SLOW SAND FILTRATION:
Timeless Technology and Recent Advances

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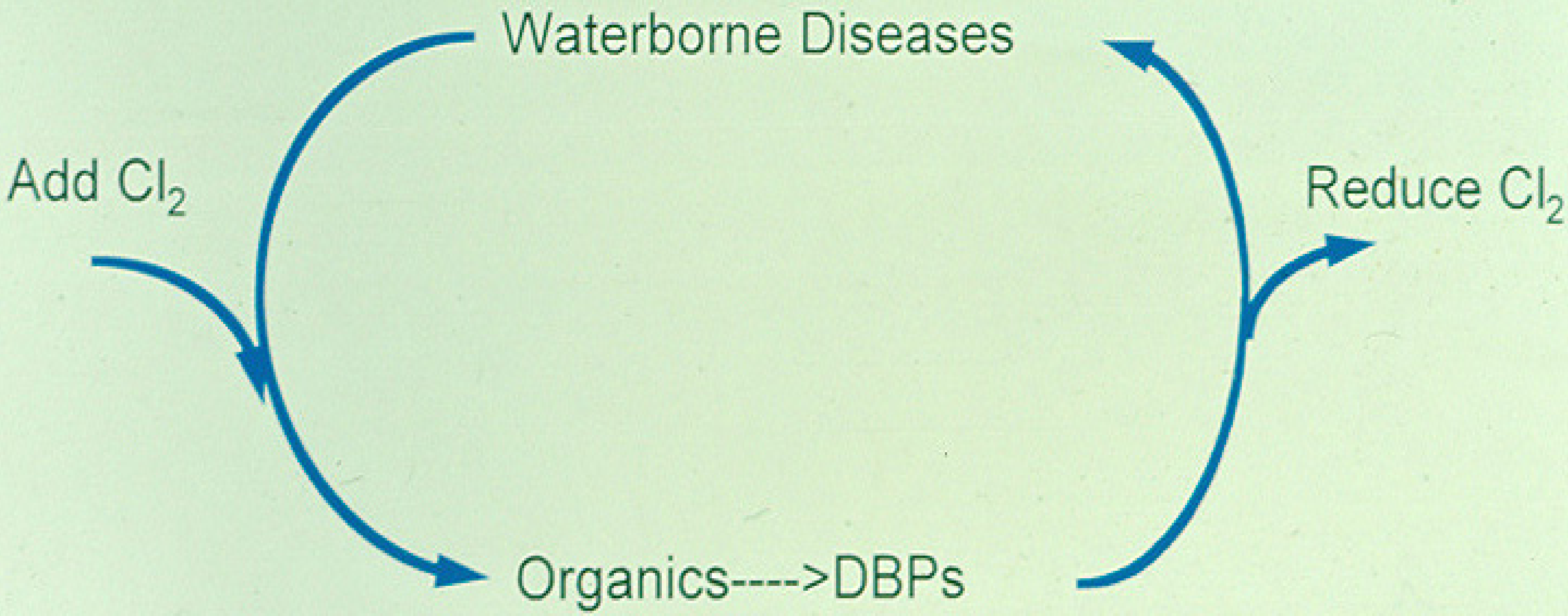
- The operators and managers of all the treatment facilities involved in these studies.
- NE-WTTAC staff and past grad students

Catch - 22



Objectives of Water Treatment

- To produce water safe for human consumption
- To produce a water that is appealing to the consumer
- To produce a water at a ‘reasonable’ cost to the consumer

Small System Concerns

- Limited Financial and Technical Resources

- Economy of Scale

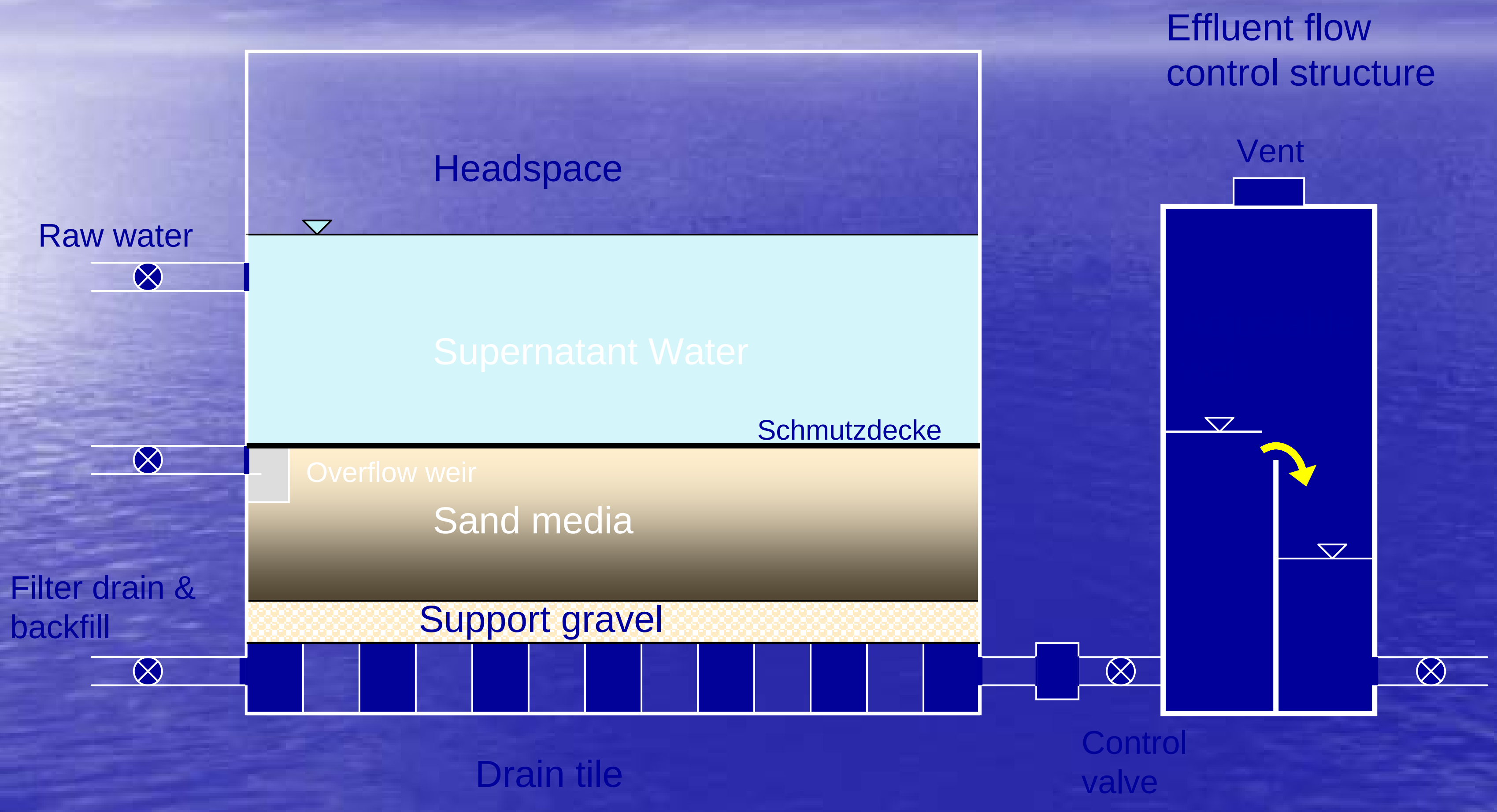
MAJOR COMPONENTS OF A DRINKING WATER TREATMENT SYSTEM

Source Water Collection/ Protection → Pretreatment → Filtration Treatment → Disinfection → Distribution/ Storage

Viable Water Treatment Options for Small Systems

- Packaged Coagulation Treatment Systems
- Pressure Filtration Systems
  - Granular Media
    - Ceramic Media
    - Diatomaceous Earth/Precoat
  - Membranes
- Biological Filtration Systems
  - Riverbank Filtration
  - Slow Sand Filtration

Slow Sand Filtration (SSF)



Characteristic Features of a Conventional Slow Sand Filter

- Slow rate of filtration
- Lack of chemical pretreatment
- Reliance on bioactivity especially at the water-media interface (schmutzdecke)
- Small effective size(d_{10}) and large uniformity coefficient (d_{60}/d_{10}) of sand
- No filter media fluidization
- Relative long filter run time

GENERAL DESIGN CRITERIA FOR SLOW SAND FILTERS

PARAMETERS	TEN STATE STDS	IRC MANUAL
Design Period	-----	10 - 15 Years
Period of Operation	-----	24 hr/day
Filtration Rate	0.08 - 0.24 m/hr (0.03-0.10 gpm/sf)	0.1 - 0.2 m/hr (0.04-0.08 gpm/sf)
Filter Bed Units	2 minimum	2 minimum
Filter Bed Depth	> 30 inches	18 - 35 inches
Sand Media Specs		
effective size	0.30 - 0.45 mm	0.15 - 0.30 mm
uniformity coeff.	< 2.5	< 3 - 5

TYPICAL TREATMENT PERFORMANCE OF CONVENTIONAL SLOW SAND FILTERS

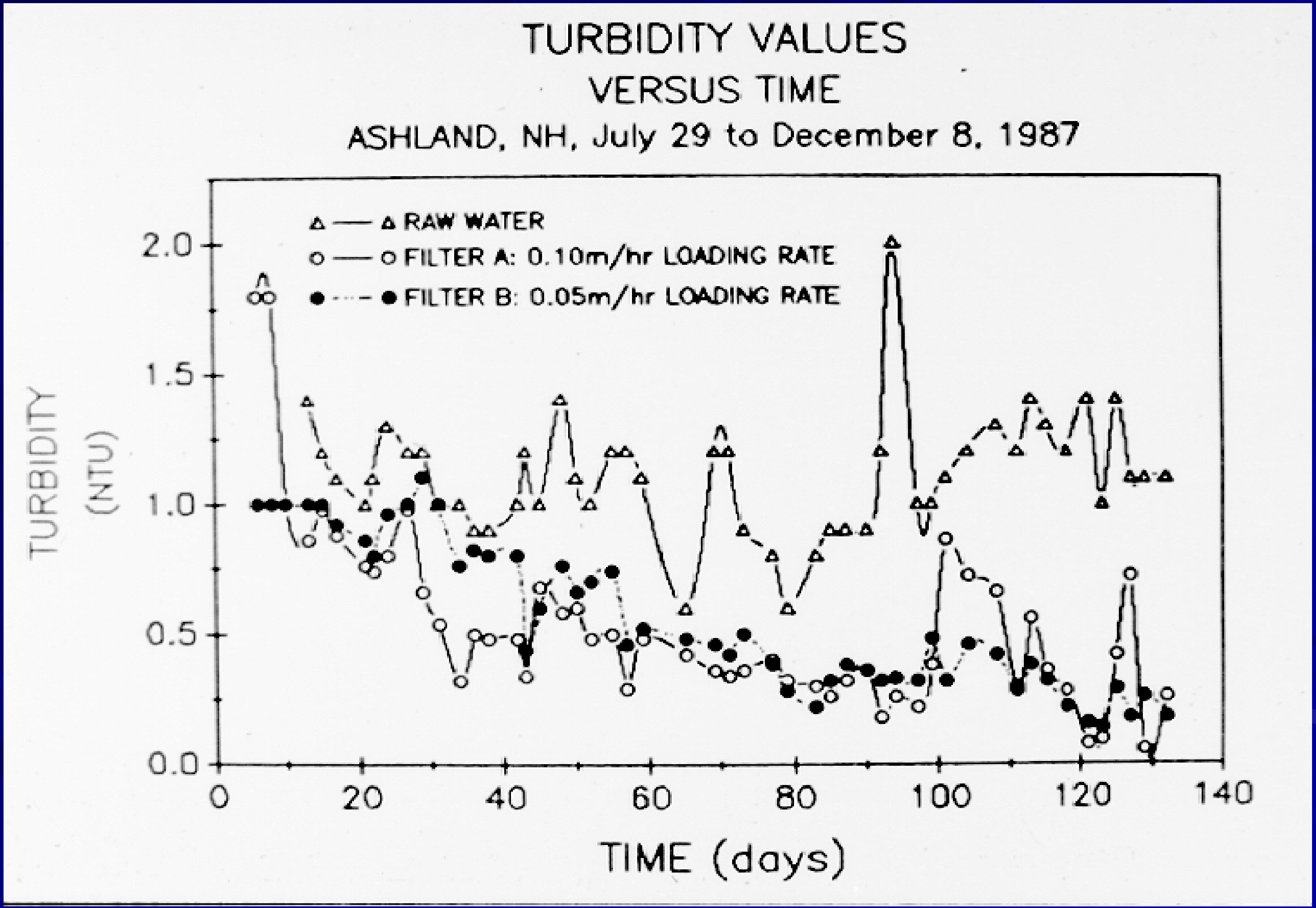
WATER QUALITY PARAMETER	REDUCTION CAPACITY
TURBIDITY	<1.0 NTU
COLIFORM BACTERIA	1-3 LOG UNITS
ENTERIC VIRUSES	2-4 LOG UNITS
GIARDIA CYSTS	2-4+ LOG UNITS
TOTAL ORGANIC CARBON	<15-25%
THM PRECURSORS	<25%
BIODEGRADABLE DOC	<50%

Comparison of RBF and SSF

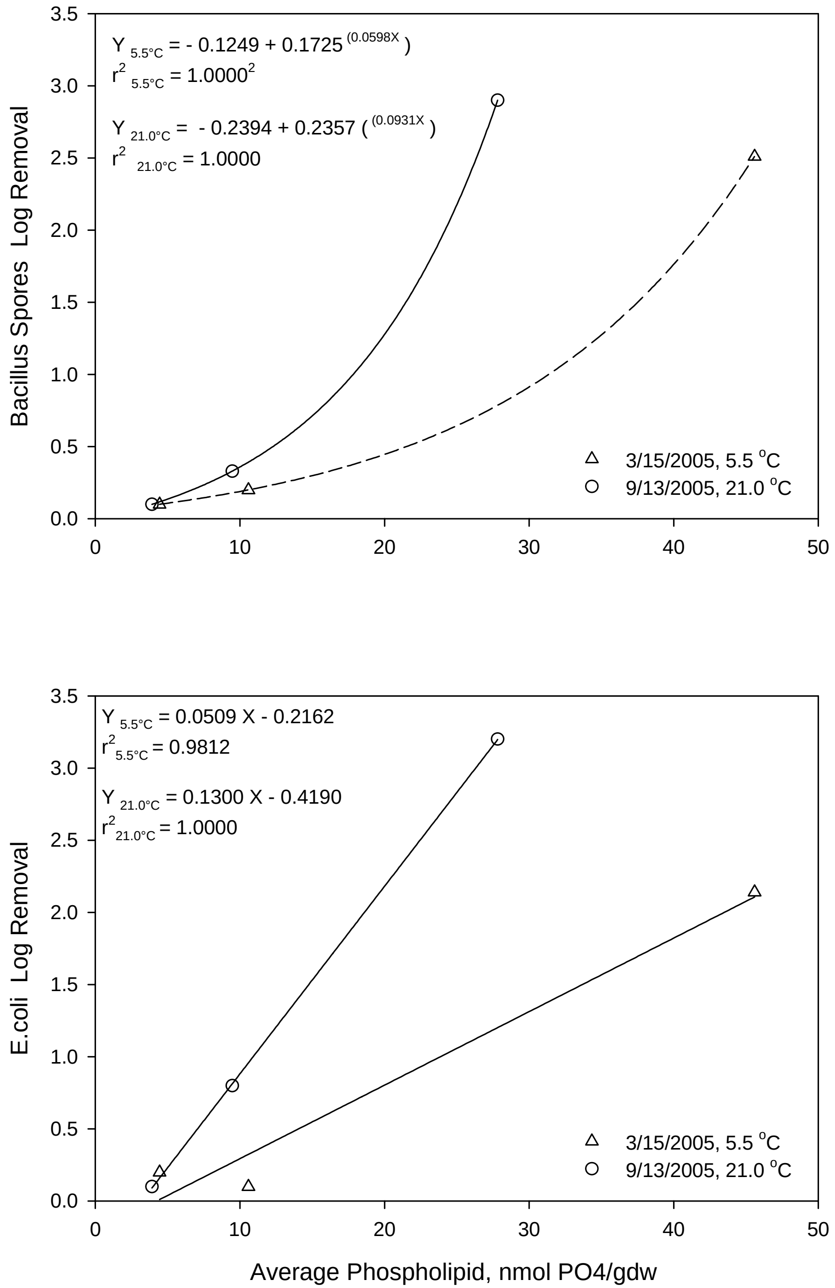
Parameter	Removal by **RBF** (Partinoudi, 2004)	Removal by **SSF** (Partinoudi, 2004)	Removal by **SSF** (based on literature)
DOC	41-85%	13-19%	8-25%
Total Coliforms	>1-1.6 logs*	>1.8-2.2 logs	>1-2 logs*
E.coli	>0.3-0.8 logs*	>1.8logs	>3-4 logs*
Aerobic spores	>1.9-3.5 logs*	>2.1-2.3logs*	>2 logs
Turbidity	77-99%	75-90%	60->90%

* Reduced to detection limit

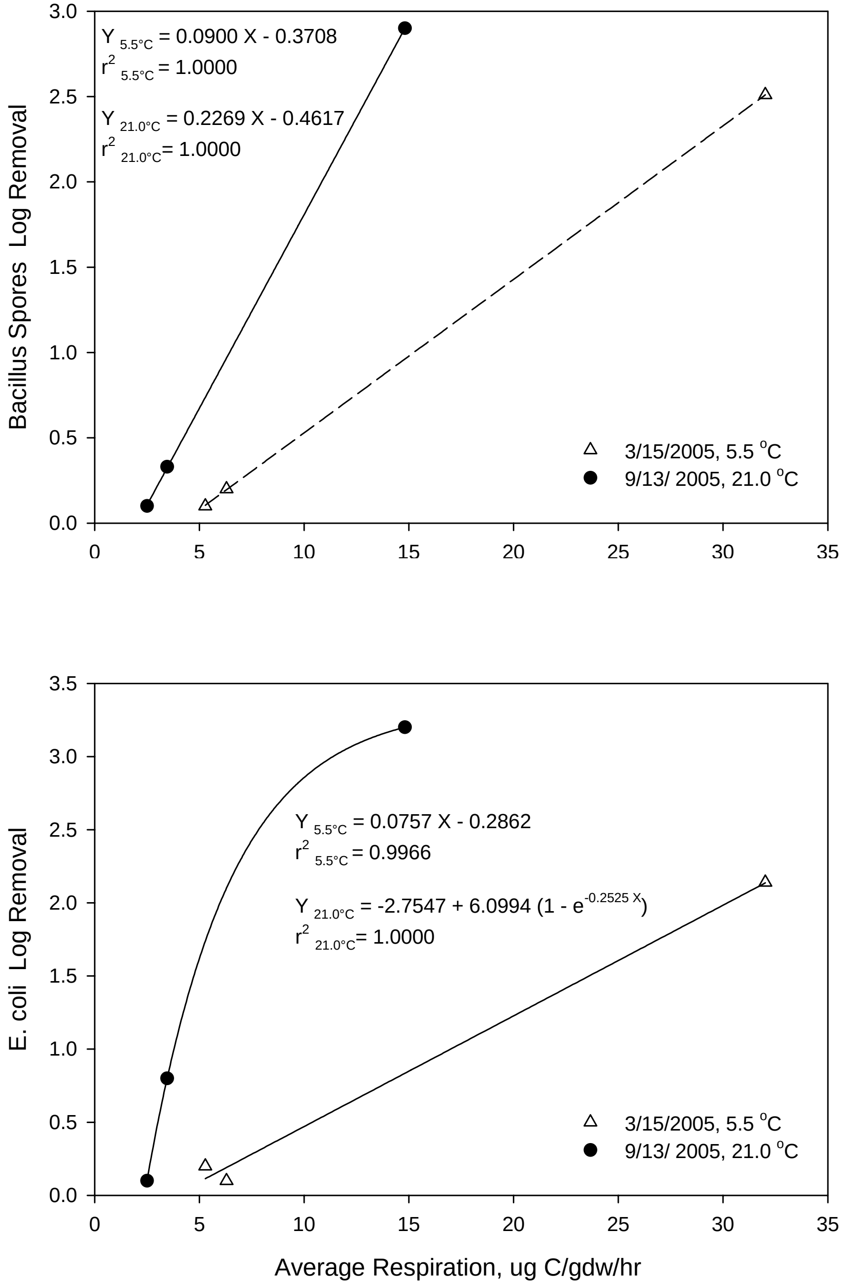
Ripening



Source: Collins et al (1989)

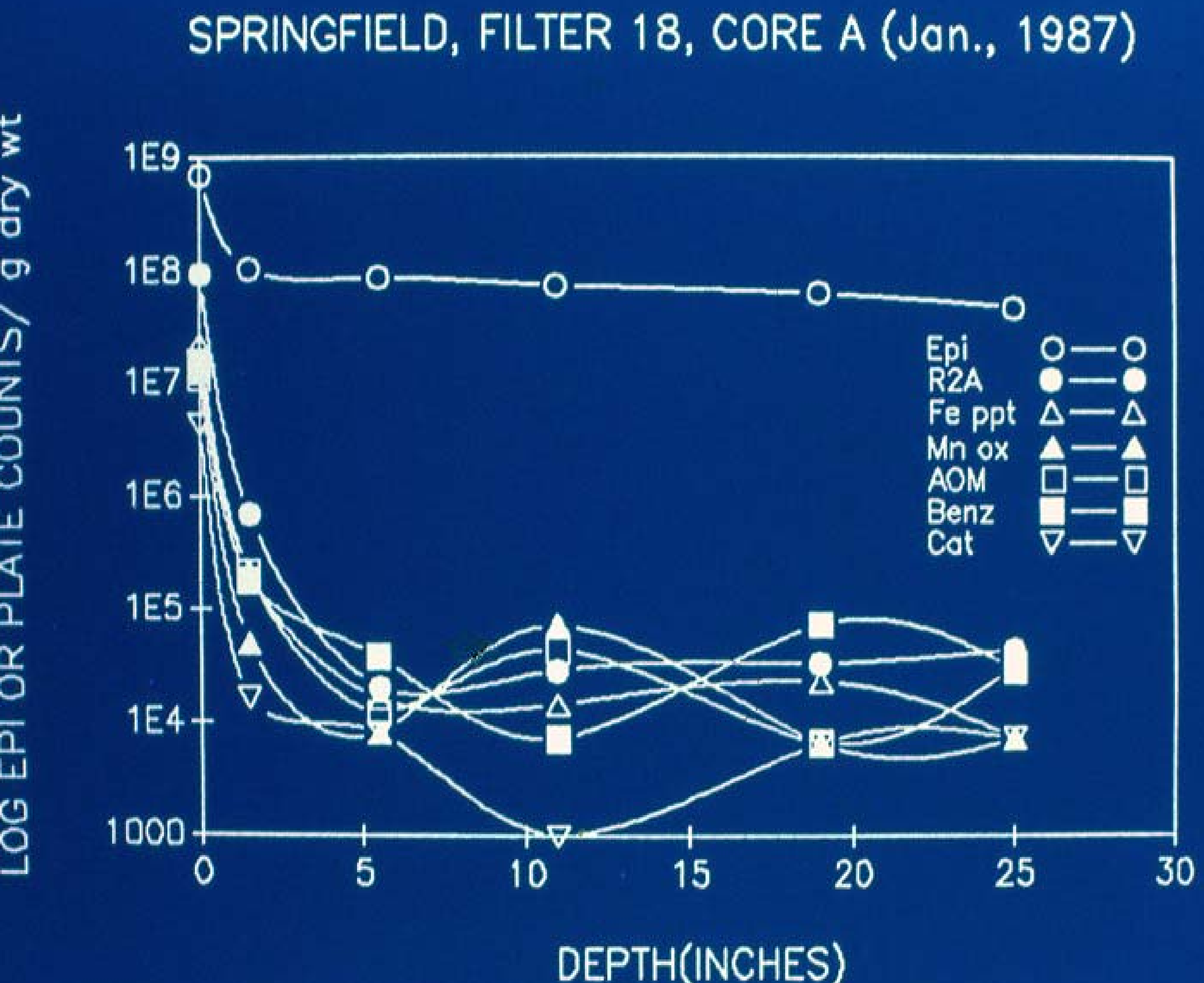


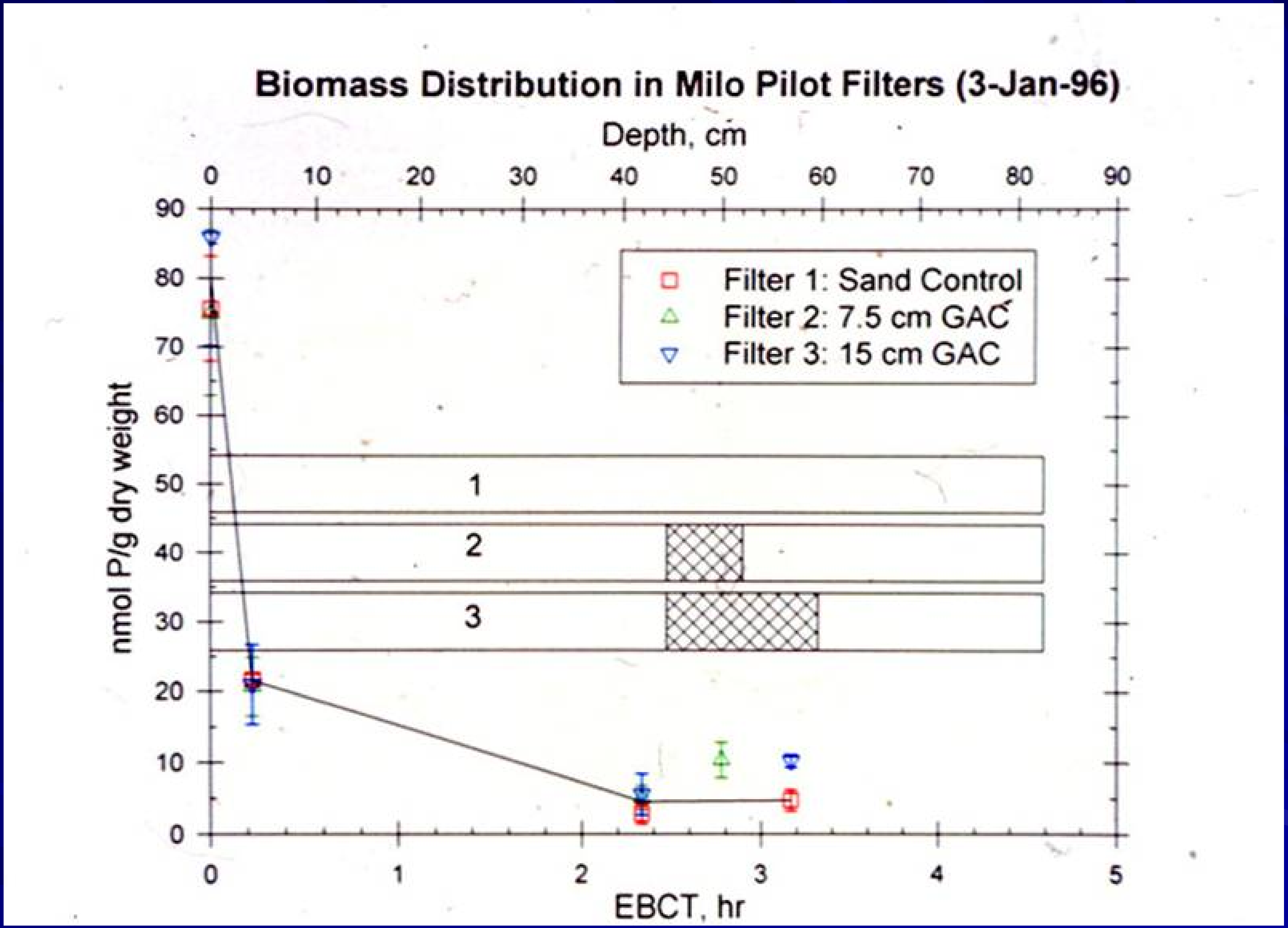
Bacillus Spores and *E. coli* Log Removal as a Function of Average Phospholipid Concentration at 5.5 and 21.0 °C in Pilot Slow Sand Filter (Winthrop, ME).



Bacillus Spores and *E. coli* Log Removal as a Function of Average Respiration Activity at 5.5 and 21.0 °C in Pilot Slow Sand Filter (Winthrop, ME).


National Bureau of Standards
Filter #3
CONTROL

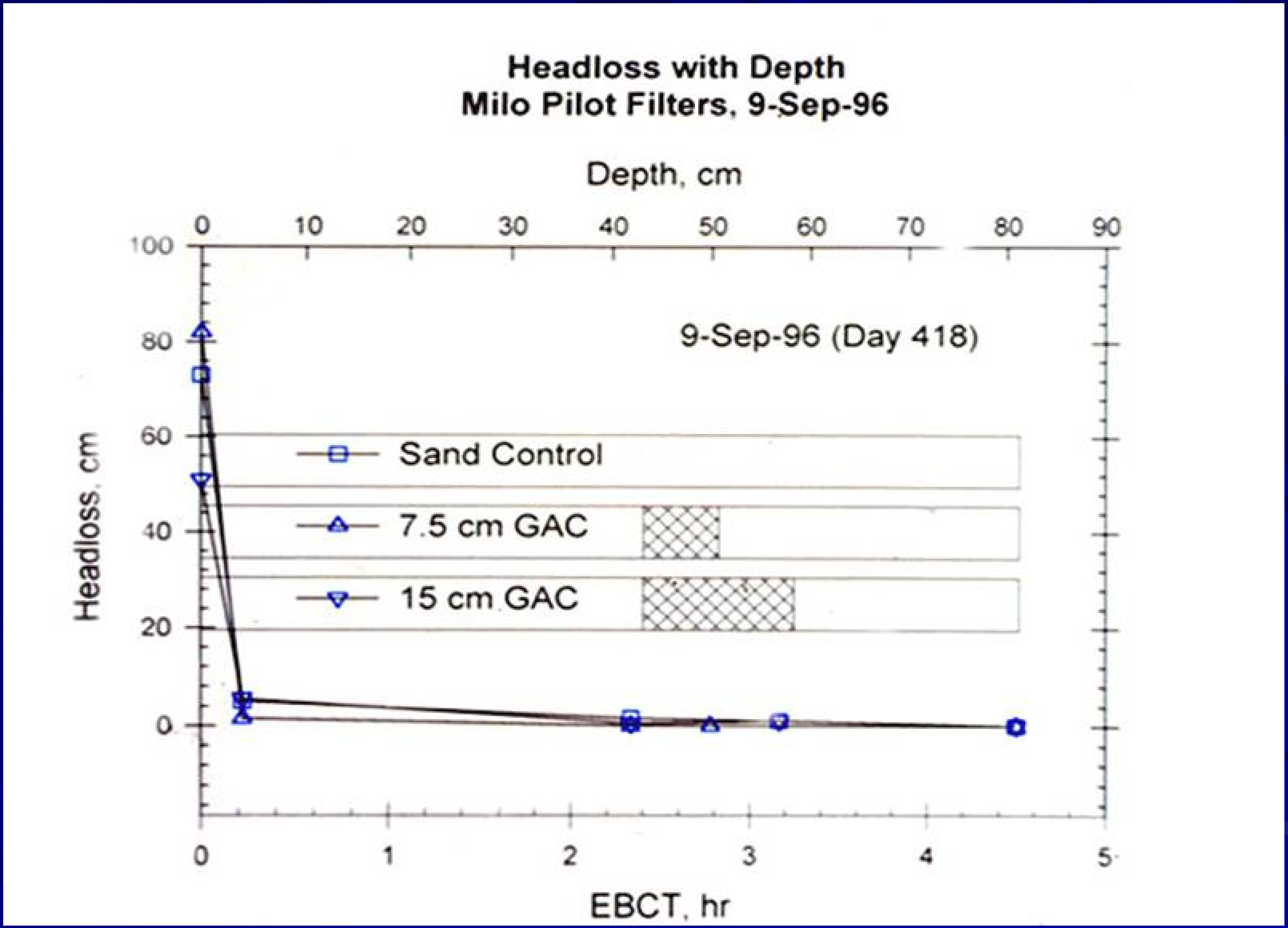

SPRINGFIELD, FILTER 18, CORE A (Jan., 1987)
LOG EPI OR PLATE COUNTS/ g dry wt
1E9
1E8
1E7
1E6
1E5
1E4
1000
0
5
10
15
20
25
30
DEPTH(INCHES)
Epi
R2A
Fe ppt
Mn ox
AOM
Benz
Cat



Source: Page (1997)

The Schmutzdecke

- German: “Schmutz” = dirt; “Decke” = covering
- Definition: “a layer of material, both deposited and synthesized, on the top of the filter bed that causes headloss disproportionate to its thickness” (AWWARF 1991)
- 2 Regions
  - – Biomat (slime)
  - – Biologically active media



Source: Page (1997)

Engineering Design Variables Evaluated by a Pilot SSF Study

- Filter media source
- Filter media size & uniformity
- Hydraulic loading rate (EBCT)
- Raw water source
- Pre-clarification needs
- Algal control needs
- Need for filter covering

OPERATING VARIABLES EVALUATED BY A PILOT SLOW SAND FILTER STUDY

- CLEANING & PREPARATION PROCEDURES FOR FILTER MEDIA
- FILTER CLEANING FREQUENCIES
- FILTER RIPENING PERIODS AND FILTER-TO-WASTE REQUIREMENTS
- EFFICIENCY OF FILTER CLEANING METHODS
- TREATMENT PERFORMANCE (SEASONAL FLUCTUATIONS)

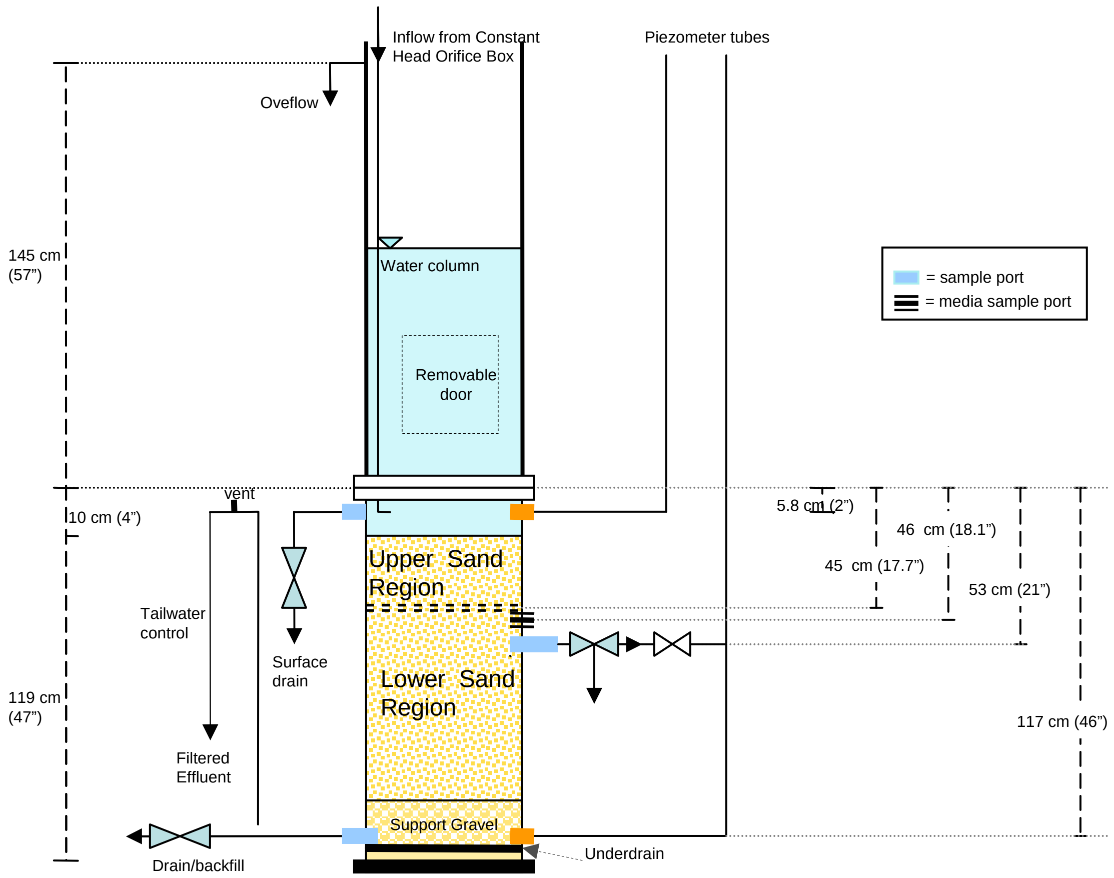
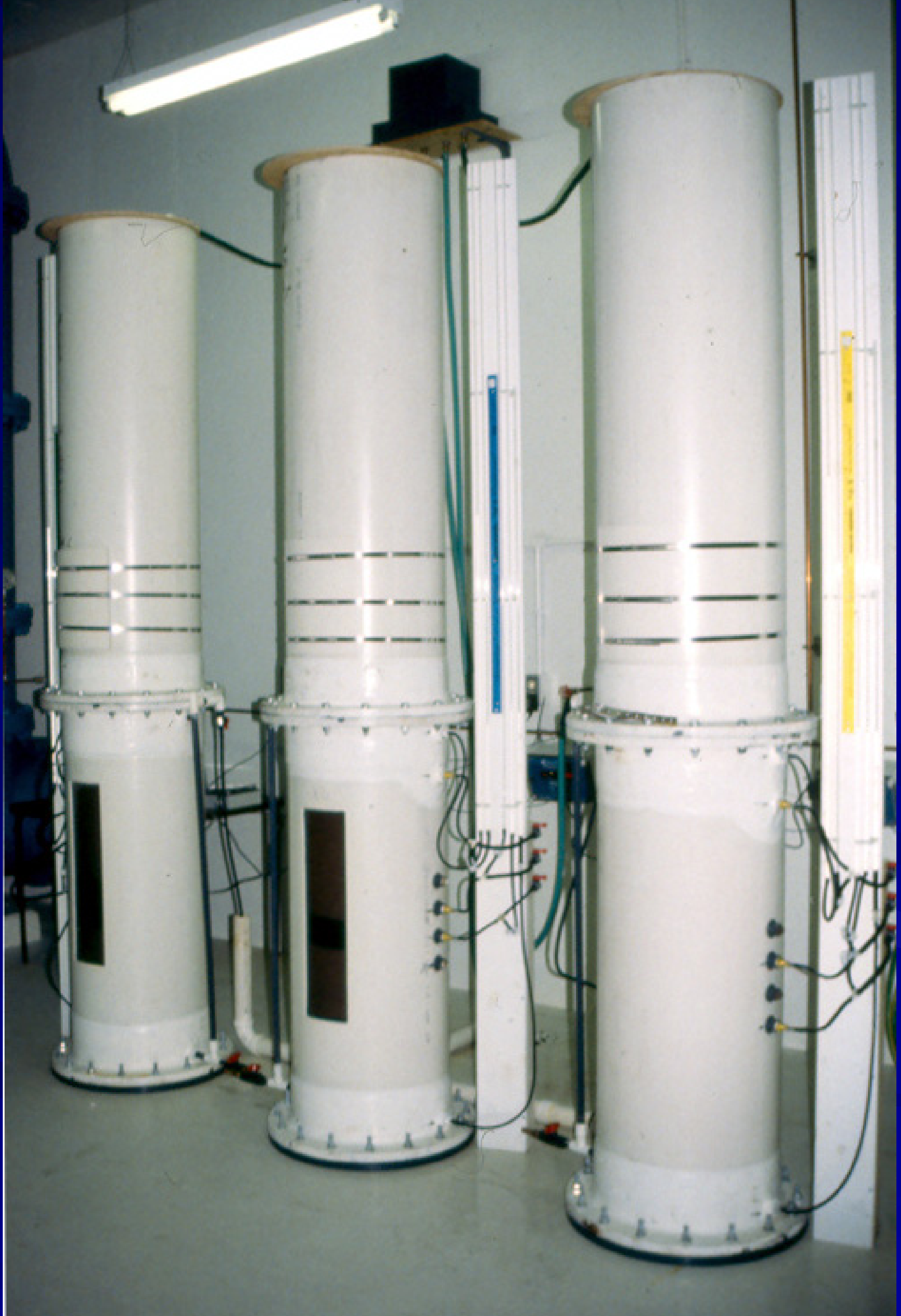


Figure 2. Schematic of Typical Pilot Slow Sand Filter Used in the Winthrop, ME Pilot Study



ADVANTAGES OF SLOW SAND FILTRATION

- SIMPLE FILTRATION TECHNOLOGY
- LOW COST OF CONSTRUCTION AND OPERATION
- EXCELLENT REMOVAL OF PATHOGENIC ORGANISMS
- GOOD REMOVAL OF TURBIDITY

Limitations of Slow Sand Filters

- Relatively long filter downtimes
- Limited to relatively high quality source waters
- Relatively poor removals of organic precursors

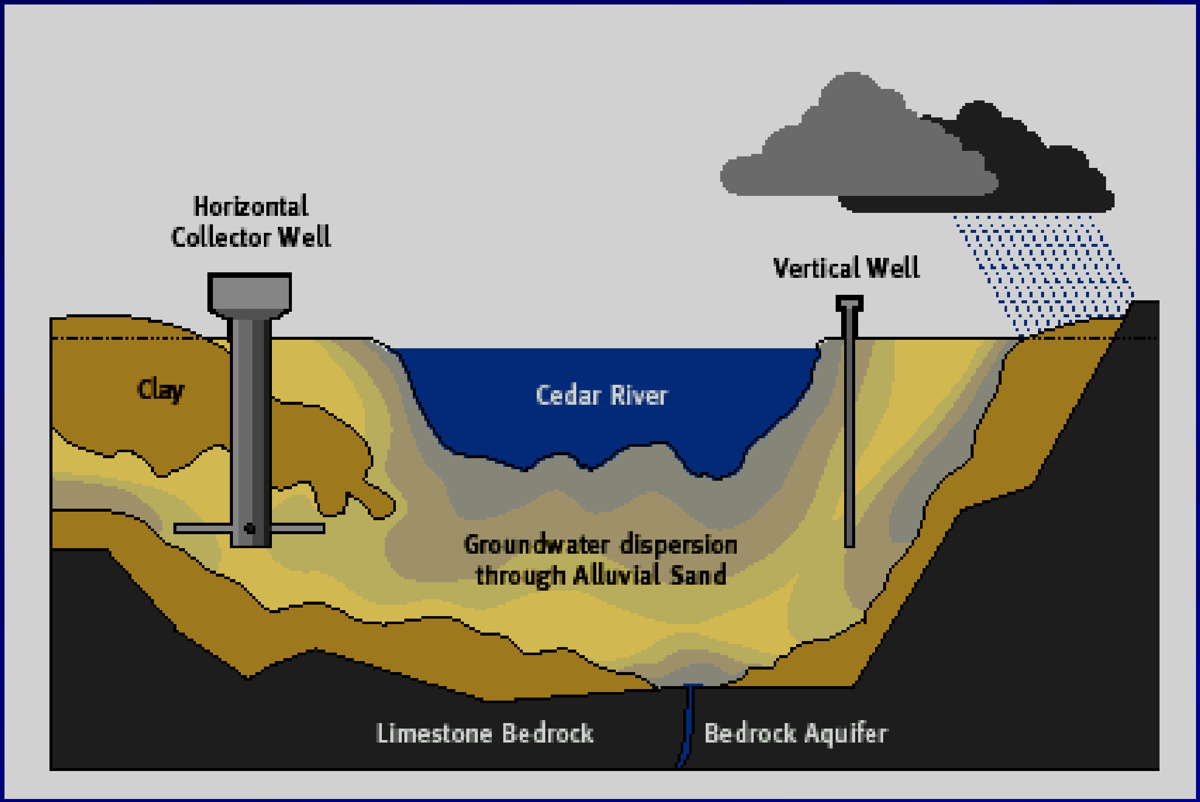
PROVEN MODIFICATIONS TO ENHANCE SLOW SAND FILTER PERFORMANCE

CONCERN	MODIFICATION
+ Increase raw water applicability	+ Roughing filters, + Microstrainers, RBF
+ Minimize filter downtimes and ripening periods	+ Filter harrowing
+ Improve organic precursor removal	+ Preozonation + Granular media amendments

PRETREATMENT OPTIONS

- RiverBank Filtration
- RiverBed Filtration
- Plain Sedimentation
- Tilted Plate Sedimentation
- Dynamic Bed Filtration
- Roughing Filtration

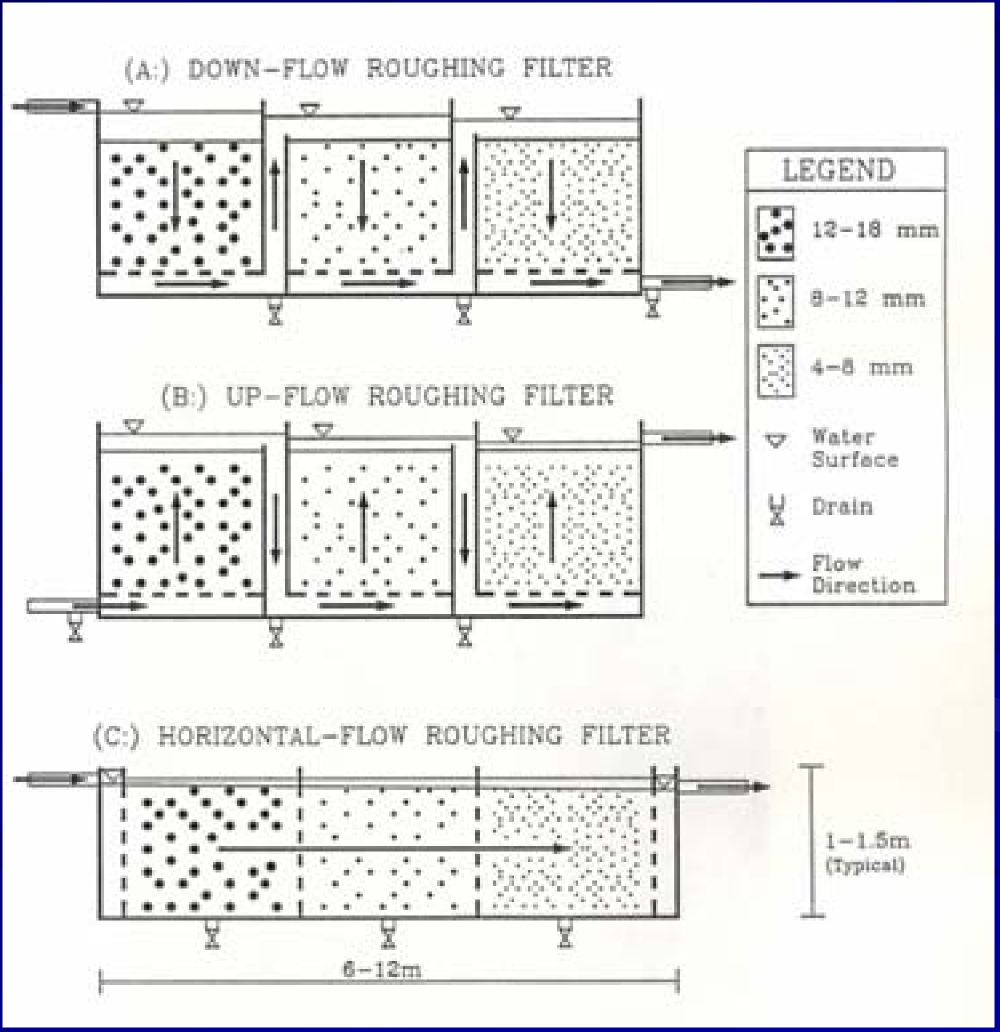
Typical Layout of a RBF Well

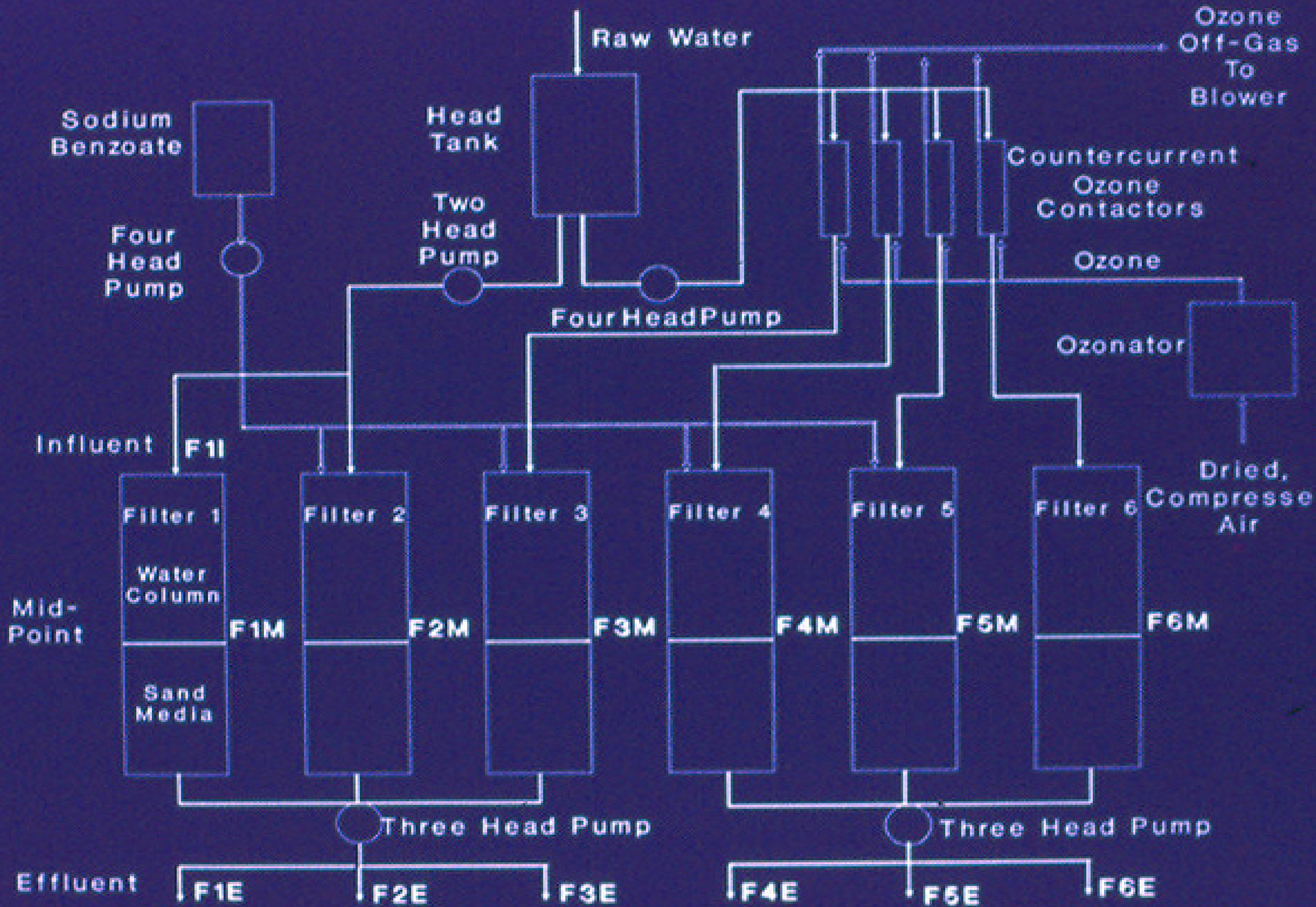


Cedar Rapids, IA

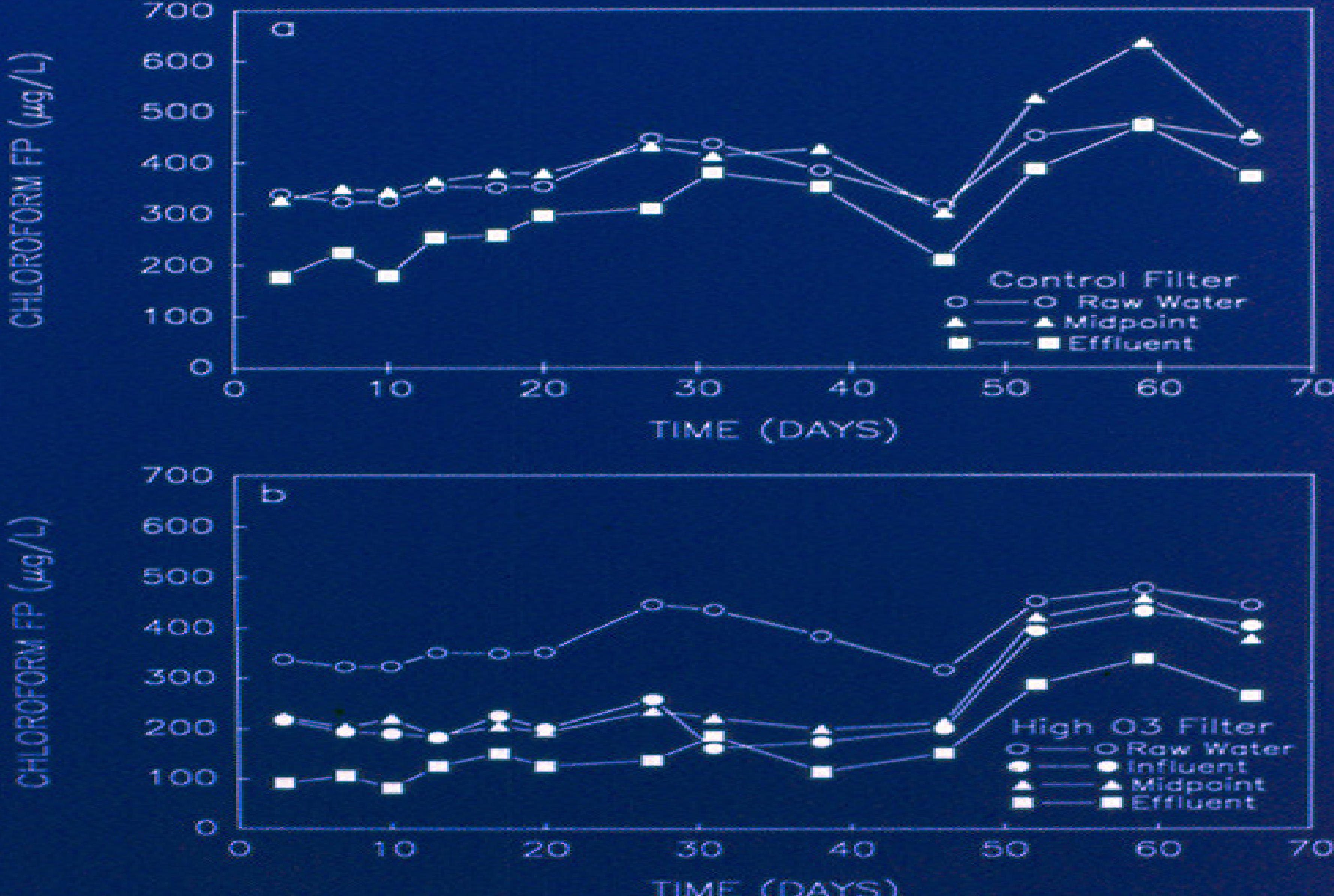
Louisville, KY

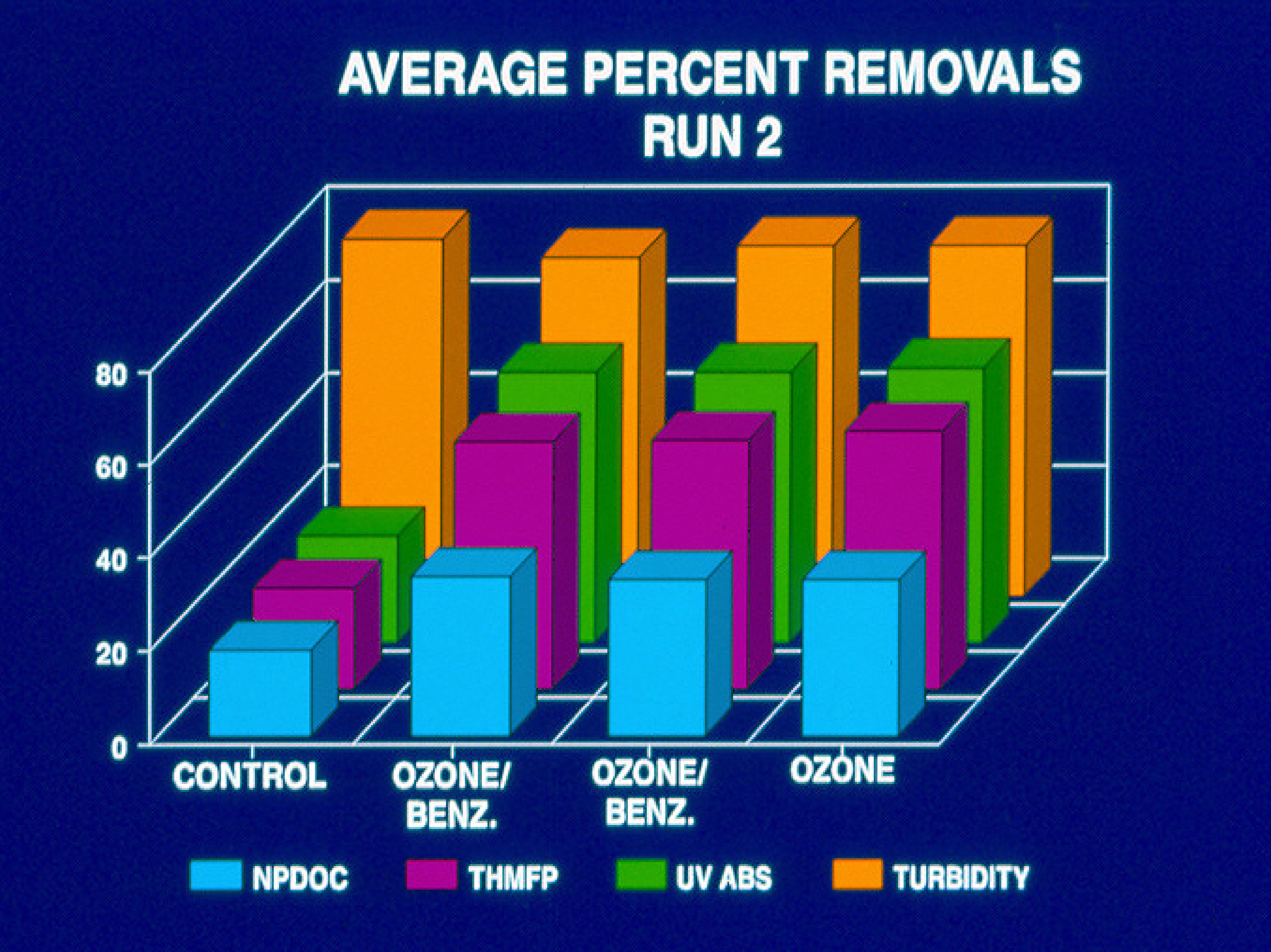
ROUGHING FILTERS



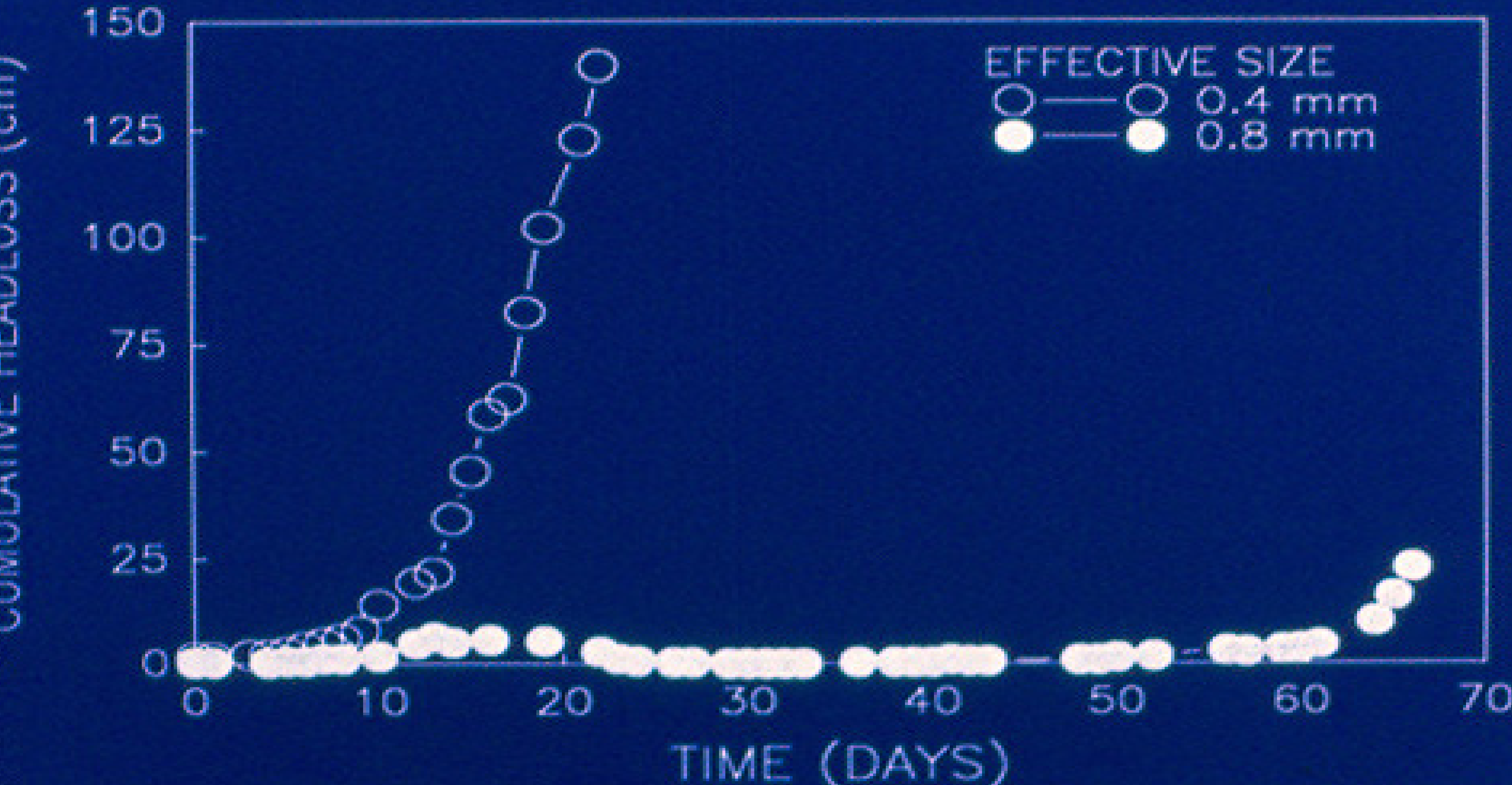

Raw Water
Ozone Off-Gas To Blower
Sodium Benzoate
Head Tank
Countercurrent Ozone Contactors
Four Head Pump
Two Head Pump
Ozone
Four Head Pump
Ozonator
Influent
F1I
Dried, Compresse Air
Filter 1
Filter 2
Filter 3
Filter 4
Filter 5
Filter 6
Water Column
Mid-Point
F1M
F2M
F3M
F4M
F5M
F6M
Sand Media
Three Head Pump
Three Head Pump
Effluent
F1E
F2E
F3E
F4E
F5E
F6E

PORTSMOUTH OZONE EFFECTS: THMFP

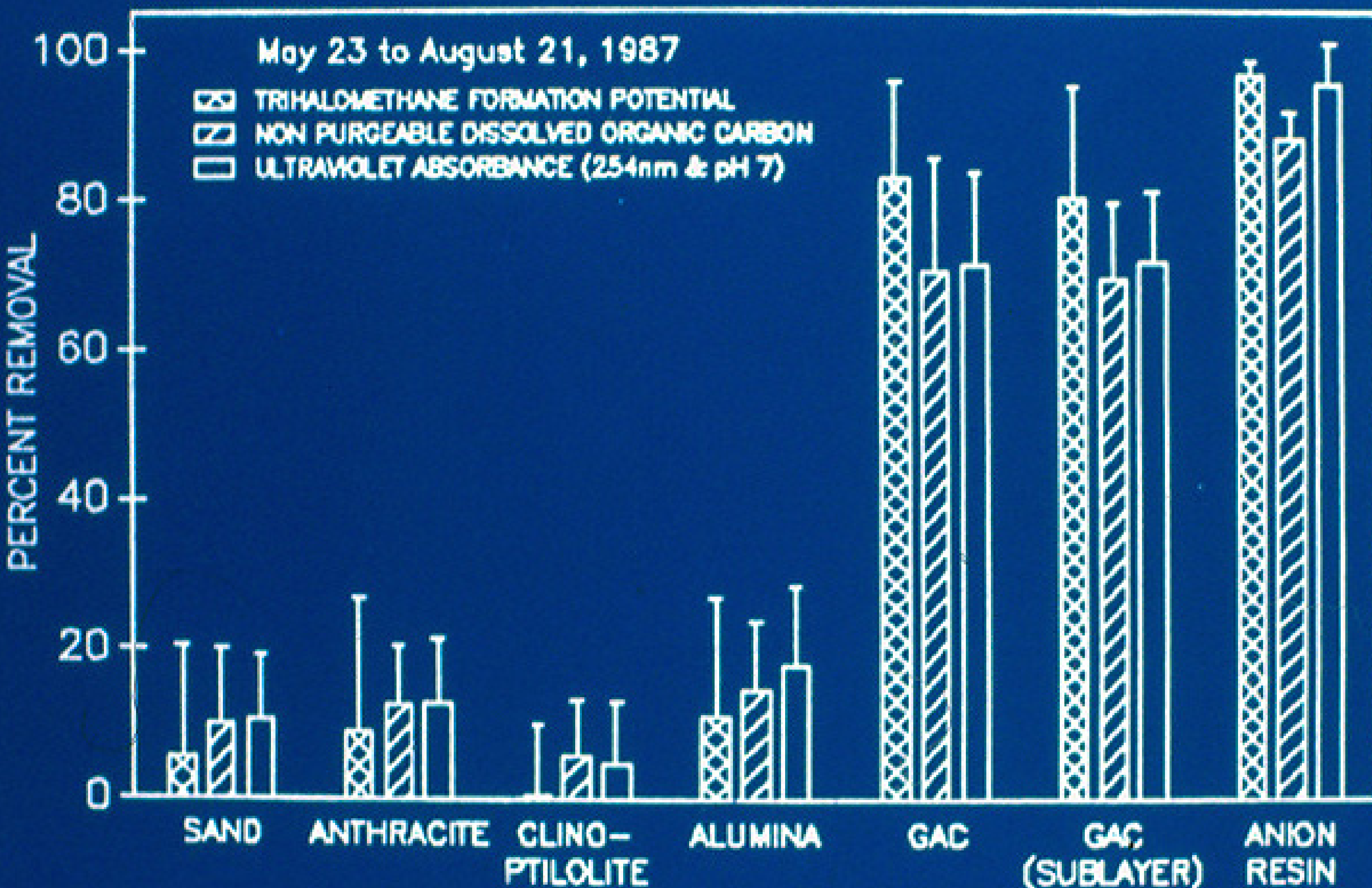



AVERAGE PERCENT REMOVALS
RUN 2
80
60
40
20
0
CONTROL
OZONE/
BENZ.
OZONE/
BENZ.
OZONE
NPDOC
THMFP
UV ABS
TURBIDITY

PORTSMOUTH MEDIA SIZE EFFECTS: HEADLOSS

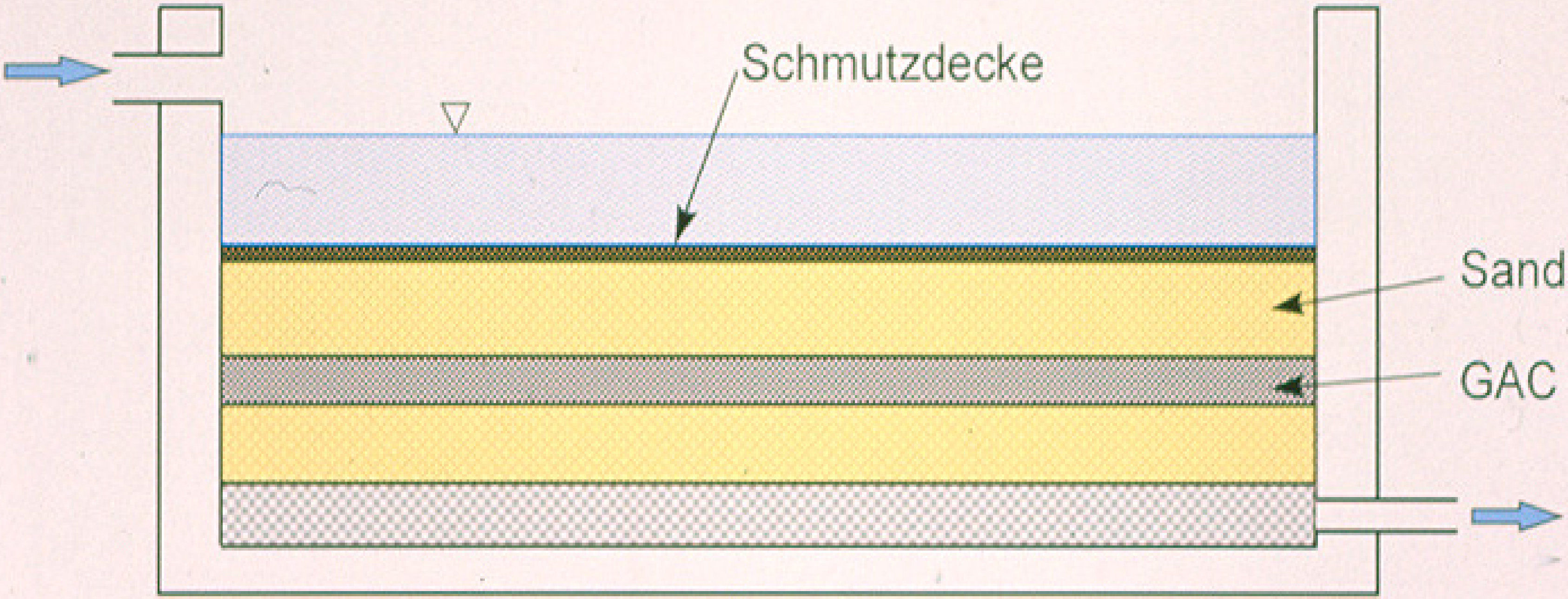


HIGH OZONE FILTER: 1 mg OZONE/mg NPDOC

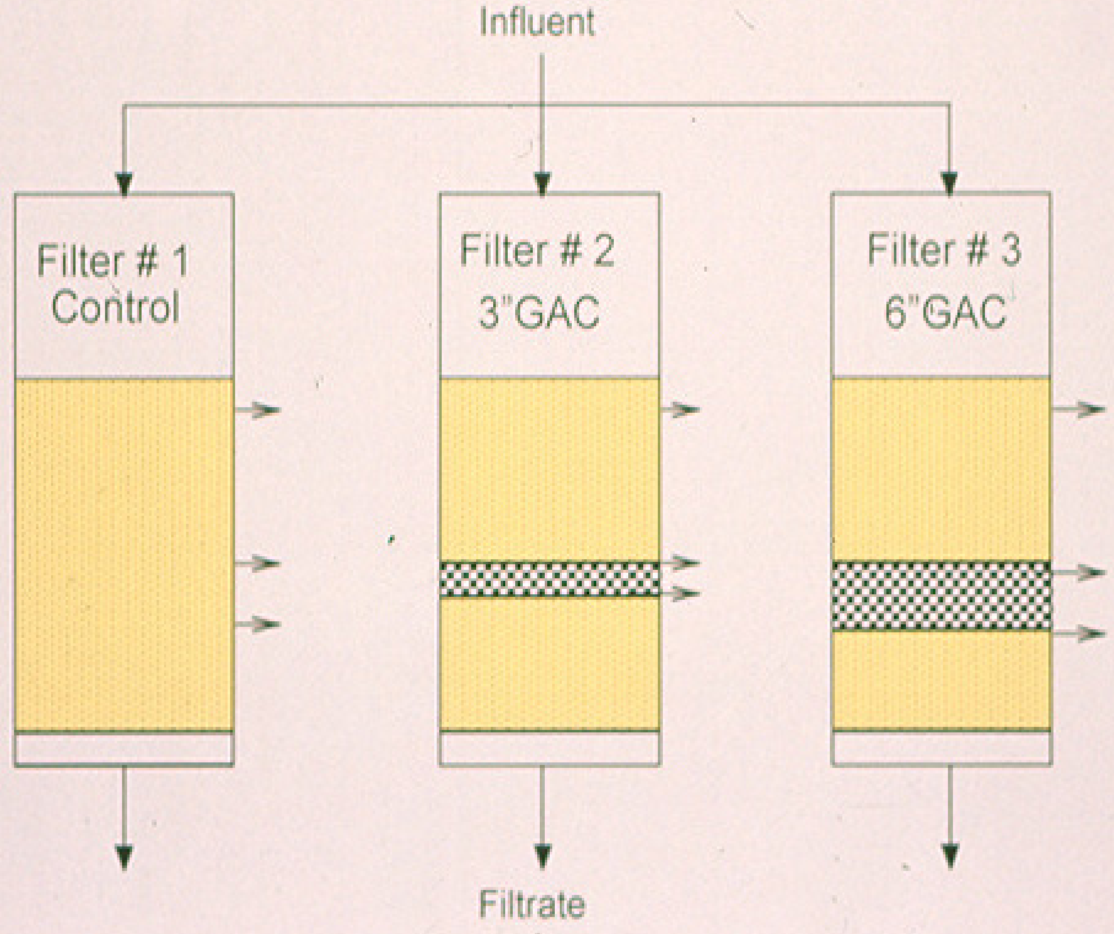


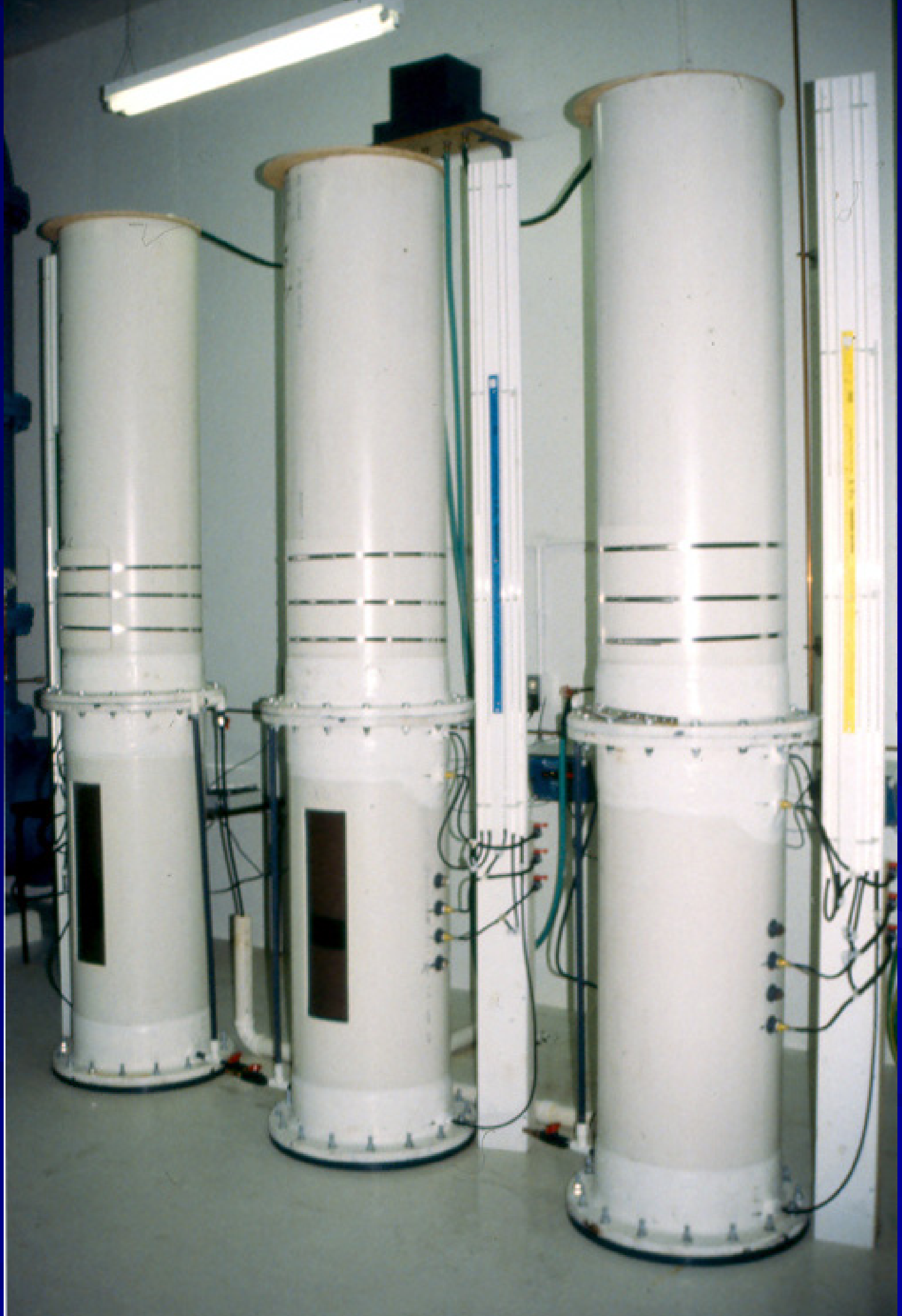
May 23 to August 21, 1987
TRIHALOMETHANE FORMATION POTENTIAL
NON PURGEABLE DISSOLVED ORGANIC CARBON
ULTRAVIOLET ABSORBANCE (254nm & pH 7)
PERCENT REMOVAL
100
80
60
40
20
0
SAND
ANTHRACITE
CLINO-PTILOLITE
ALUMINA
GAC
GAC (SUBLAYER)
ANION RESIN

Slow Sand Filter / GAC Sandwich



Experimental Design



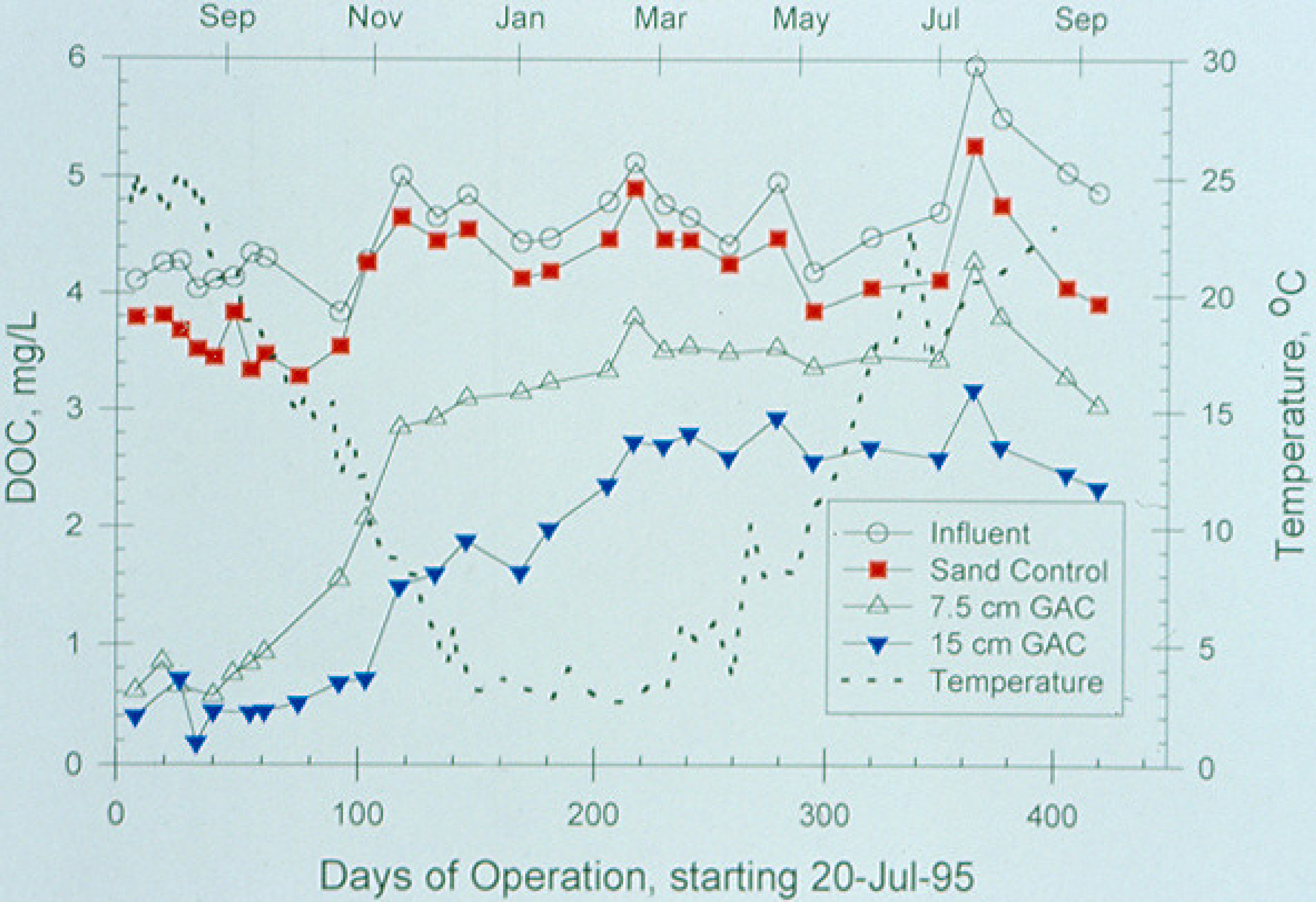


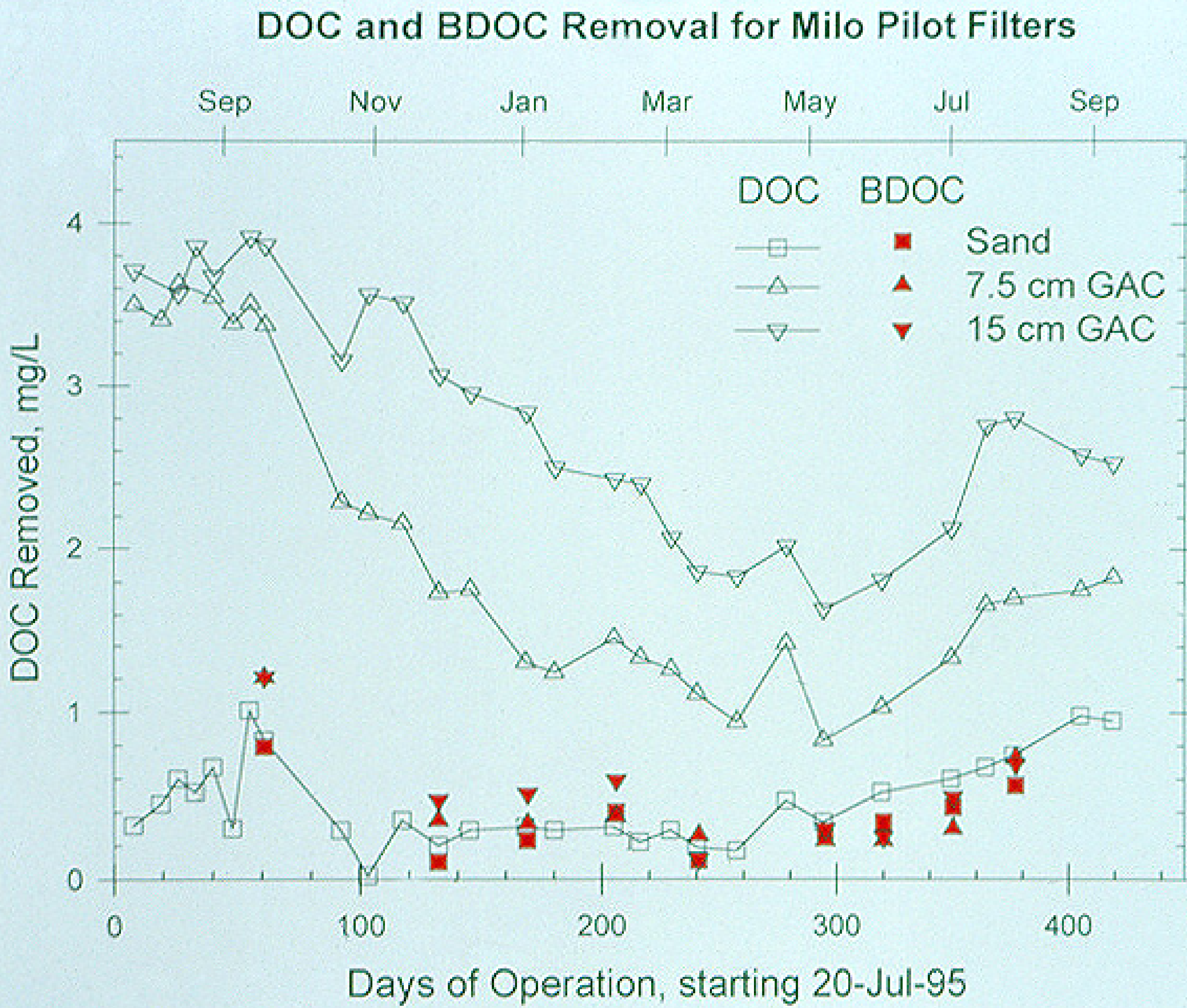
Milo Raw Water Quality

(Jul 95 - Sep 96)

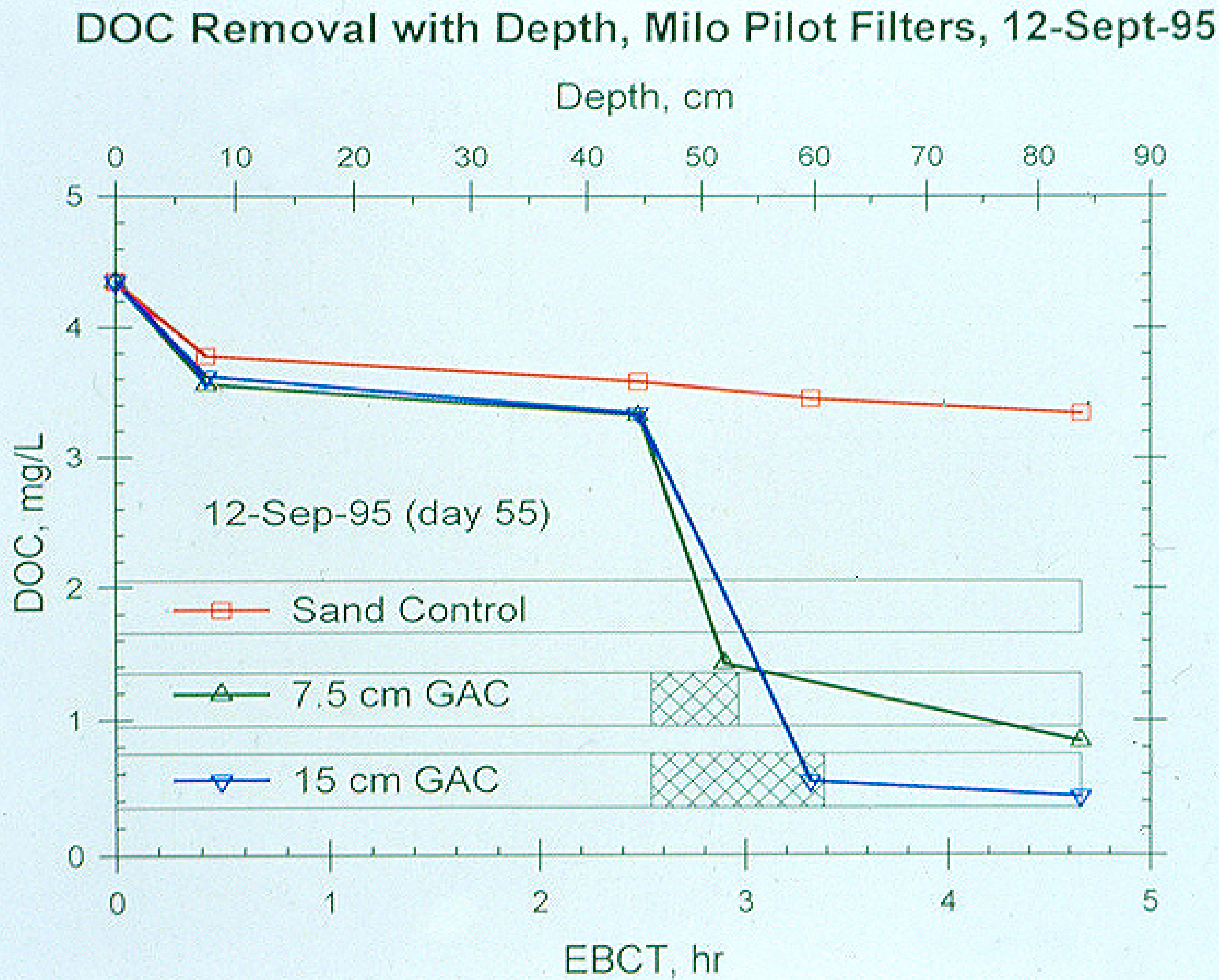
Parameter	Average	Range
Turbidity, NTU	0.43	0.25 - 1.49
Color, units PtCo	24	11 - 40
DOC, mg/L	4.6	3.8 - 6.0
BDOC, mg/L	0.6	0.4 - 1.2
UV Absorbance, cm^{-1}	0.153	0.098 - 0.229
THMFP, ug/L	430	331 - 570

DOC Removal for Milo Pilot Filters



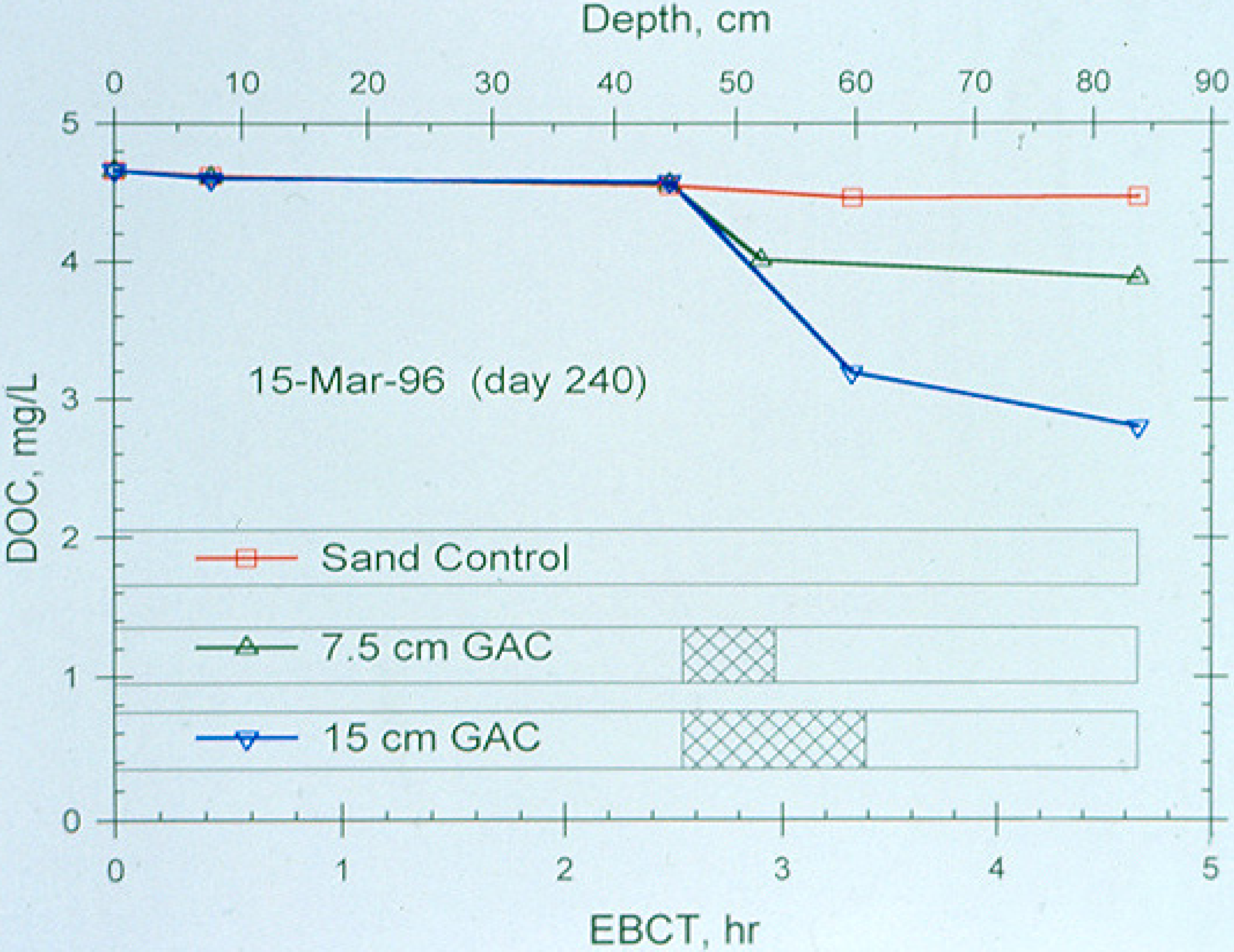


DOC and BDOC Removal for Milo Pilot Filters
Sep
Nov
Jan
Mar
May
Jul
Sep
DOC
BDOC
Sand
7.5 cm GAC
15 cm GAC
DOC Removed, mg/L
0
1
2
3
4
0
100
200
300
400
Days of Operation, starting 20-Jul-95

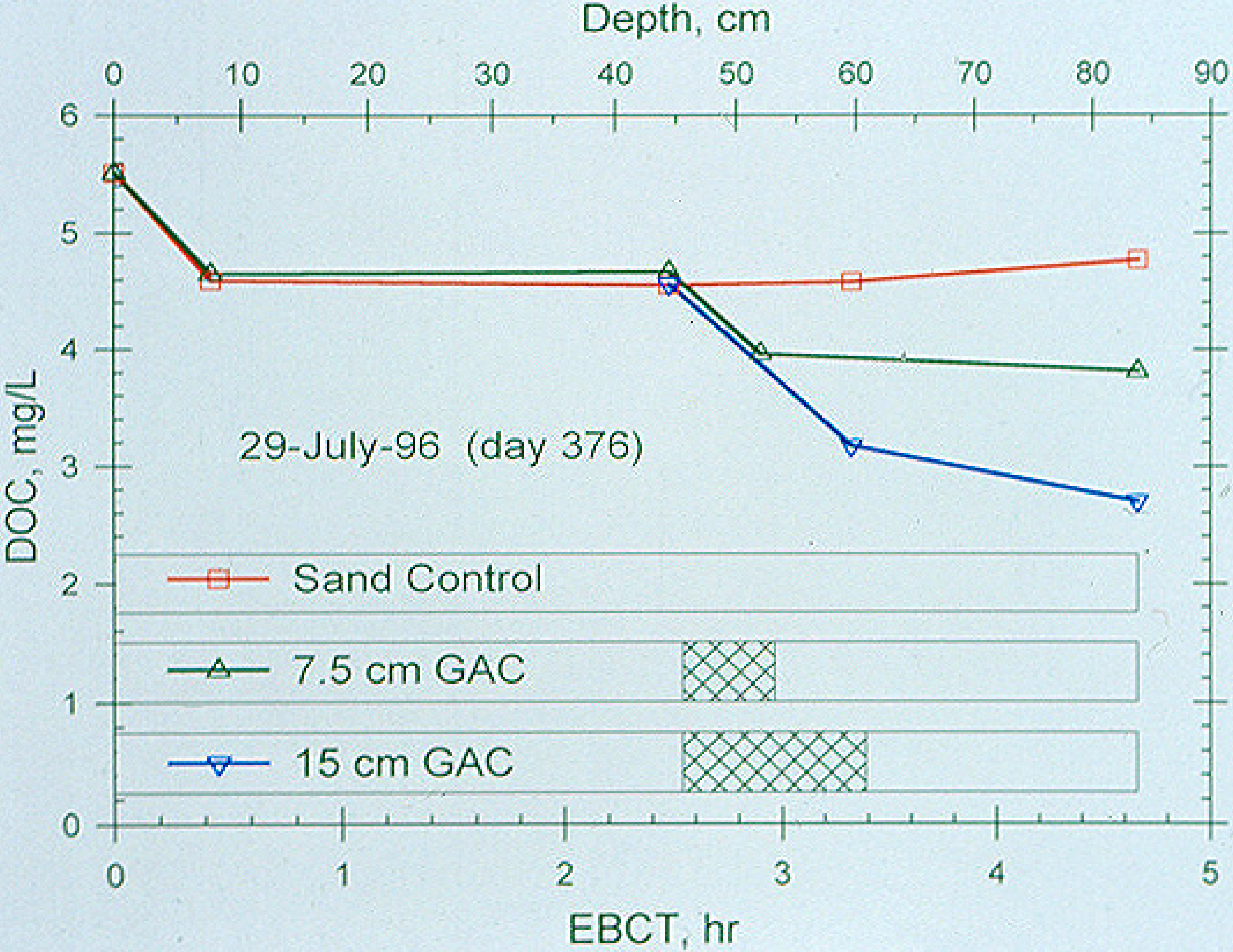


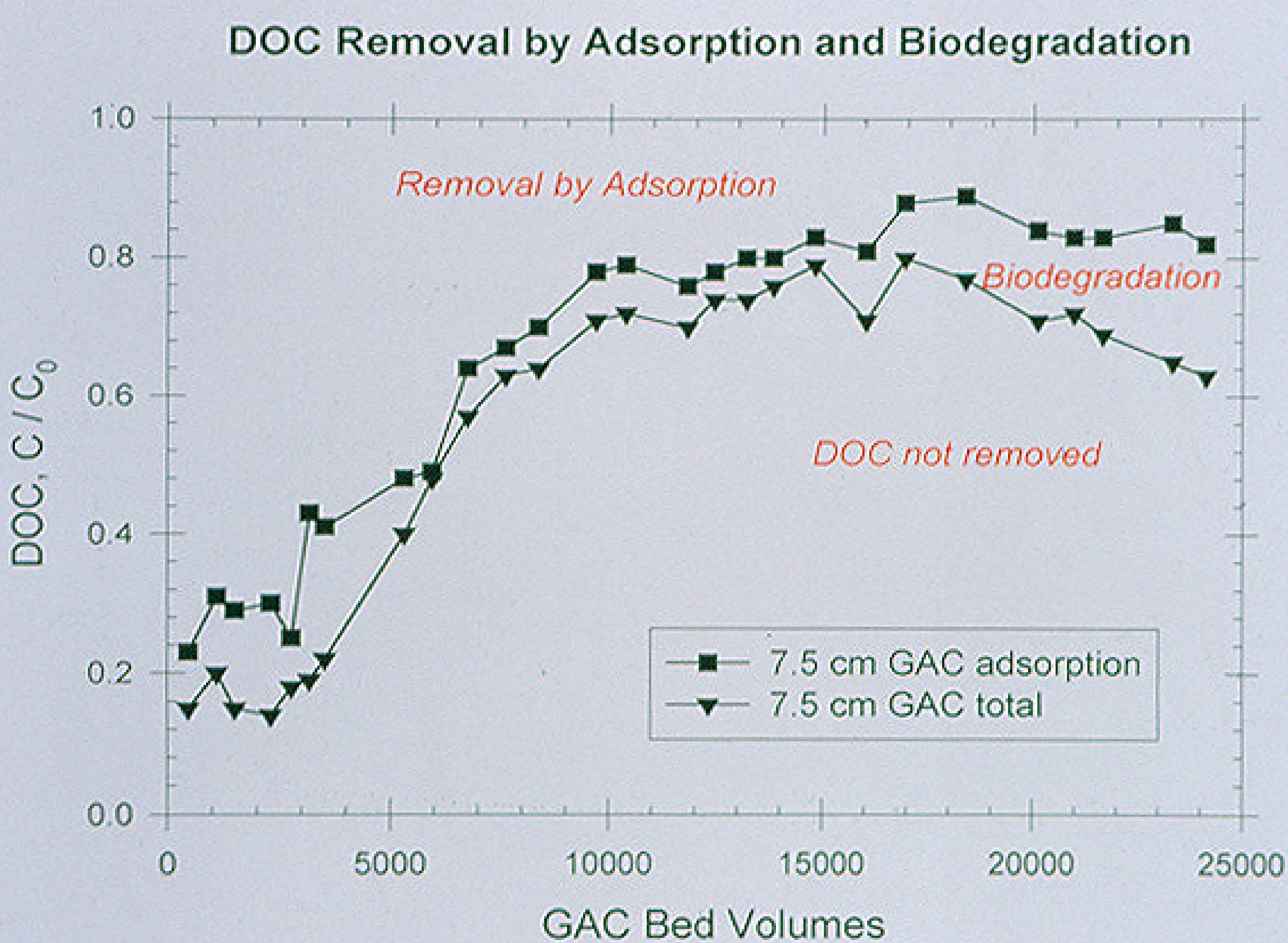
DOC Removal with Depth, Milo Pilot Filters, 12-Sept-95
Depth, cm
0
10
20
30
40
50
60
70
80
90
5
4
3
2
1
0
DOC, mg/L
12-Sep-95 (day 55)
Sand Control
7.5 cm GAC
15 cm GAC
0
1
2
3
4
5
EBCT, hr

DOC Removal with Depth, Milo Pilot Filters, 15-Mar-96



DOC Removal with Depth, Milo Pilot Filters, 29-Jul-96




DOC Removal by Adsorption and Biodegradation
Removal by Adsorption
Biodegradation
DOC not removed
7.5 cm GAC adsorption
7.5 cm GAC total
DOC, C / C0
GAC Bed Volumes
1.0
0.8
0.6
0.4
0.2
0.0
0
5000
10000
15000
20000
25000

GAC Sandwich Summary

- Adsorption dominated first 7000 - 14000 bed volumes.
- Removals reached pseudo steady-state after 200 - 300 days:

	Sand	7.5 cm GAC	15 cm GAC
Total	12%	28%	46%
Adsorption		16%	34%

- Adsorption continued at a constant rate, due to slow adsorption or bioregeneration.

GAC Sandwich Advantages over Conventional Adsorbers

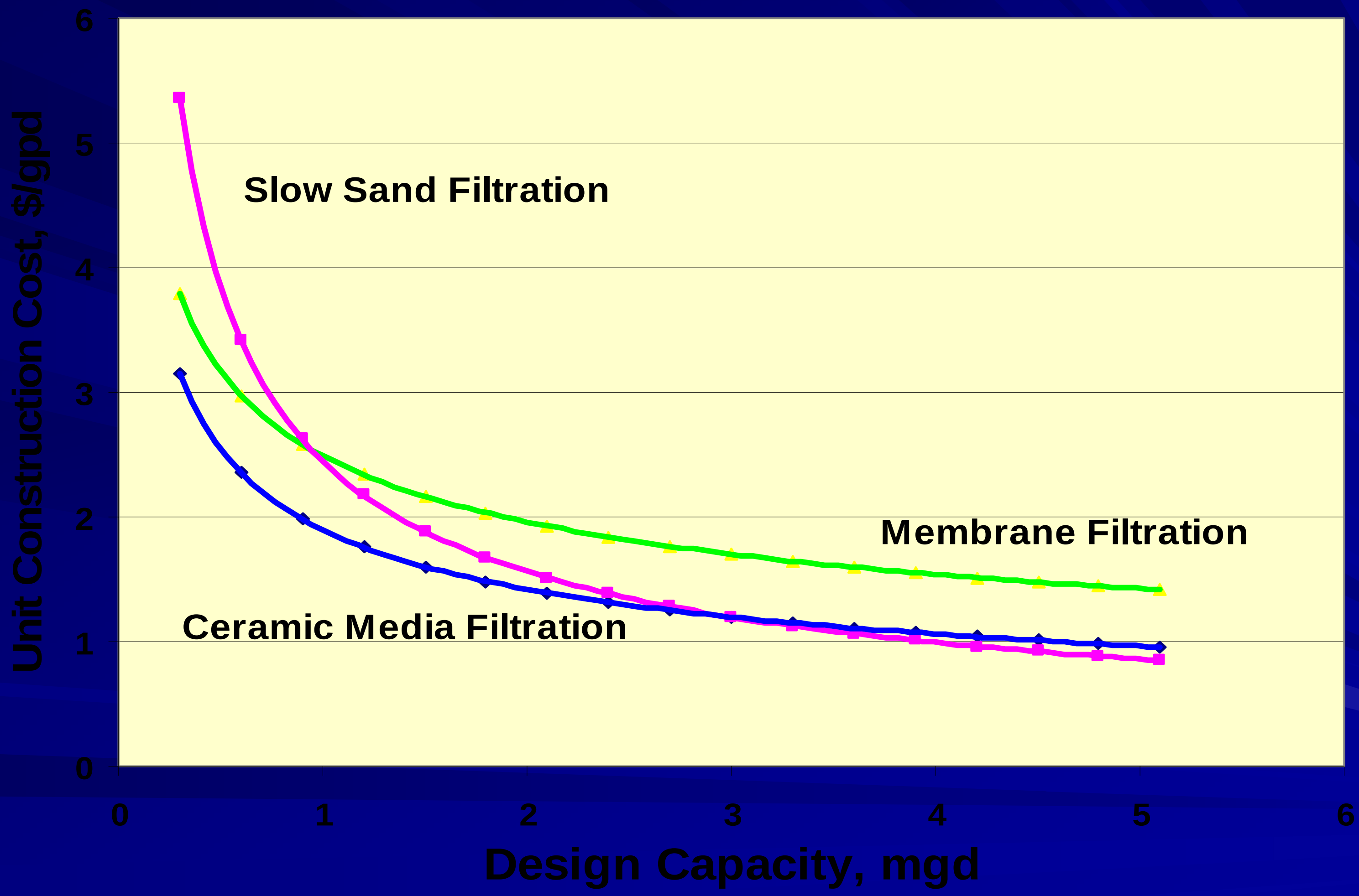
- Top sand layer reduces TOC loading on GAC
- Lower sand layer contains carbon fines
- No backwashing
- Slower filtration rate provides longer contact time with GAC
- Easier to upgrade existing facilities

“NEW” Modifications to SSF

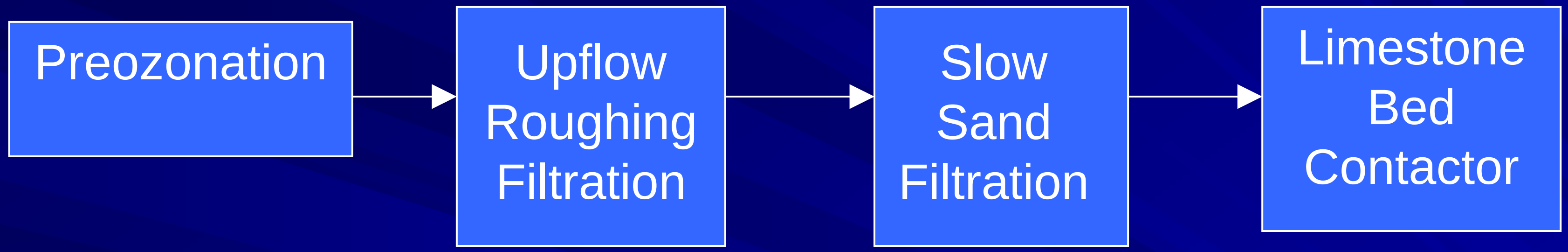
- Development of “packaged” SSF systems
- Utilize an anionic resin “mat/quilt” on top of filter media
- Use iron additions (<0.1ppm) to enhance NOM adsorption by aged (iron-coated) sand media
- Understanding Operational enhancements of SSF

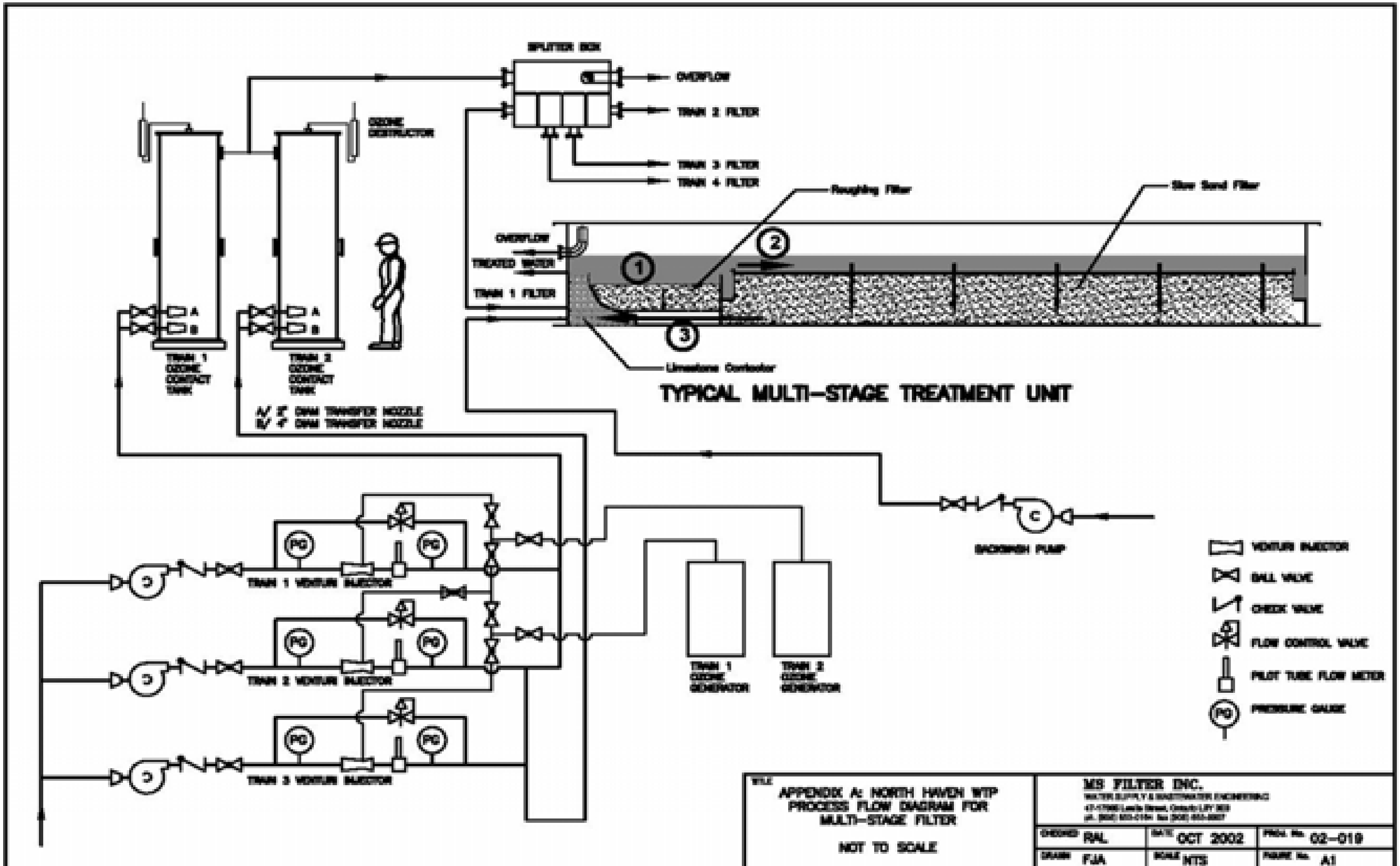
Construction Costs Comparison

(Montel, 2002)



Selected "Multi-stage" Prefabricated Treatment System




SPLITTER BOX
OVERFLOW
TRAIN 2 FILTER
TRAIN 3 FILTER
TRAIN 4 FILTER
OZONE DESTRUCTOR
Roughing Filter
Slow Sand Filter
OVERFLOW
TREATED WATER
TRAIN 1 FILTER
1
2
3
Limestone Contactor
TYPICAL MULTI-STAGE TREATMENT UNIT
TRAIN 1 OZONE CONTACT TANK
TRAIN 2 OZONE CONTACT TANK
A
B
BACKWASH PUMP
TRAIN 1 VENTURI INJECTOR
TRAIN 2 VENTURI INJECTOR
TRAIN 3 VENTURI INJECTOR
PG
TRAIN 1 OZONE GENERATOR
TRAIN 2 OZONE GENERATOR
VENTURI INJECTOR
BALL VALVE
CHECK VALVE
FLOW CONTROL VALVE
PILOT TUBE FLOW METER
PRESSURE GAUGE
APPENDIX A: NORTH HAVEN WTP PROCESS FLOW DIAGRAM FOR MULTI-STAGE FILTER
NOT TO SCALE
MS FILTER INC.
WATER SUPPLY & WASTEWATER ENGINEERING
CHECKED RAL
DATE OCT 2002
PROJ. No. 02-019
DRAWN FJA
SCALE NTS
FIGURE No. A1

NORTH HAVEN, ME FILTER PIPE GALLERY

Microbial Removal Processes

- Physical / Chemical
  - Straining
  - Adsorption (Transport and Attachment)
- Biological
  - Predation
  - Inactivation / Death due to presence of exotoxins released by antagonistic organisms
  - Biologically mediated adsorption?

Objectives

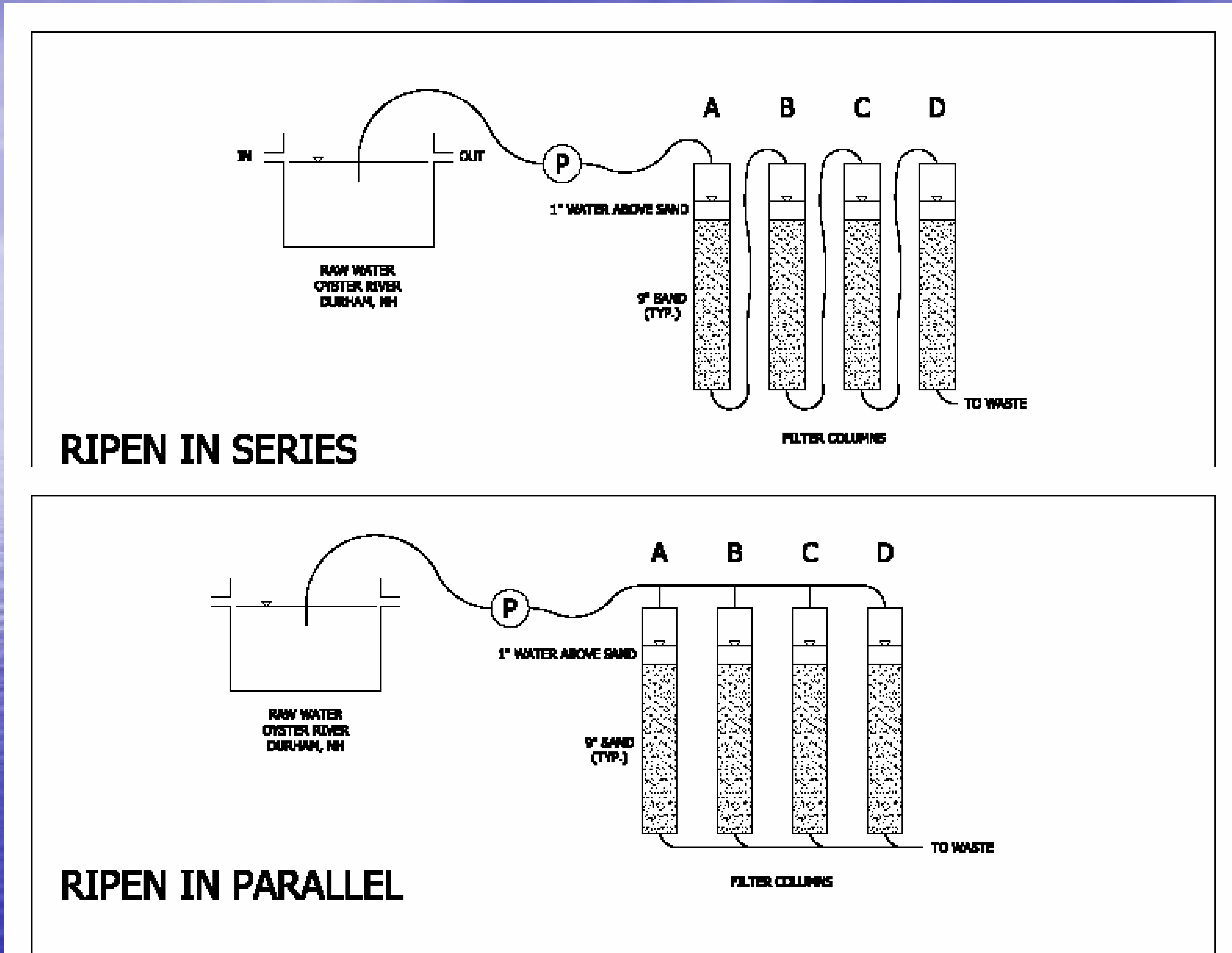
1. Rank various media characteristics and operational conditions for *E. coli* removal
2. Determine whether the extracellular polymeric excretions (EPS) of a biofilm enhance the “stickiness” of filter media
3. Assess the effect of a sudden removal of the schmutzdecke and a filter’s ability to recover
4. Estimate the potential influence of protistan predators

Interface Removal Simulation

Objectives:

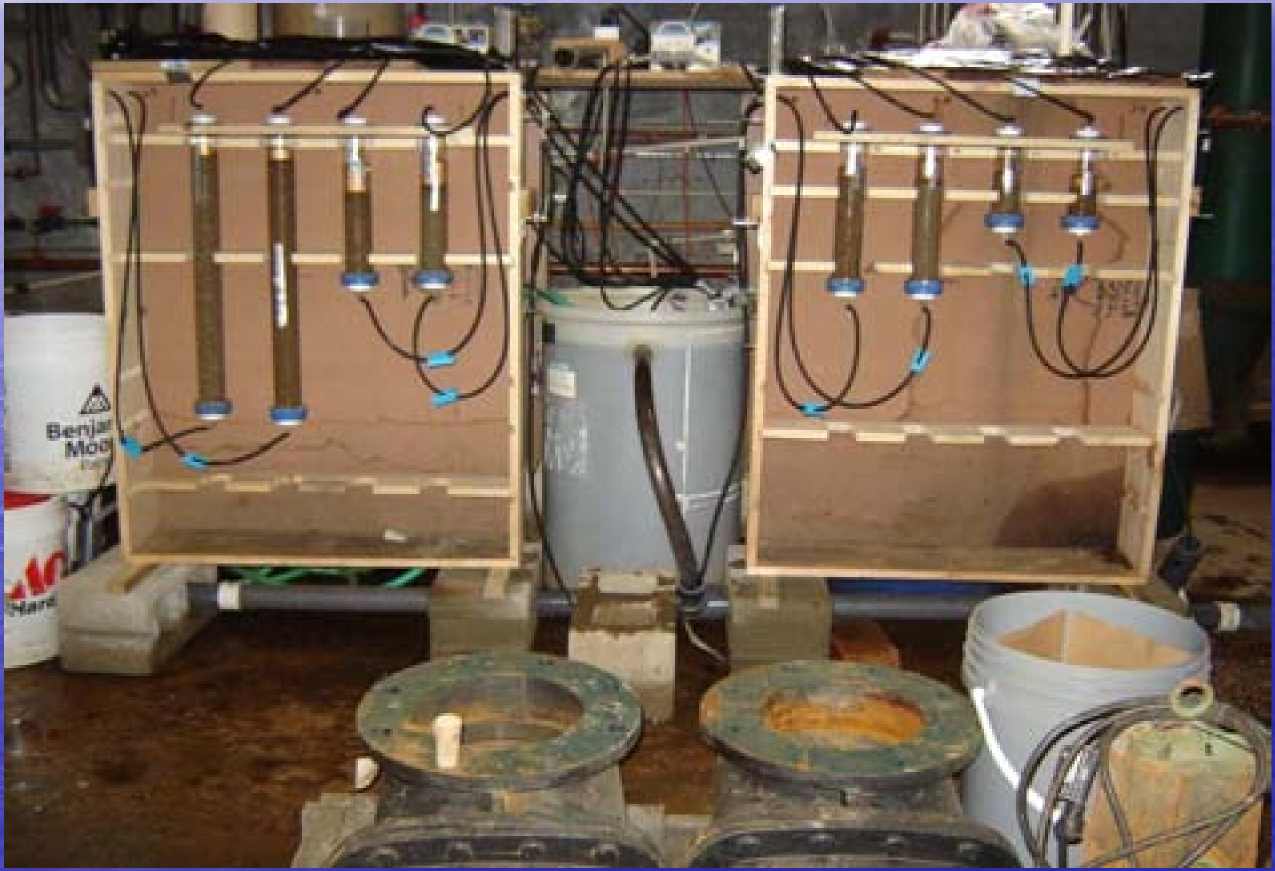
- Determine the removal efficiency after cleaning or scouring the schmutzdecke.

- Determine ability of schmutzdecke to recover from cleaning or scouring under various conditions
    - Temperature
    - Ripening Time
    - Depth of Scour



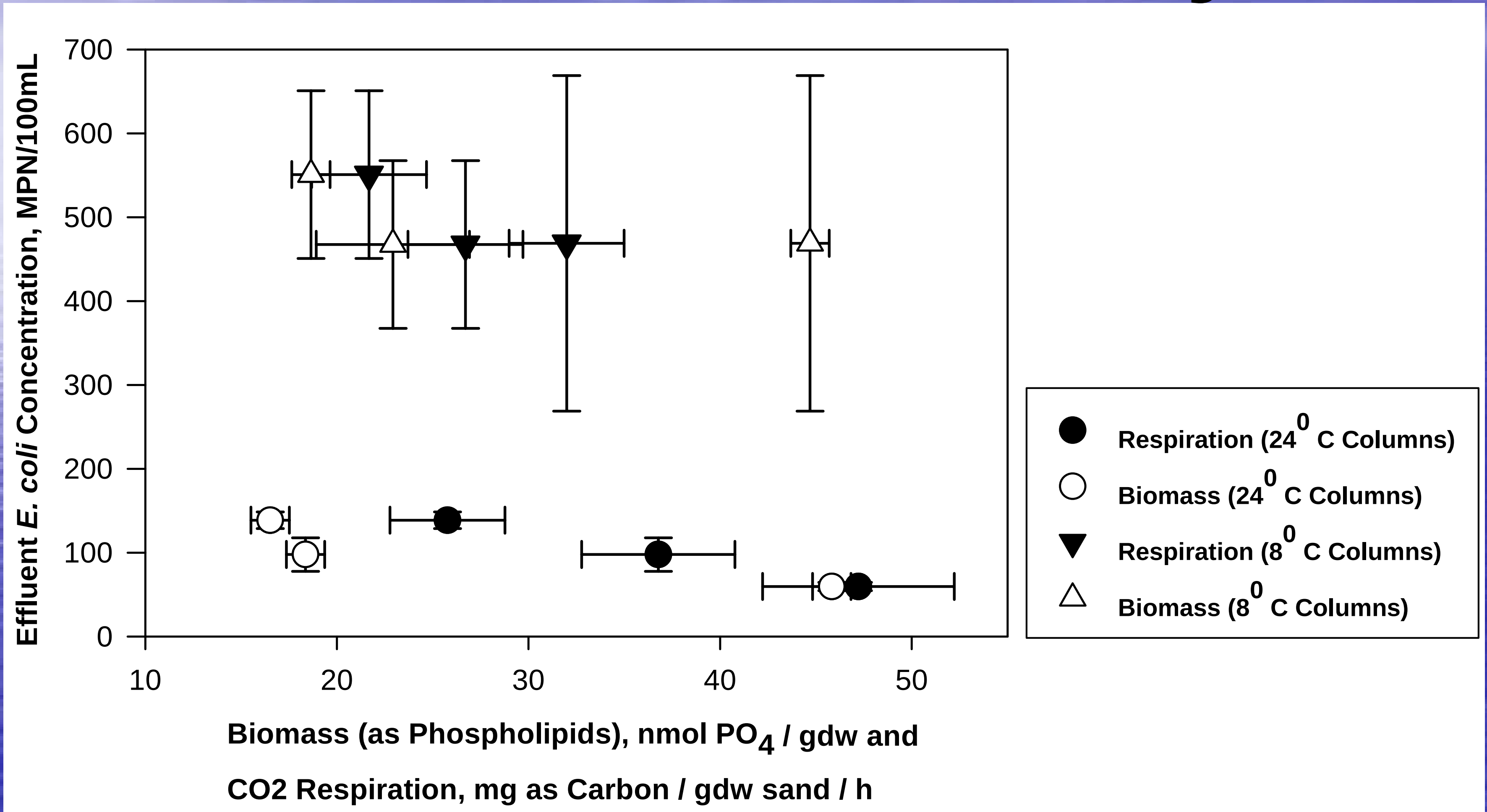
Drawing: Jim McMahon

Screening Experiment Design



	Challenge After 2 weeks Ripening in Series		Challenge After 2 weeks Ripening in Parallel	
	Log Removal of	Biomass, Top 2.5 cm	Log Removal of	Biomass, Top 2.5 cm
	Total Coliforms	(nmol PO4 / gdw)	Total Coliforms	(nmol PO4 / gdw)
Col A (0 – 22.5 cm)	1.3	36±2	1.6	42±4
Col B (22.5 – 45 cm)	0.8	14±7	1.6	29±2
Col C (45 – 67.5 cm)	0.2	9±1	1.4	31±2
Col D (67.5 – 90 cm)	0.3	11±4	1.6	39±2
Full Train (90 cm total)	2.1			

Effect of Temperature on Schmutzdecke Recovery



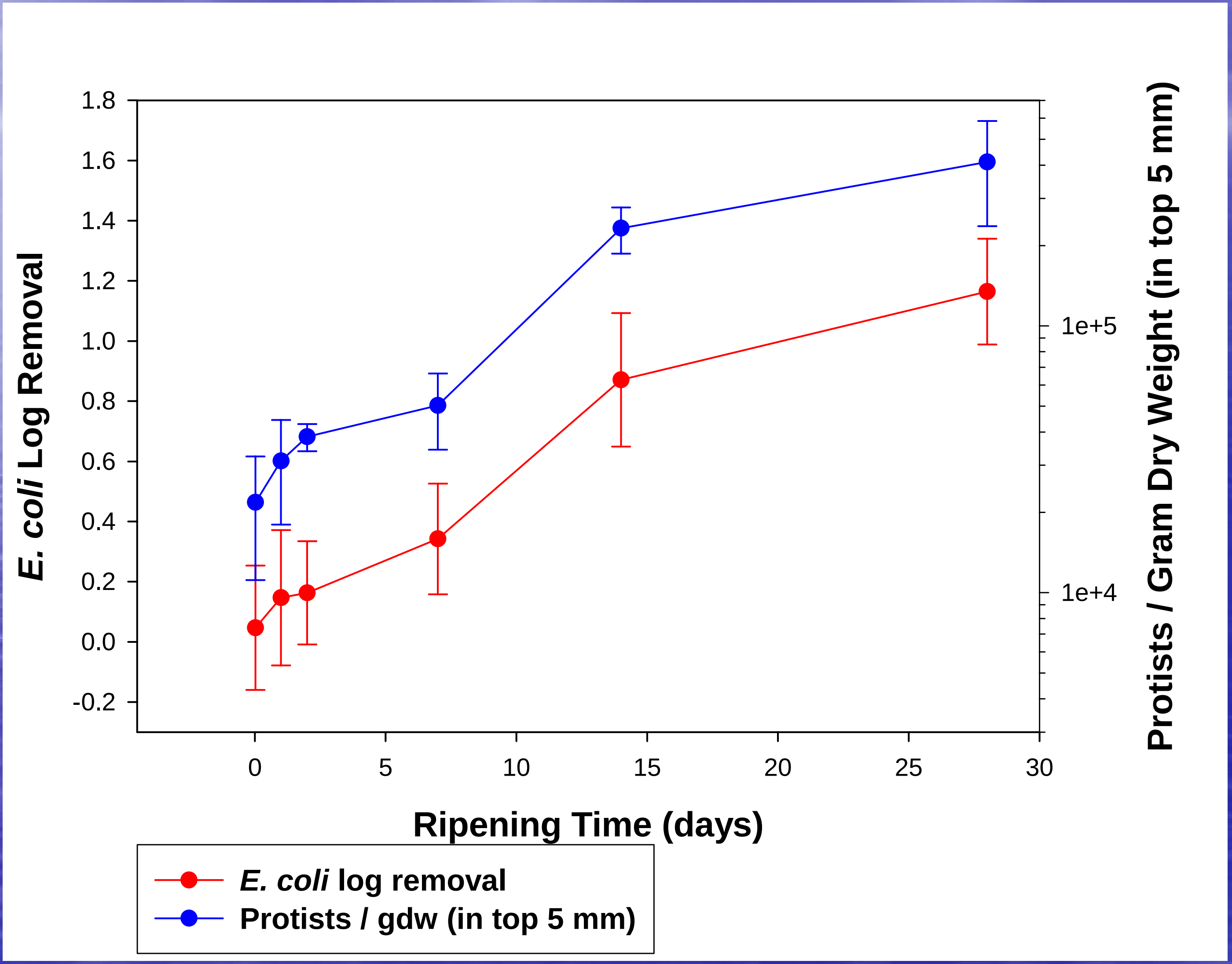
Protistan Abundance

- **Flagellates Counted:**
  - **$6 \pm 2 \times 10^6$ per cm^2 in top 5mm**
- **Potential *E. coli* Uptake Rate:**
  - **$5 \pm 2 \times 10^6$ per cm^2 / hour**
- **Actual Removal Rate:**
  - **1.3×10^2 bacteria / cm^2 / hour**
- **→ 4 orders of magnitude difference**

Assumptions

- **The *E. coli* used to spike the influent water are the only bacteria being consumed by flagellates.**
- **All flagellates are feeding continuously.**
- **Flagellates occupy the schmutzdecke uniformly in space.**

Protistan Abundance



SUMMARY

- SSF is the oldest “engineered” DWT process (in the USA and elsewhere)
- SSF has the longest design life than any other “engineered” DWT process
- SSF removals dependent on bioactivity
- SSF is one of the easiest and most inexpensive DWT process for O & M
- Proven modifications enhances SSF ability to stay viable well into the 21st century