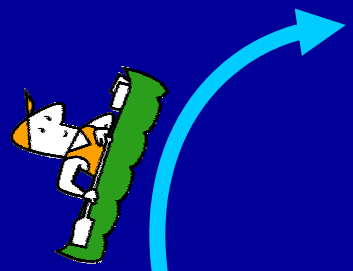
Where: D = dose (# organisms)
α = beta Poisson parameter
N_{50} = beta Poisson parameter (median infectious dose)

	β-poisson[c]		Expo.[c]	Secondary	Secondary
Pathogen	α	b	r	Attack Rate	Source
Total Enteric Viruses[a]			78.3	50%	Default Assumption
Adenovirus[a]			78.3	50%	Fox, 1989; Foy, et al 1968
Calicivirus (norovirus)[b]	0.251	6.17		86%	Rodriquez et al., 1979, J Infec Dis
Cryptosporidium			238	10%	Insulander et al., 2005 Scand J Infect Dis
Giardia			50.5	17%	Pickering et al., 1981, J Pediatrics
Salmonella	0.3126	23600		50%	Default Assumption
Escherichia coli	0.1778	8.60E+07		50%	Default; DuPont 1969 Applied Microbiology

[a] The dose-response for echovirus 12 was used as a surrogate.
[b] The dose-response for rotovirus was used as a surrogate.
[c] Dose-response relationships taken from Haas, 1999.

Dry Weather Probabilistic Risk Analysis

Simulation Procedure



Repeat analysis
1,000,000 events

1) Select a day from waterway concentrations dataset
2) Select an individual's recreation type
3) Select an exposure location
4) Select an exposure duration
5) Select an ingestion rate
6) Develop a dose
7) Determine infection/illness
8) Determine secondary illnesses

Express results as illnesses per thousand events

Illness Rates for All Pathogens

Illness Rate Per One Thousand Exposure Events

Exposure Input	Waterway		
	Northside	Stickney	Calumet
Upstream Samples[c]	0.04	0.043	0.000
Downstream Samples[c]	0.55	0.022	0.046
Combined Upstream and Downstream Samples[c]	**0.287**	**0.150**	**0.028**
Average Outfall Samples	1.003	0.713	0.680

[a] Includes all primary and secondary (family member) gastrointestinal illnesses expected from the waterway exposures.
[b] Includes combined gastrointestinal illnesses from E. coli, salmonella, total enteric viruses, adenoviruses, giardia, and cryptosporidium.
[c] Waterway concentration inputs for the simulations were randomly selected (bootstrap sampled) from datasets that includes the indicated sample sets.

Activity Risk Breakdown

Proportion of Recreational User Type Contributing to Expected Illnesses

Recreational Use	Waterway		
	North Side	Stickney	Calumet
Canoeing	51%	3%	1%
Fishing	45%	44%	70%
Boating	4%	53%	29%

Based on Combined Waterway Samples (upstream and downstream) risk estimates

Pathogen Risk Breakdown

	Illnesses per 1,000 Exposures		
Pathogen	**Northside**	**Stickney**	**Calumet**
E coli (pathogenic)	0.074	0.034	0.007
Salmonella	0.004	0.000	0.002
Giardia	0.000	0.000	0.000
Cryptosporidium	0.000	0.000	0.000
Enteric virus	0.002	0.000	0.000
Adenovirus	0.002	0.014	0.002
Total Primary Illnesses	**0.082**	**0.045**	**0.009**
Total Illnesses Including Secondary	**0.287**	**0.150**	**0.028**

Dry Weather Risk Results

- **Risks of Gastrointestinal Illness Low**
  - Both primary and secondary risks below EPA recreational guideline of 8 per 1000 exposures.
  - Risks predominately from *E. coli*.
  - Receptor type and exposure duration most important inputs.
- **Risks Developed Using Conservative Assumptions**
  - Waterway concentrations developed from sampling points near WRPs without accounting for attenuation.
  - Ingestion rates and exposure durations account for high exposure events.